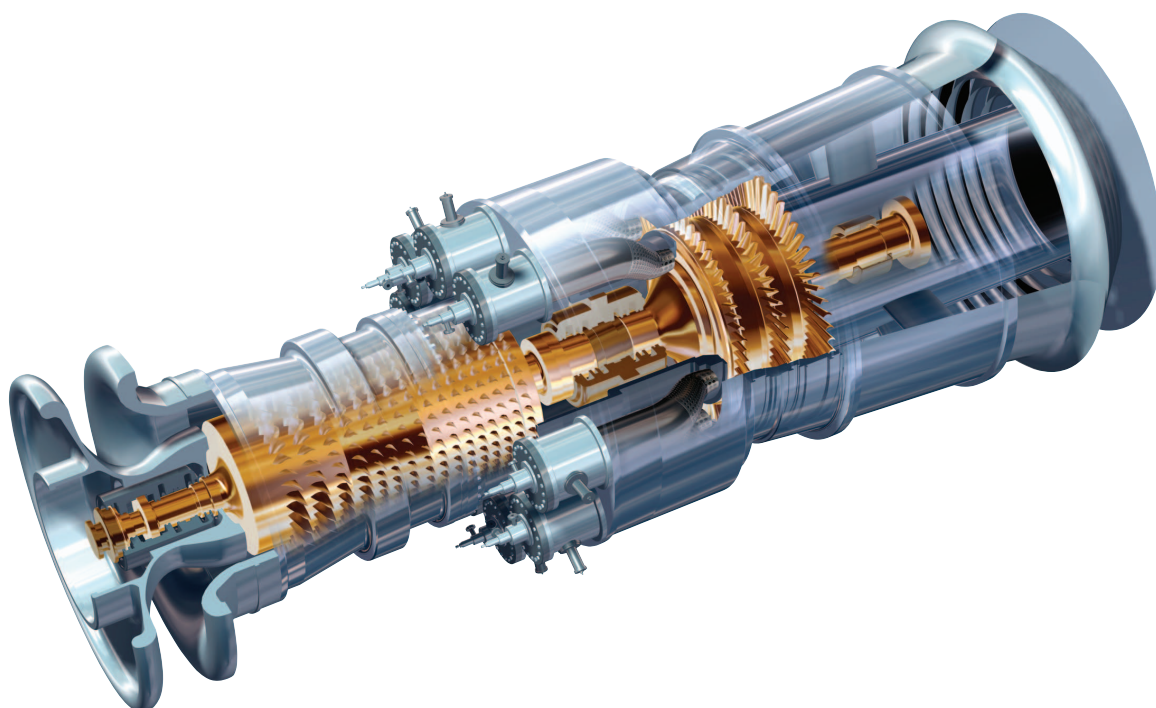


GE
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Uprate Options for the MS7001 Heavy Duty Gas Turbine



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Uprate Options for the MS7001 Heavy Duty Gas Turbine

Abstract

Advances in materials, cooling technology and design techniques have allowed GE MS7001 turbines to be operated with higher firing temperatures and airflows, which result in higher turbine output and efficiency. Improvements in combustion technology have also made significantly lower emission levels a reality.

Advanced design technology is usually introduced for new unit production and subsequently applied to customer-operated gas turbines by a gas turbine uprate program. Many new uprate programs have been introduced for installed GE-designed heavy-duty gas turbines, including the MS7001A, B, C, E, and EA models. Each uprate program provides increased output, improved heat rate and efficiency, improved reliability, reduced maintenance costs, longer inspection intervals, and longer expected parts lives. Additional benefits result because uprates are based on current production components—parts that are not specifically unique to older machines—and thus readily available.

This paper discusses the application of current production MS7001EA component technology to older MS7001 machines. The paper provides a detailed technical description of the improved components, scope, and benefits for each uprate, tabulations of performance improvement, and experience lists.

The major uprate programs discussed include the MS7001 “B to E” turbine uprate package, and the MS7001 uprate packages to 2020°F, 2035°F, and 2055°F. These uprate packages use current production advanced technology MS7001EA components to meet user demand for increased performance and reliability. The benefits of using upgrade components in a spare part replacement program are quantified. Also included is a tabulation of emission levels for original and uprated turbine configurations.

Introduction

Turbine uprate packages have been introduced because of strong customer interest in extending intervals between maintenance, improving efficiency, and increasing output. *Figure 1* lists the main items that must be considered when evaluating a unit for an advanced technology uprate option. This paper covers new uprates that have been successfully developed using engineered components developed for current new unit production.

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

Figure 1. Benefits of uprates offered that use new technology components.

The uprates discussed include the “B to E” (current production EA turbine components installed in a 7B unit) and uprating 7C/E/EA units to an advanced technology configuration with a 2020°, 2035°, or 2055°F firing temperature. Uprate benefits are discussed, including turbine performance and maintenance improvements.

Each owner of GE heavy-duty gas turbines should evaluate the economics of the various uprates for the specific application. In many cases, the economic evaluation will justify 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 can provide extended life to the existing turbine.

Many improvements have been made to the current production 7EA in *Figure 2* that can be utilized in older fielded units. Combustion systems, turbine buckets, nozzles, and compressor components have been redesigned using improved materials that increase component life and reduce repairs. (See *Figures 3 and 4*.) While GE moves forward to address marketplace needs, it will continue to improve its products and serve as a world-class high quality supplier of power generation equipment. As a leader in the gas turbine industry, GE is committed to applying the latest available technology parts to the large installed base of GE-designed gas turbines.

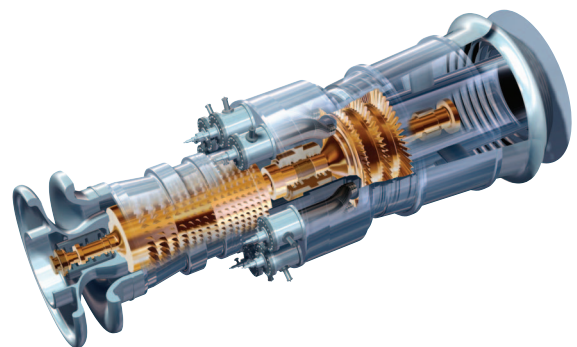


Figure 2. The MS7001EA simple-cycle single-shaft, heavy-duty gas turbine.

7EA HGP and rotor materials

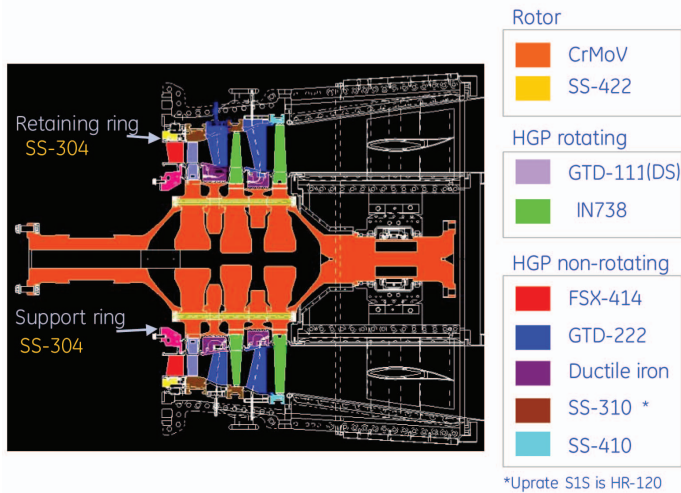


Figure 3. Current materials in 7EA hot gas path.

E-Class Evolution – Technical Innovation

Rotor Structure Unchanged:

- Material Upgrades

- Increased operating temperature

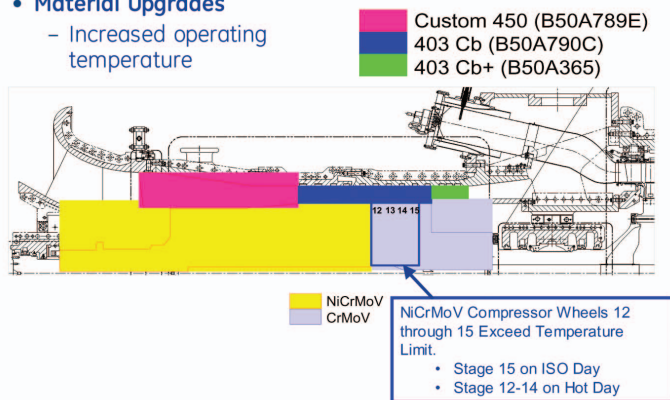


Figure 4. Current materials in 7EA compressor.

Gas turbine Sourcebook reference codes (e.g., FT5X for an MS7001B to E advanced technology uprate) have been included in the text, and in many of the figures and tables for easier correlation to other published information on specific uprate packages or components.

MS7001 Uprate Experience

Each uprate offered herein has been applied and installed on GE-designed turbines operating at power plant.

There have been many engineering reviews generated for customers, resulting in several successful customer uprate programs being initiated. Some customers with several units have installed uprates

in some units and placed orders for additional units to be installed in upcoming years to coincide with their maintenance overhaul schedules. Additionally, hundreds of upgrades and uprates are being reviewed with customers every week. Many other customers have chosen to install current design 7EA components as single spare parts replacements just as components are required—a path that could eventually lead to an uprate. Customers are encouraged to inquire with a GE sales representative or with Gas Turbine Application Engineering for questions or information.

The first MS7001B to EA uprate was successfully completed at a utility in Alaska in 1988. Since this was the first B to EA uprate, extensive testing was completed to evaluate the effects of using the 7E stage 1 nozzle in a B machine to monitor compressor performance and start-up characteristics. Upon successful completion of the first uprate, this customer uprated the two units at the site.

Another customer in the Southwest decided to uprate all eight MS7001B units to make them EA units. Several of the uprates have been installed and exceed all performance guarantees. The installations included optional DLN combustion as well as Mark V control systems. This customer is extremely pleased with the added performance, improved maintenance, emissions reduction, and increased reliability that GE supplied.

An industrial user in the west has decided to implement 7E uprates for eight turbines. The uprate to the existing 7E units will include raising firing temperature to 2035°F, adding DLN for emission control, and upgrading the compressor on select units to EA configuration. Since the uprates are scheduled during major overhauls, the outage time is not much greater and the incremental cost of the uprate is very small, since major components would need repair/replacement due to age.

The first unit conversion to 2035°F was successfully completed in early 1995. Extremely positive results were recorded for performance and emission levels as all guarantees were exceeded. Effective project management, continuous engineering development, and dedicated field support culminated in an outstanding uprate program.

Installing MS7001EA Individual Upgraded Parts

Installing individual upgraded components for maintenance considerations is another excellent opportunity to use current production “EA” components in fielded units. It is GE’s practice to

stock the latest design components. Customers with different vintage machines have the opportunity to use the latest design, current production components for all models of MS7001 units to obtain the benefits of the advanced technology components.

Since some customers may prefer to order only certain components as individual parts, GE can develop a staged uprate program that best suits the customer’s needs. Once enough components are installed in an uprate candidate machine, an uprate (performance/efficiency) package can be completed with the required control modifications to bring the customer to the uprated design firing temperature in cases where added output is desired.

Absolute Performance Guarantees and Turbine Degradation

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

Quantifying turbine performance degradation is difficult since consistent and valid field data is difficult to obtain. Further, several variables exist, including mode of operation, site maintenance characteristics, and various site conditions, etc., that affect turbine performance and degradation trends. In reviewing an uprate to an existing turbine, it is imperative to realize that older machines will have degradation present and the current operating performance is expected to be somewhat lower than the original nameplate rating. Delta uprates, which provide a percentage change, are generally

consistent with or without turbine degradation factors. Absolute guarantees, on the other hand, must factor in degradation losses in order to calculate the final expected performance level. Therefore, the absolute performance guarantees offered usually appear slightly different from Delta percentage changes in order to account for turbine degradation.

Recognizing that many customers prefer absolute performance guarantees, *Figure 5* was prepared to show common performance guarantee points for typical advanced technology uprates. All performances listed on *Figure 5* are based on ISO conditions (59°F, sea level, 0”/l) inlet/exhaust pressure drops, 60% relative humidity, natural gas fuel and base load, and assumes the axial flow compressor is not re-bladed. Similar performance can be easily provided for variations on these conditions.

Since uprate performance increases are based on real airflow and/or firing temperature increases, the performance increases provide real and lasting performance improvements. *Figure 6* is plotted to show the approximate performance increase for a typical MS7001B uprate option III at approximately 48,000 fired hours, the recommended major overhaul time. The expected typical non-recoverable performance degradation is plotted for the original configuration as well as for uprate B/EA uprate option III. This sketch illustrates that the performance increase of approximately 15% at 48,000 fired-hours still returns an expected incremental performance increase of about 11% at 100,000 fired hours. By comparison, uprates that are based on component refurbishment and/or blade coatings will usually disappear completely in 10,000 to 15,000 fired hours.

Advanced Technology Uprate Model	Firing Temp (°F)	Output, kW*	Heat Rate Btu/kW-hr*	Exhaust Flow 10 ³ #/hr	Exhaust Temp (°F)
MS7001B/E	1965	65,120	11,180	2024	991
MS7001B/E	2020	68,410	11,090	2025	1025
MS7001E	2020	75,730	10,970	2281	1001
MS7001EA	2035	85,580	10,240	2332	994
MS7001EA	2035	90,681	10,095	2401	1002

**Uprates are based on using reduced camber high flow IGVs

*Uprate performance is based on ISO conditions, natural gas fuel, base load, and assumes axial flow compressor is not re-bladed

Figure 5. Absolute performance guarantees for advanced technology – generator drive.

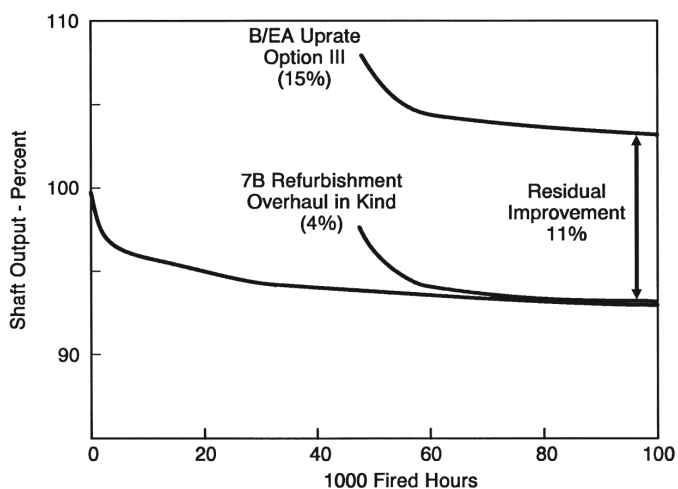


Figure 6. Estimated non-recoverable performance degradation effects—MS7001B/E gas turbine Option III.

Emission Levels

The impact on emission levels must be accounted for when considering an uprate to an existing gas turbine. Figure 7 lists typical NO_x emission levels before and after uprates for many of the uprate programs discussed. Also listed in Figure 7 are reduced emission levels with various options available for emission control (water injection and DLN). Detailed review of site requirements and specific emissions levels can be provided with each uprate study.

Single-Shaft Model	Firing Temperature (°F)	Dry		Water/Steam Injection		Dry Low NO _x	
		Gas	Dist.	Gas FG1A/FG1B	Distillate FG1C/FG1F	Gas FG2F	Dist. FG2F
MS7001B	1840	109	165	25	42	–	–
MS7001B Option 1	1840	119	180	25	42	–	–
MS7001B Option 2	1905	126	193	25	42	–	–
MS7001B Option 3	1965	134	208	25	42	25	42
MS7001B Option 4	2020	143	223	25	42	25	42
MS7001C	1950	134	207	25	42	25	42
MS7001C	1985	136	209	25	42	25	42
MS7001E	1985	142	211	25	42	–	–
MS7001E	2020	147	221	25	42	25**	42
MS7001EA	2020	154	228	25	42	25**	42
MS7001C/E	2035	151	226	25	42	25**	42
MS7001EA	2035	157	232	25	42	25**	42
MS7001EA	2055	160	236	25	42	5/7/9/15	42

Distillate oil fuel assumes less than 0.015% fuel bound nitrogen
 * With water injection for distillate fuel
 ** Lower NO_x levels may be available and require engineering review

Figure 7. Estimated ISO NO_x emission levels at 15% O₂ (ppmvd).

MS7001 HISTORY

The MS7001 design originated in 1966 and has evolved as seen in Figure 8. At that time, there was enormous demand in the U.S. for gas turbines with the capability for peak load power generation. Because large blocks of power were often required, many installations resulted in numerous MS5001 units at a single site. Thus, a primary objective of the MS7001 program was to develop a larger gas turbine for power generation applications that would incorporate design experience from earlier machines, such as the successful—but smaller—MS5001.

The result of the MS7001 development program was a new gas turbine model that included a 17-stage compressor and a three-stage turbine that operated at 3600 rpm. The significance of the 3600 rpm shaft speed is that the necessity of a speed-reducing load gear—previously required on other models for power generation—was eliminated for the 60 HZ market. Figure 9 illustrates the historical performance improvements.

The MS7001 compressor’s aerodynamic design was derived from the MS5001N and scaled to the required larger design of the MS7001. The compressor rotor has undergone various changes in the past 25 years. Figure 10 is a representation of the relative dimensional changes in the MS7001 series compressor. More

7E Fleet Product-line Evolution

Model	Output	HR	Press Ratio	Firing Temp	Comp Stages	Turbine Stages	Op Date
PG7651(A)	47,260 KW	11,910 Btu/KWh	Not Found	1650°F	17	3	1970-1971
PG7711(B)	51,800 KW	12,090 Btu/KWh	Not Found	1800°F	17	3	1971-1972
PG7821(B)	60,000 KW	10,960 Btu/KWh	Not Found	1840°F	17	3	1972-1978
PG7851(B)	61,750 KW	10,920 Btu/KWh	Not Found	1850°F	17	3	1978
PG7931(C)	68,500 KW	10,970 Btu/KWh	Not Found	1950°F	17	3	1974-1977
PG7971(E)	71,700 KW	10,600 Btu/KWh	Not Found	1985°F	17	3	1974-1975
PG7981(E)	73,200 KW	10,530 Btu/KWh	Not Found	1985°F	17	3	1976-1978
PG7101(E)	75,000 KW	10,590 Btu/KWh	Not Found	1985°F	17	3	1978-1981
PG7111(E)	76,900 KW	10,590 Btu/KWh	Not Found	2020°F	17	3	1981-1984
PG7111(EA)	80,080 KW	10,650 Btu/KWh	Not Found	2020°F	17	3	1984-1987
PG7111(EA)	81,760 KW	10,600 Btu/KWh	Not Found	2020°F	17	3	1987-1988
PG7111(EA)	83,310 KW	10,470 Btu/KWh	12.596	2020°F	17	3	1988
PG7121(EA)	85,080 KW	10,420 Btu/KWh	Not Found	2020°F	17	3	1995
PG7121(EA)	86,580 KW	10,340 Btu/KWh	12.637	2035°F	17	3	1998
PG7**1(EC)	116,000 KW	9,850 Btu/KWh	Not Found	2200°F	17	3	1996

Installed Fleet Size: 71A = 2 71B = 240 71C = 12 71E = 137 71EA = 478 71EC = 0

Figure 8. Evolution of frame 7 E-Class fleet.

detailed discussion of the compressor rotor will be included in the compressor rotor improvements section.

The first MS7001A was factory tested and shipped in 1970. As outlined in *Figure 9*, the MS7001A offered significantly different performance levels from today's design. *Figure 9* is a valuable reference in outlining the MS7001 performance history that allows users to estimate the current rating capability of their machine. Operating with a design firing temperature of 1650°F (base load), the stage 1 turbine nozzle employed internal air cooling, but there were no internally cooled buckets.

In parallel with the MS7001A development, an air-cooled stage 1 turbine bucket was developed. This feature, along with additional stage 1 nozzle cooling and a stage 2 bucket material change, resulted in the MS7001B, which operated with a nominal 1840°F base load firing temperature. As a consequence of the early development of the MS7001B configuration, only two MS7001A units were built. The first MS7001B was shipped in 1971. Approximately 260 MS7001B units were built and shipped through 1978.

Development of the MS7001C commenced in 1972. The major new features of this model turbine included a change in compressor

aerodynamic design to increase the airflow and improve output and efficiency, as well as a change in both stage 2 bucket and nozzle designs to add air cooling. The combustion system was also reconfigured by including a newly designed slot-cooled combustion liner. (See *Figure 11*.) The compressor change increased airflow by 12%, and the additional cooling allowed for an increase in firing temperature to 1950°F. Approximately 15 MS7001C units were shipped and all are candidates for the advanced technology uprate package, or for selective individual component replacements.

In 1972, a program was initiated to develop an MS7001D machine that would be capable of accepting large quantities of steam injected into the combustion system for increased performance. The program was terminated before any MS7001D units were produced when market review reflected that applications of this type were limited. The result was the commencement of the MS7001E development program shortly after.

The MS7001E development began in 1973 with the primary objective of increasing the gas turbine thermal efficiency. The major changes to the MS7001E design included a new stage 1 turbine nozzle which provided an increase in pressure ratio, and a

Model	Ship Dates	Performance* kW (NEMA) ⁽¹⁾	Firing Temp (°F/°C)	Air Flow (10 ³ lbs/hr/10 ³ kg/hr)	Heat Rate (Btu/kW-hr/kJ/kWh)	Exhaust Temp (°F/°C)
PG7651A	1970-1971	47,260	1650/899	1.851/0.840	11,910/12,563	844/451
PG7711B	1971-1972	51,800	1800/982	1.851/0.840	12,090/12,753	944/507
		kW (ISO) ⁽¹⁾				
PG7821B	1972-1978	60,000	1840/1004	1.905/0.864	10,960/11,560	947/508
PG7851B	1978-1979	61,750	1850/1010	1.967/0.892	10,920/11,518	944/507
PG7971E	1974-1975	71,700	1985/1085	2.040/0.925	10,600/11,181	992/533
PG7981E	1976-1978	73,200	1985/1085	2.125/0.964	10,530/11,107	974/523
PG7101E	1978-1981	75,000	1985/1085	2.176/0.987	10,590/11,170	977/525
PG7111E	1981-1984	76,900	2020/1104	2.210/1.002	10,590/11,170	1000/538
PG7111EA	1984-1987	80,080	2020/1104	2.303/1.045	10,650/11,234	989/532
PG7111EA	1987-1988	81,760	2020/1104	2.366/1.073	10,600/11,181	987/531
PG7111EA	1988-1995	83,310	2020/1104	2.332/1.058	10,470/11,044	982/528
PG7121EA	1995-1997	85,080	2020/1105	2.332/1.058	10,420/10,991	995/535
PG7121EA	1998	86,580	2035/1113	2.382/1.079	10,340/10,907	994/534
PG7211F	1988-1991	147,210	2300/1260	3.241/1.470	9,960/10,506	1,100/593
PG7221FA	1992-1995	159,100	2350/1288	3.347/1.518	9,440/9,957	1,087/586
PG7231FA	1995-1999	167,000	2400/1316	3.428/1.555	9,420/9,936	1,101/594
PG7241FA	1999	171,700	2420/1327	3.581/1.622	9,400/9,915	1,131/601
PG7251FB	2001	181,400	2555/1402	3.600/1.631	9,310/9,820	1,149/621

*Base load distillate fuel, includes 0/0 inches H₂O inlet/exhaust pressure drops

⁽¹⁾ In early 1970s, rating standards were changed from NEMA (1000 ft/300 m altitude and 80°F/27°C) to ISO (sea level and 59°F/15°C) conditions. To convert from NEMA to ISO rating for approximate comparison, multiply NEMA rating by 1.12. Includes 0/0 inches H₂O inlet/exhaust pressure drops.

Figure 9. MS7001 performance history.

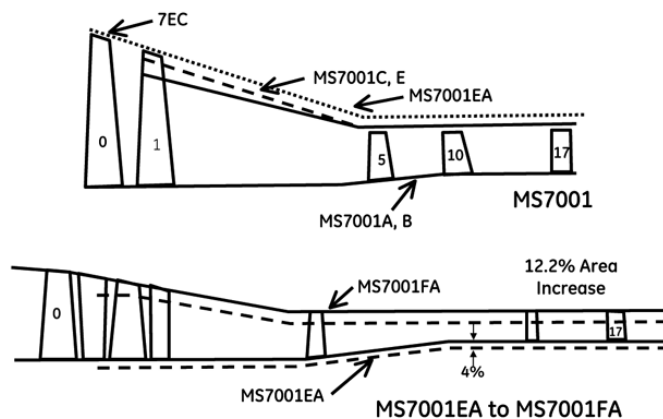


Figure 10. History of MS7001 compressor design.

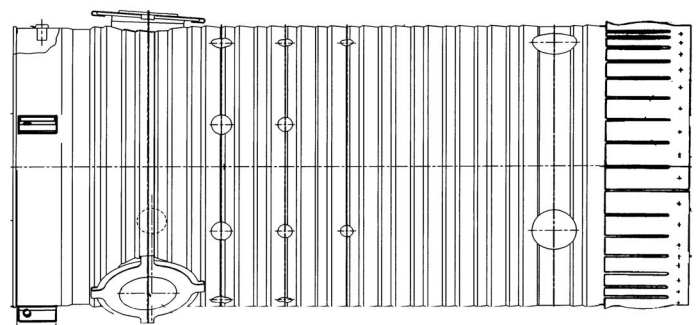


Figure 11. Slot-cooled liner with TBC coating.

new stage 3 bucket that allowed for a 35°F increase in firing temperature to 1985°F. Subsequently, the MS7001E firing temperature was increased to 2020°F in 1981.

The first MS7001EA was shipped in 1984 and is still being manufactured today. The major design change in the 7EA turbine was a larger compressor (*Figure 10*) to allow increased airflow and, thus, improved turbine output and efficiency. The base firing temperature was 2020°F for 7EA units. Many design improvements have since been incorporated into today's version of the MS7001EA, allowing a firing temperature increase to 2035°F. The improved design techniques and materials in the current production MS7001EA turbine components will be discussed in further detail, since they provide the basis for the uprates GE offers.

The next step in the continuing evolution of the MS7001 machines was GE's "F Technology" gas turbine design. GE's experience with the earlier "E Technology" MS7001 models was combined with advanced technology from GE's aircraft engine business and GE Global Research. The first MS7001F with a design firing temperature of 2300°F shipped in 1988. As technology continued to advance, improvements were implemented to uprate the FA-class units to 2420°F. Because of machine size differences, the advanced technology production components used in the MA7001F cannot be used directly as part of the "E Technology" uprate programs that are the subject of this paper.

Figure 12 illustrates the evolution of the E-Class compressor from 1971 to the present EA configuration.

Figures 13 through 16 illustrate the evolution of buckets in stages 1, 2, and 3. These improvements and others have led to a hot gas path capable of 2055°F when upgraded in a CMU offering.

7EA Current Production Component Technology

This section of the paper will discuss the advanced technology features that have been incorporated in the current production. Many of the design improvements for components involve a change in the materials used. *Figure 17* lists the composition of many gas turbine alloys discussed in this paper. In addition, the rupture stress for the bucket and nozzle materials is compared in *Figure 18*, illustrating the improvements associated with the new materials developed and offered in uprates.

MS7001A to B, circa 1971

- IGV max open angle was changed from 80° to 82°
- IGV startup and low flow angle was changed from 50° to 59°
- 7A and early 7Bs shipped with 100% blade/rings assemblies
- Current only stage 1 – 4 stators replacements are blade/ring assemblies
- Stg 5 – 17 stators, current design are ind square base blades that can be used in place of blade/ring assemblies on early 7Bs.

MS7001B to C, circa 1972

- Forward stub dovetail angle changes from 70°26' to 75°43'
- Increase stage 1-4 casing diameter w/corresponding blade length changes in rotor and stator (C & E)
- Shorten aft stub shaft to get forward #2 bearing seal on shaft rather than on the bolt flange
- Result is effectively the Phase 0 compressor, Refer to GE Tech Information Series (not TIM) Report 81 GTD-054 for information on low corrected speed surge phenomenon.
- Changed IGV from 7A/B profile to 7C profile
- Flow raised from 530 lb/sec to 585 lb/sec (10.38%)
- IGV max open angle was changed from 82° to 77° – due to surge problem
- IGV low flow angle was changed from 59° to 57° – hopefully based on testing (lowest w/o comp bleed)
- IGV startup angle was changed from 59° to 34°

MS7001C to MS7001E Phase 0 (first four 7Es only), circa 1974

- Opened IGV angle
- Improved blade surface finish
- Flow raised from 585 lb/sec to 604 lb/sec (3.25%)
- Phase 0 compressor, has low corrected speed surge sensitivity

Phase 0 (first 4 7Es only) to Phase 1 (all remaining 7Es) circa 1976

- Re-staggered stator stages 1-8
- Twisted stator 4 at tip
- Flow remained at 604 lb/sec
- Compressor became Phase 1 compressor. Phase 2 compressor was a second step contingency plan if Phase 1 did not correct the low corrected speed surge phenomenon. Phase 2 was never implemented.
- IGV max open angle was changed from 77° to 84°

MS7001E to MS7001EA circa 1985

- Increased compressor outer diameter (all new casings, blading)
- Flow increased from 604 lb/sec to 640 lb/sec (5.96%)
- 7F IGV profile (GTD-450, formerly C-450 IGVs) introduced 1987
- Max IGV angle held at 84° in 1987

Figure 12. Frame 7 E-Class Compressor rotor evolution.

7E/EA stage 1 bucket evolution (1981-1992)

6B stage 1 bucket failures around ('89-'92) prompted an investigation of failure potential of the earlier 7E/EA versions. Results showed initial stages of 6B failures (reduction in creep life accelerated by oxidation/corrosion).

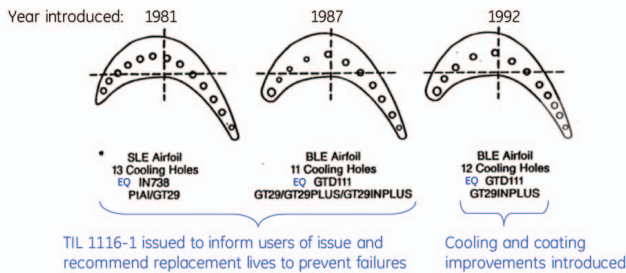


Figure 13. Previous versions of 7EA stage 1 bucket.

7EA stage 2 bucket evolution

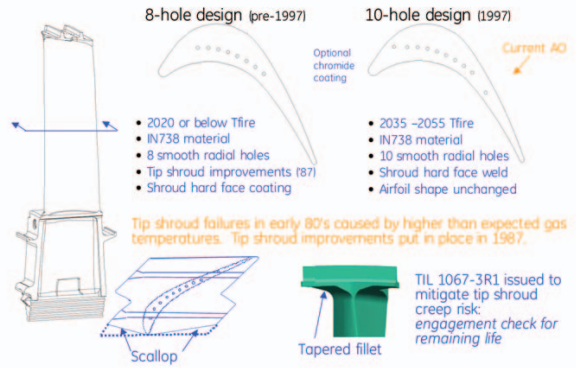


Figure 15. 7EA stage 2 bucket evolution.

7EA stage 1 bucket evolution (1994 - present)

Improved technology:

- DS GTD-111 material introduced
- Perimeter cooling introduced for increased bulk creep capability

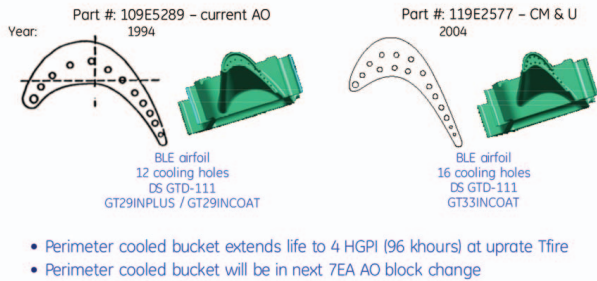


Figure 14. Current 7EA stage 1 bucket.

Figure 19 lists all the PEDs codes currently applicable for E-Class turbines. Other uprates do exist that have not yet been assigned a PEDs code, such as exhaust plenums.

Compressor Rotor Improvements

The MS7001 history section outlined several changes that have been designed into the various MS7001 models, including general compressor airflow increases. (See Figure 10.) The first four stages of the 7B compressor were redesigned for the 7C and 7E models. When the MS7001EA compressor was designed, the flow path was increased radially for all stages (approximately 1/4" to 3/8"). Because new compressor casings and all new compressor rotor and stator blades would be required to upgrade the 7B compressor to the later design compressors, this is usually not an economically feasible option and is not typically quoted as part of the turbine uprate options discussed.

7EA stage 3 bucket evolution

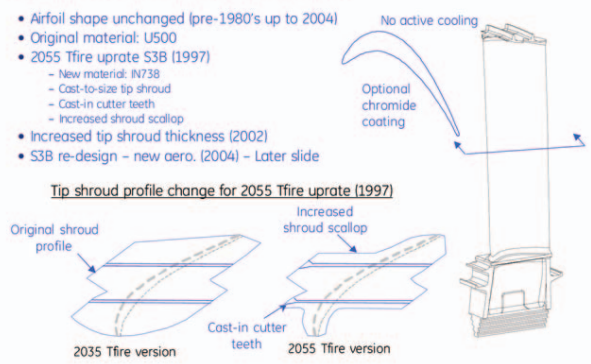


Figure 16. Stage 3 bucket evolution.

Instead, the existing MS7001 B compressor can be re-bladed with the same design/length blades, with special blade coatings or materials available for certain applications. A Ni-Cad coating helps to prevent corrosion pitting on the blades by combining a tough barrier coating (nickel) with a sacrificial cadmium layer. This coating, which is standard on the first eight stages, has been found to possess outstanding corrosion resistance in neutral and sea salt environments.

There are certain compressor improvements that have previously been recommended in Technical Information Letters (TILs) that would be required to implement a complete uprate package. Extraction cooling air for turbine components originates in the compressor and is removed through a passage in the forward side of the compressor aft stub shaft. Many of the earlier MS7001B machines have straight flutes on the compressor aft stub shaft to

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™ (U700™)	15	BAL	17	-	-	5.3	3.35	4.25	-	-	0.07	0.02	-
IN-738™	16	BAL	8.3	0.2	2.6	1.75	3.4	3.4	0.9	-	0.1	0.001	1.75
GTD-111*	14	BAL	9.5	-	3.8	4.5	4.9	3	-	-	0.1	0.01	2.8
Nozzles													
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 17. Gas turbine alloys.

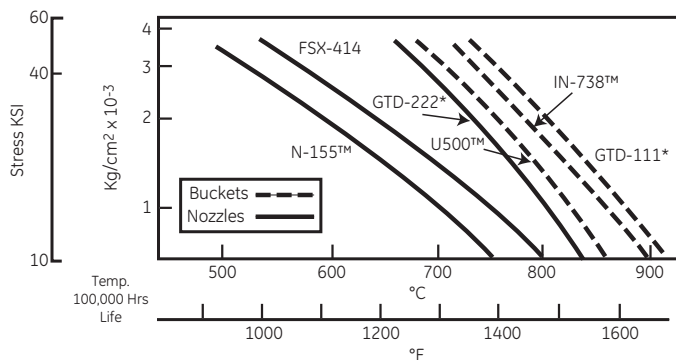


Figure 18. Creep stress rupture comparison of bucket and nozzle materials.

guide the extraction air. This design could pose potential problems as the straight flutes could lead to a degree of aerodynamic instability, acting as an excitation source to fret the compressor through bolts.

A better design, with involute flutes, has been developed that significantly reduces the amplitude of the turbulence. Figure 20 illustrates a comparison of the two stub shaft designs. All operators of MS7001B units still using the straight flute aft stub shaft design are urged to upgrade to the curved flute design, (See Figure 34.) As part of an uprate package, the upgrade to the curved flute design is required due to the increase in compressor pressure ratio.

Uprate	Description	Uprate	Description	Uprate	Description
FT5C	Increase in Tf and Controls Mod	FS2X	#2 Bearing Brush Seals	FC4C	Add Turbine Water Wash
FT5Y	Increase to 2035°F Tf and Controls Mod	FR1V	Extendor* Component Retrofit	FC4A	Add Compressor Water Wash
FT5Q	Increase to 2055°F Tf and Controls Mod	FR1W	Extendor Component New	FF1E	Dual Fans, Turbine Compartment
FS2G	S1B with 12-hole cooling	FS2Y	S1S HR-120™ Cloth Seal	FG1A	Add Water Injection
FS2K	S3B with IN-738™	FS2Z	Interstage Brush Seal	FK5C	Extended Exhaust Thermocouple
FS2J	S1N With Chordal Hinge	FR1C	Heavy Wall TP	FS1F	GTD-450 Compressor Stages 1-8
FT5B	IGVs Reduced Camber GTD-450	FR1D	Niomonicon TP	FS1W	Exhaust Frame Uprate
FS1P	S2N GTD-222+*	FR1G	TBC Coated Liners	FS2A	Re-Blade Compressor
FS2D	Exhaust Frame Motor Blowers	FR1H	71/C combustion for 71/E	FS4B	S2B with Improved Cooling
FS1L	S2B Air-Cooled	FR1N	Hard Facing on X-fire Tubes	FS4G	S1B TBC Coated 12-Hole
FS2T	S2B Shroud Honeycomb Seals	FR1E	Multi-Nozzle Quiet Combustor	FS4K	S3N Advanced Aero
FS2U	S3B Shroud Honeycomb Seals	FR1T	Breech Loaded Fuel Nozzle	FS4L	S3B Advanced Aero
FT5J	S1B Blunt Leading Edge	FG2B	Dry Low NO _x 1.0	FS6A	Abradable Coating, S1S
FS2V	HPP Brush Seals	FS4A	S1B with 16-hole cooling	FS6E	S1N Enhanced TBC
FS2B	S17 + EGV1&2	FA2L	Convert to Universal Liquid Fuel	FW1L	Exhaust Diffuser Horizontal Gasket
FS1R	S3N GTD-222+	FA1A	Convert to Gas Only	FW2E	Exhaust Diffuser Double Plate
		FA1S	Gas Fuel Change Study	FW3E	Discourager Seal Replacement
		FA3D	Convert from Liquid to Dual Fuel	FW3V	Replace Stage 17 Blades

Figure 19. Uprates available for E-Class Frame 7 units.

Comparison of Compressor Aft Stub Shafts

- Straight flutes can cause aerodynamic instabilities which act as an excitation source to fret compressor through bolts
- Curved flutes significantly reduce the amplitude of the turbulence

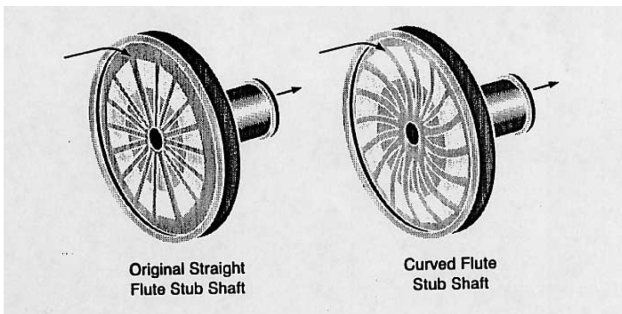


Figure 20. Comparison of compressor aft stub shafts.

Re-Blade Compressor Stages 1 thru 8 (FS1F)

This modification for MS7001A and B and MS7001E through EA units involves replacing the stage 1-8 compressor blades and stator vanes with GTD-450 material. The GTD-450 material provides corrosion resistance and significantly increases the strength of the blades and stator vanes. It applies to 5/1N-P, 5/2A-B, 6/1A-B, 7/1A-B, 7/1E-EA, and 9/1E.

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)

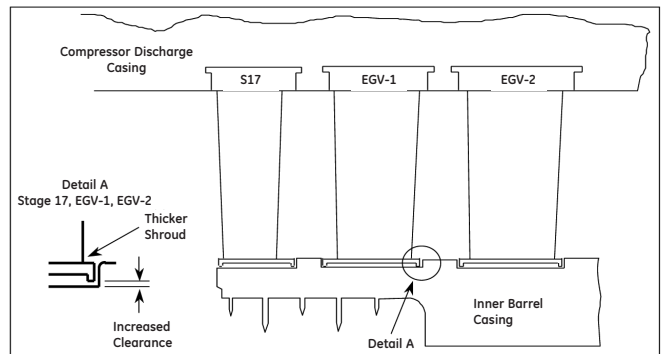


Figure 21. Side view of the three stages of shrouded compressor blades.

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

Re-Blade Compressor Stage 17 (FS2B)

For MS7001B, 7001C, and 7001E units, the need to implement the stage 17 stator correction is evaluated on an individual basis. Exit guide vane problems on some MS7001 units have been attributed to aerodynamic vane stall when running under certain operating conditions. To prevent this failure, the stage 17 stator vanes, and the two stages of exit guide vanes (EGVs) that follow the 17th stage, have been redesigned. (See Figure 21.) The vanes have all been shrouded and each stage of vanes goes into a broached ring that slides into a corresponding groove in the compressor casing. Setting the vanes in rings and shrouding them reduces the sensitivity of the structure and prevents blade failure. The stator 17 modification will be reviewed for low ambient temperature sites, or where frequent operation with modulating inlet guide vanes occurs.

A CM&U analysis is conducted to determine if shrouded compressor exit hardware is required for any specific unit. 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. Figure 22 illustrates an example of a CM&U analysis

for a unit configuration in ambient temperatures from 41° to 85°F and maximum IGV angle of 84 degrees. The figure proves that shrouded hardware is needed for most ambient temperatures at the used IGV angles.

Compressor Rotor Upgrades

There exists the option of performing a complete compressor uprate which would increase airflow and thus result in improved gas turbine output and efficiency. While a compressor upgrade can be substantially field intensive, certain applications dictate this to be an option for review. The MS7001 performance history (Figure 9) shows the relative airflows of different vintage models while the evolution of the MS7001 compressor design (Figure 10) shows how a compressor upgrade would affect the compressor diameter.

The compressor upgrade options that exist for the earlier units would include uprate to "E" compressor (FT5D) and uprate to "EA" compressor (FT5F). Note that for 7C and early 7E models, an upgrade to the latest "E" compressor configuration would be required to perform the full hot gas path uprate to 2035°F/1112°C firing temperature. This compressor uprate is based upon blade replacement and does not require any new casings. The compressor uprate to the latest 7E compressor requires new stator blading on the first eight stages (FS1F). The original blade design

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

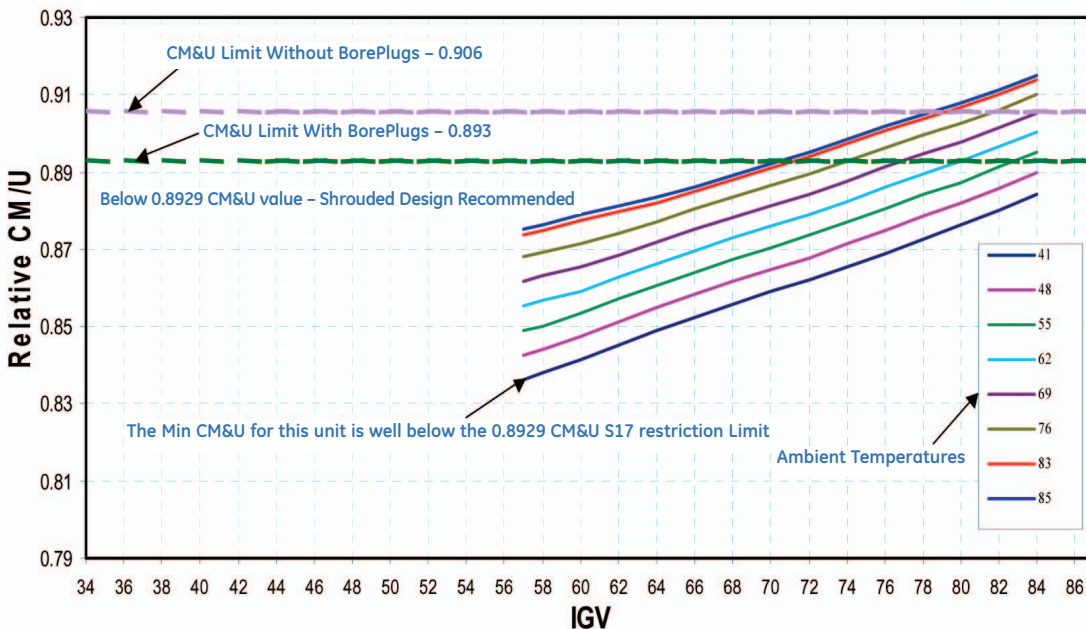


Figure 22. CM&U analysis for a specific unit illustrating need for shrouded design.

for these stages had a minor problem with the blade pitch, so the IGVs were closed slightly (77° running angle) to account for the operation of these forward blades. Additional blades may be desired/required for a particular 7C or 7E application and possible reblade of the entire compressor might be recommended in certain instances.

While compressor upgrades might be a good option for specific customers to review based upon their specific site needs, it has been determined that the hot gas path uprate does not require a complete compressor uprate (except for the corrective action on 7C and early 7E units). Therefore, the compressor upgrade option is not generally included when review of a hot gas path uprate is provided. Specific applications may dictate that several options including compressor updates be reviewed as well. Airflows associated with each compressor design are illustrated in *Figure 9* and provide an idea of expected airflow increases, and thus output gains, possible with compressor upgrades.

Compressor Stator and Blade Improvements

High Flow Inlet Guide Vanes (FT5B)

This upgrade applies to MS7001B through EA units shipped pre-1987. In 1986, a “reduced camber” high-flow inlet guide vane (IGV) design was introduced as a byproduct of the MS7001F development program. *Figure 23* illustrates a reduced camber inlet guide vane for an MS7001EA model. Due to the significant performance improvement from this IGV airfoil, the new design was quickly applied across the entire GE heavy-duty product line for both new unit production and field unit performance improvements.

GTD-450 High Flow Inlet Guide Vane

- Features
 - Improved Airfoil Design for Higher Flow
 - Variable Airfoil Thickness to Maintain Reliability
 - GTD-450, Precipitation-hardened, Martenistic Stainless Steel Material for Higher Tensile Strength & Superior Corrosion Resistance

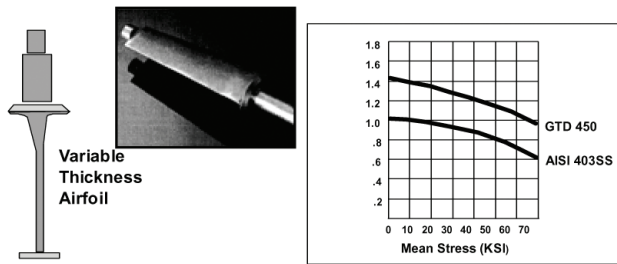


Figure 23. MS7001EA GTD-450 reduced camber inlet guide vane.

The reduced camber high flow IGV is a flatter, thinner inlet guide vane designed to increase air flow. There are two modification kit options. The first includes only the vanes and the installation hardware. The second includes the vanes, the rack and ring, gears, and installation hardware. For more detail refer to GER-3571H.

The reduced camber, high flow IGV is directly replaceable with the original IGVs. The new airfoil design allows increased airflow. The new IGVs have higher reliability due to the use of a special stainless steel alloy, GTD-450. This material is precipitation-hardened, martensitic stainless steel, which is improved over the Type 403 previously used. These improvements include increased tensile strength, high cycle fatigue, corrosion fatigue strength, and superior corrosion resistance due to higher concentrations of chromium and molybdenum. Tests have shown that the uncoated GTD-450 gives better corrosion resistance than the coated Type 403s. Also new bushings help to prevent blade cracks due to binding of the IGV shaft. *Figure 24* details design improvements with the GTD-450 high flow IGV design.

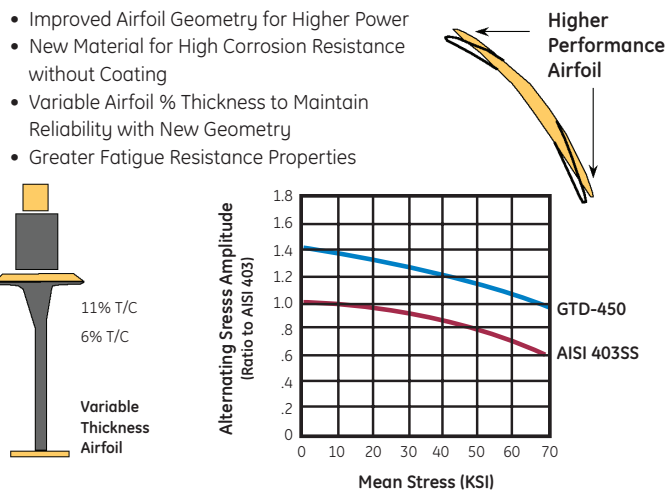


Figure 24. Design improvements with GTD-450 high-flow IGV designs.

If the actual ring and rack are not in good condition and/or the turbine experiences any VIGV seizing, they have to be replaced.

The new gears and gear rack have been improved with a zinc-nickel plating to reduce seizing. For more information, refer to TIL-517CR1.

The IGV angle can also be increased from the standard 84 degrees to 86 degrees with C-450 IGVs. This will increase output (~ +0.4%) with a slight heat rate penalty (~ +0.2%).

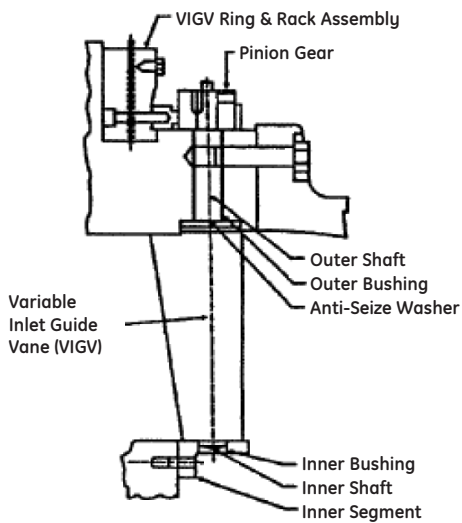


Figure 25. Variable IGV arrangement.

As part of the modification kit for GTD-450 IGVs, a set of tight clearance, self-lubricating IGV bushings are supplied. The general arrangement of the IGVs and the bushing interface are illustrated in *Figure 25*.

The design of the reduced camber high flow Inlet guide vane provides increased performance and corrosion and crack resistance. See below for typical performance benefits by model (with 84 degree IGV angle):

- Model 71B change in output: +4.4%, change in heat rate: -0.9%
- Model 71C change in output: +4.1%, change in heat rate: -0.1%
- Model 71E (pre-1988) change in output: +1.5%, change in heat rate: -0.3%
- Model 71EA (pre-1988) change in output: +1.4%, change in heat rate: -0.3%

Special attention is required for the turbine stage 1 nozzle due to its significant impact on the overall gas turbine performance. Document TIM 00-S-566 provides details of critical levels of clearance needed after installation of the nozzles to realize the performance benefit.

High Pressure Packing Brush Seal (FS2V)

A new option for MS7001B through EA units also enhances performance by improving the aft compressor section for the MS7001. This option is a part of the MS7001EA 2035°F/1113°C uprate program.

In the aft end of the compressor, the mating seal between the compressor discharge case inner barrel and the compressor aft stub shaft is known as the high-pressure packing arrangement. The inner barrel is a stationary inner casing which forms a seal to prevent high pressure, compressor discharge air from leaking into the #2 bearing and forward stage 1 wheelspace areas. This option consists of replacing the existing labyrinth tooth/land seal arrangement with a more effective brush seal element. With this option, a new inner barrel with a new brush seal mating material is installed to maintain desired clearances in the compressor aft section. *Figure 26* compares the current labyrinth seal to the new brush seal high-pressure packing arrangement.

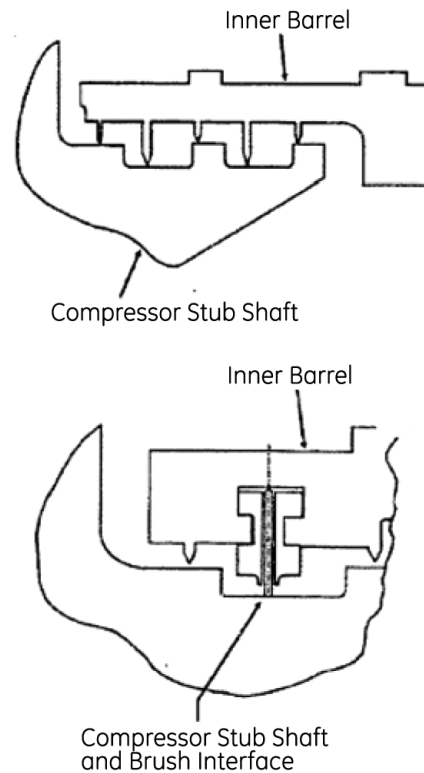


Figure 26. 7EA high pressure packing seal arrangement – labyrinth vs. brush seal.

Brush seals consist of a pack of fine wire held in a frame mounted on one component of a pair having relative motion. (See *Figure 27*.) The brush bristles push against a surface on the mating part. A pressure gradient can be maintained across the brush bristle path; fluid/air can be trapped on one side with a minimum of leakage occurring through the bristle pack.

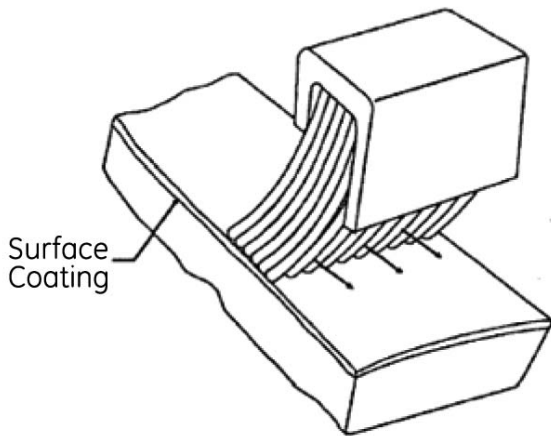


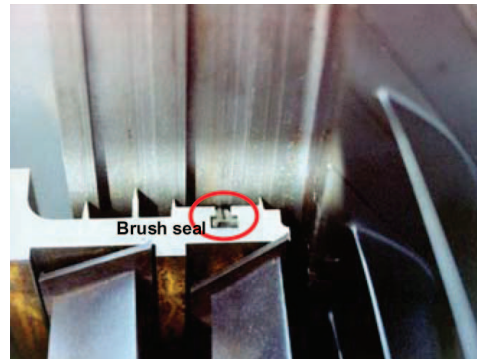
Figure 27. Typical brush seal element – schematic.

In testing, the sealing efficiency of a single brush is found to be about 10 times that of a labyrinth seal under similar conditions. A brush seal can easily accommodate misalignments normally not tolerated by labyrinth designs and wear is tolerable over long hours of operation. The inherent flexibility of the brush seal material allows for bending under conditions in which the standard design labyrinth packing could potentially rub and introduce leak passages.

In addition to a more durable seal interface arrangement, the brush seal maintains tighter clearances than the previous labyrinth design. The expected performance gain due to the improved sealing (reduced leakage) characteristics of the brush seal design at the compressor aft end high pressure packing area, with a new compressor inner barrel, is estimated at more than 0.5% output increase and nearly 0.5% efficiency gain.

To prevent high-pressure compressor discharge air from entering the turbine areas, newer factory units currently incorporate a honeycomb seal design instead of the older, previously installed hi-lo labyrinth seal design. The honeycomb is similar to the design previously described for the stage 2 and 3 shrouds. The brush seal uprate for the high pressure packing seal can be installed on either the honeycomb (older units) or labyrinth designs (newer units). Performance increase for the brush seal uprate is the same for either case.

Figure 28 illustrates a photograph of an installed high-pressure packing brush seal.



Typical Brush Seal Element

Brush Seals
 Reduce air leakage
 Tolerant of misalignments
 More durable than labyrinth seals

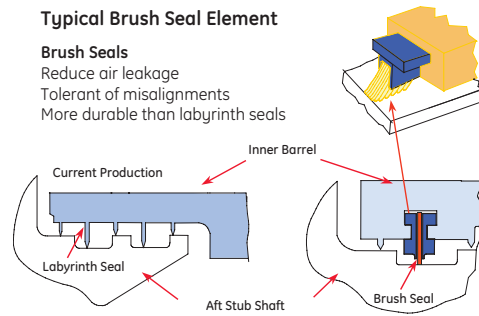


Figure 28. Installed HPP brush seal.

Re-Blade Entire Compressor (FS2A)

For all MS7001 units, during the lifetime of the turbine, inefficiencies develop due to non-recoverable degradation of the airfoils on the turbine and compressor section. Although the rate at which degradation occurs may be slowed by water washing (Reference FC4A-D), proper fuel treatment, inlet air filtration and good maintenance planning, inefficiencies still tend to develop. One method to recover performance losses due to degradation is by re-blading the entire compressor section of a machine. (See Figure 29.) This option will supply a new set of compressor rotor and stator blades, including the exit guide vanes

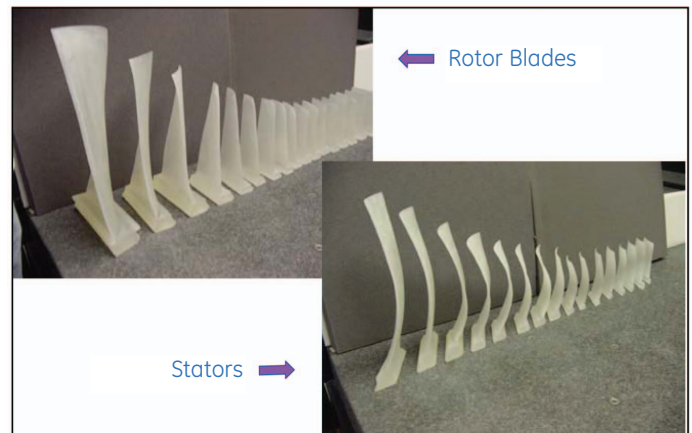


Figure 29. Rotor blades and stator vanes are replaced.

(EGVs) that are matched to the customer's machine. Note that with this modification the material supplied is the same as that supplied as a spare part with the addition of new compressor wheel spacers, and rotor through bolting.

One of the main reasons customers may choose to re-blade their compressor is to regain performance lost to irreversible material degradation of the compressor blading from oxidation, corrosion, erosion or fouling. A re-bladed compressor provides a return to like-new performance and efficiencies. A damaged compressor section—by ingestion of a foreign object (FOD)—may also warrant compressor re-blading. New compressor blading is often required as part of a performance uprate guarantee, or to handle the increased operating pressure ratio and load that the blades will operate with when uprated.

Discourager Seal Replacement (FW3E)

For MS7001E and EA units, this inspection and possible replacement of the deteriorating aluminum bronze seal tooth material will help reduce the risk of excessive leakage from the seal. Excessive leakage could reduce the cooling flow to the second stage buckets, which increases creep and reduces tip shroud engagement.

The aluminum bronze material has been found to be the cause of premature discourager seal failures in the field. It is advised that the discourager seal between the stage 1 to stage 2 spacer be inspected on all units shipped prior to 1996 for brittleness of the B50A422A aluminum bronze seal teeth material. (New units shipped after 1996 should have the stainless steel replacement material.) For this reason, a new seal material has been used as a replacement called B7B2A-stainless steel. The replacement of the old seal material is necessary because it reduces the risk of excessive leakage from the seal. This leakage has the potential of contributing to issues such as reduced cooling flow to the stage 2 buckets, which increases creep. It could also contribute to cooled stage 2 bucket tip shroud deflection, resulting in a condition of reduced engagement of the tip shroud interlock feature. The reduced shroud engagement is a result of airfoil/shroud creep. This is accelerated by a reduction in bucket cooling caused by discourager seal degradation.

With this uprate, the customer will be ensured that the risk of increasing creep and tip shroud engagement will be reduced with the installation of the new 410 stainless steel seal tooth material.

Replace Stage 17 Blades (FW3V)

For MS7001EA units, GE has evaluated the implications of uprates and concluded that upgrades/modifications that raise compressor pressure ratio should not be considered without first upgrading R-17 blading to current production. The recommended upgrade is associated with modifications that:

- Increase firing temperature
- Increase or add diluent injection (water, steam, nitrogen)
- Significantly increase volumetric fuel flow (fuel heating, lower Btu gases)
- Add Dry Low NO_x
- Otherwise require opening the turbine shell or compressor discharge casing to execute

Addition of diluent injection in any form changes the R17 blading status of any MS7001EA unit to requiring R-17 replacement at every major inspection. If diluent injection is proposed for any MS7001EA, a copy of TIL 1346-1 must be attached to the proposal so that the customer understands the R17 replacement schedule.

Add Compressor Water Off-Line Wash (FC4A)

For heavy duty GE gas turbines, the off-line compressor water wash system 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. A detergent can also be added if conditions warrant it. Shutting down the turbine allows for a more thorough cleaning than an on-line wash only. Off-line washing will decrease deterioration of the compressor and improve performance. The customer must purchase a water-wash skid, from GE (or other) that meets the parameters listed in FC4D.

Combustion System Improvements

The evolution of gas turbine combustion systems has been driven by the continuing desire to achieve higher firing temperatures and by the increasingly strict regulatory requirements to reduce exhaust emissions. Relatively simple parts in earlier gas turbines have evolved into hardware that requires advanced technology designs, sophisticated materials and modern production processes. There are 10 can-annular combustion chambers on each of the MS7001 class

machines that this paper addresses (“F Technology” machines have 14 combustors). *Figure 30* illustrates the arrangement of the standard combustion chamber for the MS7001EA. All MS7001 combustion systems can be designed for multiple fuel capability. Typically single or dual fuel systems have been supplied, with natural gas and distillate oil being the most common fuels. The original combustion systems utilized a single-body fuel nozzle arrangement per combustion chamber.

component life and/or for extensions in recommended combustion inspection intervals.

Figure 31 details the more significant combustion system design improvements incorporated into new unit 7EA production over the past several years. All these design improvements are available individually or as a package. The Sourcebook codes listed for each option provide a reference number to quickly provide detailed information on each option.

Breach-Loaded Fuel Nozzle (FR1T)

This modification for MS7001A through EA units will provide the turbine and on-base material to convert a water injection system from a standard, combustion casing end-cover-located water injection system to a breach-loaded system in which the water is injected through the fuel nozzle. This modification applies to either gas/liquid or liquid only. If the unit is not currently equipped with water injection, see *FG1A*.

With the latest design breach loaded fuel nozzles, the water is injected through the center of the fuel nozzle, directing the water at the combustor flame. As a result, the water injection spray does not impinge on the fuel nozzle swirler or combustion cowl assembly.

Thus, the breach-loaded fuel nozzles will reduce or eliminate the associated combustion liner cap cracking. This new design nozzle will extend combustion system inspection intervals plus reduce downtime as well as repair costs.

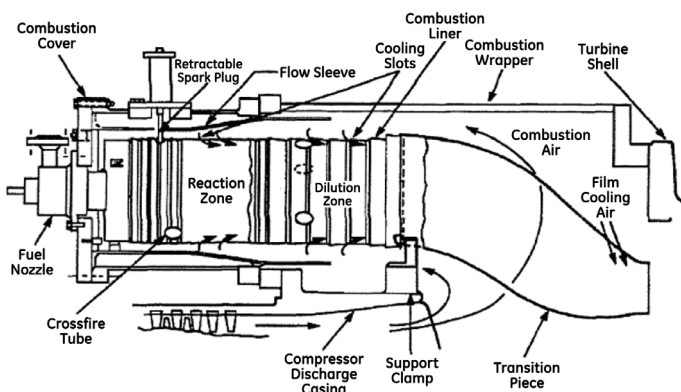


Figure 30. MS7001EA combustion chamber arrangement.

In each case, the advanced technology upgrades discussed in this paper include significant improvements to combustion system components. These combustion system upgrades can also be supplied as individual options for substantial improvements in

Sourcebook Codes	Combustion Uprate	Gas Turbine Models				
		7/1A	71AB	7/1C	71E	71EA
FR1C	Heavy Wall Transition Piece	Y	Y	Y	Y	Y
FR1D	Nimonic Transition Piece	Y	Y	Y	Y	Y
FR1G	TBC Coated Liners	Y	Y	Y	Y	Y
FR1H	7E Combustion for B Units	Y	Y	N	N	N
FR1N	Hard Facing	Y	Y	Y	Y	Y
FR1E	Multi-Nozzle Quiet Combustor	Y	Y	Y	Y	Y
FR1T	Breach Loaded Fuel	Y	Y	Y	Y	Y
FR1V	Extendor Component Retrofit	Y	Y	Y	Y	Y
FR1W	Extendor Component New	Y	Y	Y	Y	Y
FG2B	DLN 1 with 25 ppm CO _x	Y	Y	Y	Y	Y
FG2L	DLN 1 with 7 ppm CO _x	N	Y	Y	Y	Y
FG2L	DLN 1 with 5 ppm CO _x	N	N	Y	Y	Y

Some uprates require additional upgrades to be implemented.

Figure 31. MS7001 combustion uprate applications.

The primary benefit of breech loaded fuel nozzles is to put the injected water at the same relative position as the fuel entry to the combustion system. This in turn allows for proper mixing and, based on this, reduced hot gas path wear and increased inspection intervals. An MS7001EA operating on gas fuel with an emissions requirement at 42 ppmvd will consume about 2800 pounds of water (335 gallons) per hour at base load per nozzle.

Dry Low NO_x Combustor (FG2B)

For MS7001E and EA units, an alternative multi-nozzle design combustion system, the DLN combustor in *Figures 32 and 33*, can be supplied for customers who have NO_x emission requirements and no direct supply of water or steam for injection. DLN combustors offer low emissions without the need for water or steam injection to lower flame temperature. This combustion system uses fuel staging along with lean fuel/air ratios to obtain low emission levels.

Dry Low NO_x (DLN) is a two-stage premixed combustor designed for operation on natural gas. 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

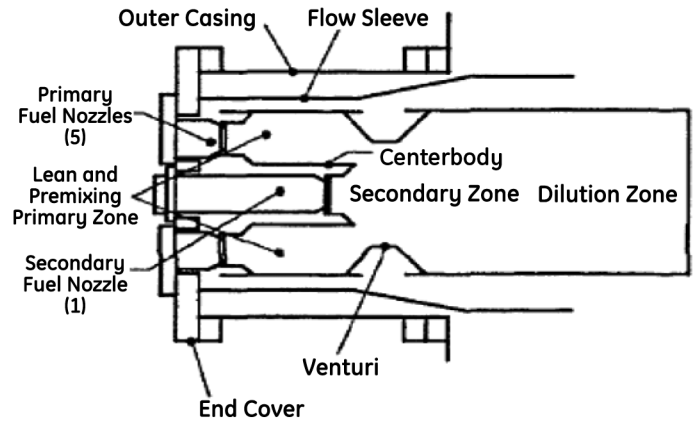


Figure 32. Dry Low NO_x combustor.

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 does not premix the fuel with air. While operating on liquid fuel, water injection is used for NO_x control. DLN operates at a constant flame temperature, and so has limited turndown in the premix operation mode. A product called “inlet bleed heat” mixes compressor discharge air with inlet air to extend turndown with DLN premix combustion.

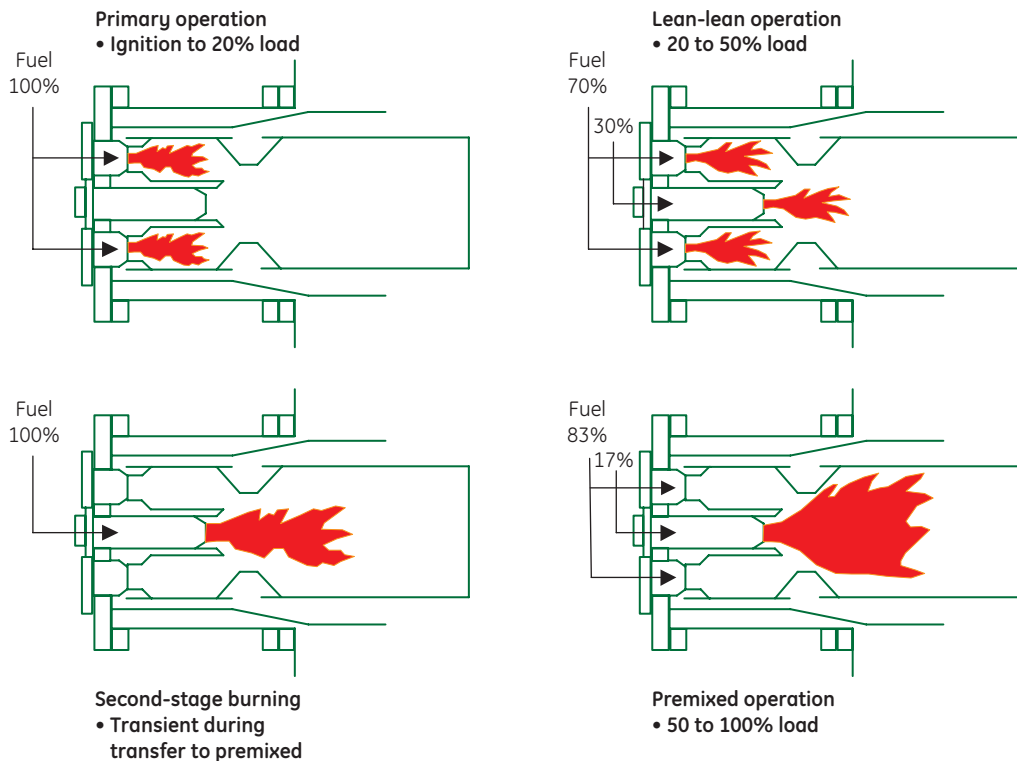


Figure 33. DLN operating modes.

The DLN combustor is similar to the Multi-Nozzle Quiet Combustor (MNQC) in that there are six individual fuel nozzles in the first, or primary, stage combustor zone. The fuel is staged, involving thorough pre-mixing of fuel with compressor discharge air in the primary zone, and introduced into a secondary combustor zone downstream where combustion occurs. DLN depends upon pre-mixing of the fuel with hot compressor discharge air, resulting in a very lean fuel-air mixture allowing a lower temperature rise across the combustor and limited NO_x production rates. Refer to GER-3568G, *Dry Low NO_x Combustion Systems for GE Heavy-Duty Gas Turbines*, for further information about GE's DLN system.

A typical DLN combustor for the MS7001EA is illustrated in *Figure 34* and for fuel delivery in *Figure 35*. DLN combustors can offer emission levels of 25 ppmvd (or less in some cases) at 15% O₂ on natural gas fuel without impacting parts lives as with water or steam injection. (Note that in order to install DLN on a 7B model, an uprate to B/E option 3, 1965°F/1074°C firing temperature, is required in conjunction with the DLN upgrade. Similarly, 7C and 7E models must be uprated to base firing temperature of at least 2020°F/1104°C).

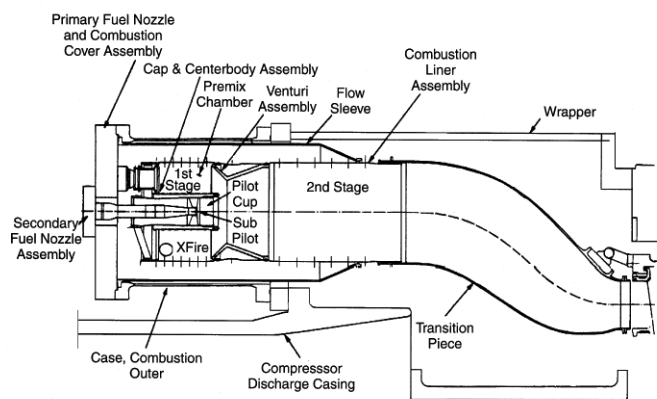


Figure 34. MS7001EA Dry Low NO_x combustion system.

GE offers an advanced Dry Low NO_x system, DLN 1+. (See *Figure 31*.) As illustrated in the figure, this system can reduce NO_x to 5 ppm with 25 ppm CO @15%O₂ for firing temperatures of 2055°F. Important aspects of DLN 1+ include: can level fuel-turning valves; secondary fuel nozzles with independent pilot fuel injection control; improved venturi cooling flow and coolant rejection with low variation; and a closed loop emissions control system. DLN 1+ can be installed in units with firing temperatures 2020°F to 2100°F to achieve 24,000-hour combustion inspection intervals with no impact on turbine durability while reducing NO_x to the levels in *Figure 31*.

Dry Low NO_x Gas Fuel System

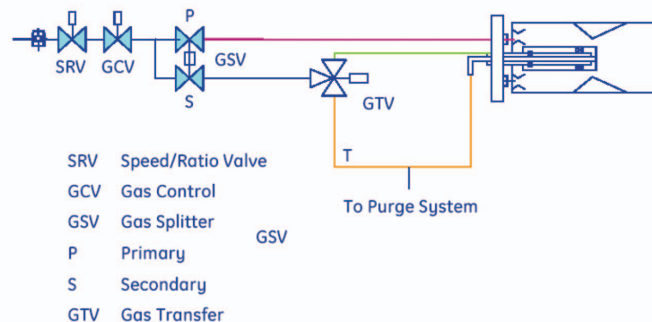


Figure 35. DLN fuel system.

Multi-Nozzle Quiet Combustor (FR1E)

For MS7001B through EA units, the MNQC was developed to reduce combustion dynamic pressure activity, thereby increasing combustion system component life. In addition, the amount of water or steam that can be injected for emissions control can be increased substantially.

The MNQC liner cap differs from the standard 7EA single-body fuel nozzle design in that it provides for six individual fuel nozzles instead of one (*Figure 36*). This multi-fuel nozzle arrangement has shown excellent field results operating on an MS7001 gas turbine in utility service with both water and steam injection for NO_x control. Tests, confirmed by extensive laboratory full-scale combustion tests, clearly demonstrated a significant reduction in combustion noise (dynamic pressure) level achieved when operating with multi-nozzle, as opposed to single-body fuel nozzle systems. The noise reduction resulting from replacing the single-body standard fuel nozzle with a multi-nozzle system reduced combustion wear and allows combustion inspections to be increased substantially for water and steam injection applications.

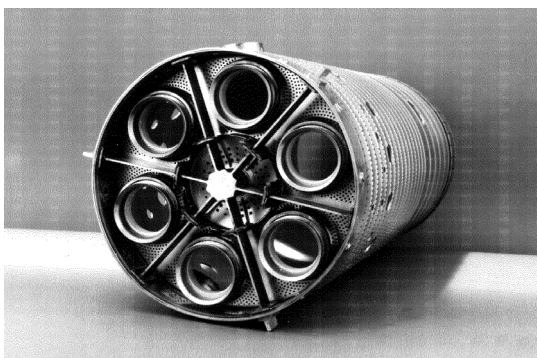


Figure 36. Multi-nozzle quiet combustor (MNQC).

In cases where water or steam is injected for NO_x control, this combustor allows for reductions down to 25 ppmvd at 15% O₂ for natural gas fuel (42 ppmvd for distillate oil fuel), substantially lower than the 42 ppmvd level attainable with the conventional single-body standard or breech-load fuel nozzle combustor.

The six fuel nozzles are mounted directly the combustion end cover such that no more piping connections are required than if a single fuel nozzle were employed; this is accomplished through manifolding integral with the cover. The MNQC combustion liner is slot cooled with heavy wall construction and thermal barrier coating (TBC) on the inner surface.

Combustion Liners (FR1G & FR1H)

For FR1G TBC liners, the applicable frames are MS7001A through EA units, and for FR1H liners for B Class, the applicable frames are MS7001A and B units. The original combustion liner on the MS7001 was the louvered liner, which obtained its cooling through louvered punches in the liner body. This liner was susceptible to cracking due to stresses introduced during the manufacturing process. The louvered liner has been replaced with a shorter, slot-cooled liner in *Figure 37*, fabricated using a combination of brazing and welding which offers considerably more liner cooling effectiveness and durability. A cutaway view of a slot-cooler liner section is illustrated in *Figure 38*.

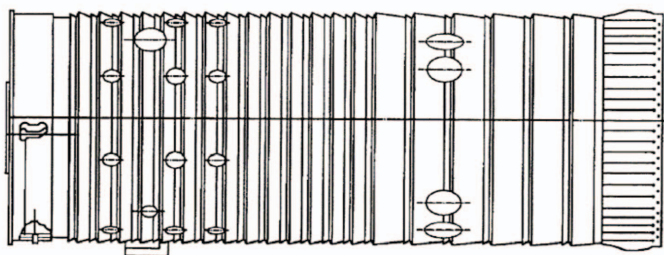


Figure 37. Current design 7EA slot-cooled combustion liner.

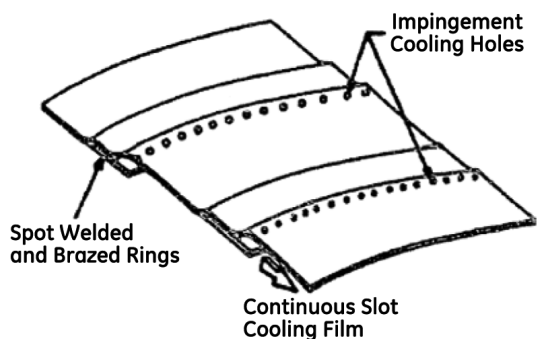
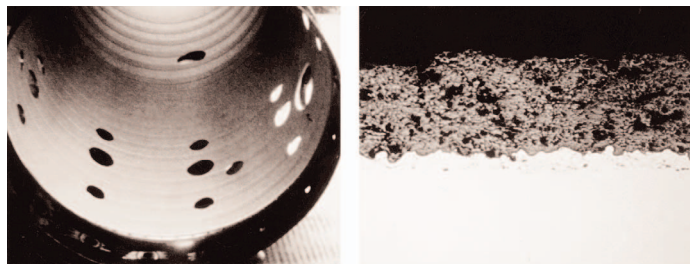


Figure 38. Slot-cooled combustion liner; cutaway view.

The slot construction provides a much more uniform circumferential distribution of cooling air flow. Air enters the cooling holes, impinges on the brazed ring and discharges from the internal slot as a continuous cooling film. To further increase the effectiveness of cooling, the slot-cooled liner was shortened by approximately 18 inches (457 mm) in axial length compared to the original louvered liner. Peak liner temperatures on the MS7001 have been reduced approximately 200°F/111°C to 250°F/139°C by converting from a louvered to a slot-cooled liner. This decrease in liner metal temperature translates into increased life and the ability to operate with high radiant fuels.

The liner material Hastelloy-X™, a nickel-based alloy, has remained constant it was first used to make liners on the 7B. However, a thermal barrier coating (TBC) that is now applied to the liners provides an insulating layer which reduces the underlying base material temperature by approximately 100°F/56°C, and mitigates the effects of uneven gas temperature distribution. The TBC consists of two materials applied to the internal hot side of a component: the first provides a bond coat that is applied to the surface of the part; the second is an insulating oxide that is applied over the bond coat. The total thickness is approximately .015 inches (0.38 mm). *Figure 39* illustrates the TBC layer applied on the interior of the liner body, along with a microview of the coating layer.



Liner

TBC Cross-Section

Figure 39. Thermal barrier coated liner.

To install the shorter slot-cooled liner on an MS7001B, the original long outer combustion casings must be replaced with new shorter 7EA style cans to accommodate the combustion system's shorter length. Combustion flow sleeves are also introduced with the slot-cooled liners. Flow sleeves are incorporated on the 7EA design to improve flow symmetry and to accelerate the air velocity outside of the liner, thereby enhancing cooling effectiveness. Flow sleeves are included as needed when upgrading older units.

Transition Pieces (FR1C & FR1D)

For FR1C heavy wall transition pieces the applicable frames are MS7001B through E units, and for FR1D Nimonic transition pieces the applicable frames are MS7001A through E units. Three different transition piece designs have been used on the MS7001 gas turbine. The first, used on the early 7B units, was the thin wall Hastelloy-X™. The second design, used on later 7B and 7E turbines, was the heavy wall Block III Hastelloy-X™ transition piece (FR1C). The third and current production 7EA transition piece is the Nimonic style (FR1D).

The thin wall and heavy wall (FR1C) Block III transition piece were made of Hastelloy-X™ material. The heavy wall Block III design was made 50% thicker and had a redesigned curvature to reduce vibration and improve the combustion gas profile. The transition piece change allowed higher firing temperatures and an increase in recommended inspection intervals from 3,000 to 8,000 fired hours. (See Figure 44.)

In the mid-1980s, a new design transition piece utilizing Nimonic 263™ was developed (FR1D). (See Figures 40 and 41.) Nimonic 263™ material is a stronger, precipitation-hardened, nickel-based alloy with improved strength and creep characteristics over the previously used Hastelloy-X™ material. Nimonic 263™ has been successfully used in aircraft gas turbines for more than 25 years, has demonstrated superior creep life, and can increase the inspection interval to 12,000 hours. (See Figure 44.)



Figure 41. Full Nimonic 263™ transition piece with cloth seals.

Like the combustion liners, the transition pieces are now coated with the TBC, thus reducing metal temperatures and increasing component life. The Nimonic transition piece has the added benefit of a redesigned curvature and includes a redesigned aft bracket, which reduces cracking at the bracket weld area by allowing it to pivot about the pin when ample force is applied. The new cylinder mount bracket has dual bolting to provide torsional restraint to the body, which will reduce wear. A comparison of the older and the redesigned bracket is illustrated in Figure 42. The aft bracket is now a forged cylindrical mount welded to the body, which eliminates cracking the body-to-mount weld region. Cooling air is admitted to the cylinder mount via cooling holes and an impingement plate to film cool the mount area. This film cooling, in conjunction with the thermal barrier coating, 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.

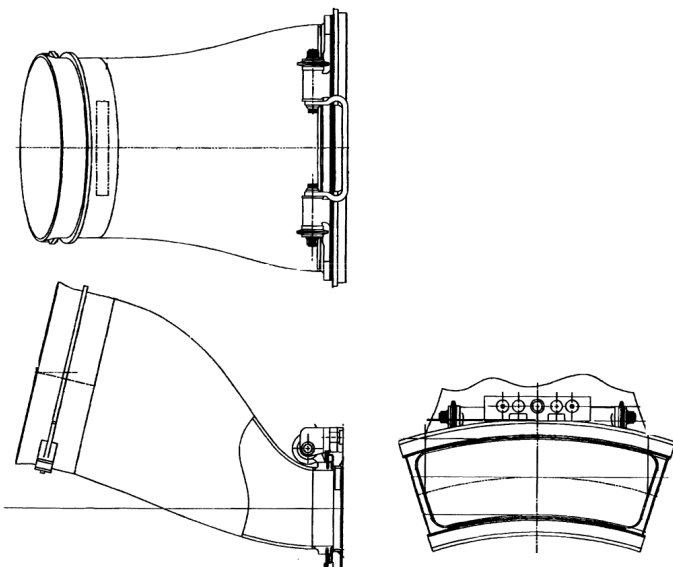


Figure 40. 7EA Nimonic transition piece illustrating downstream aft end coated inside only with TBC.

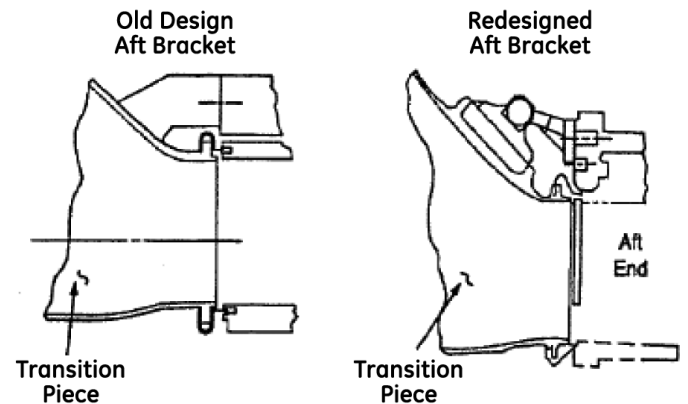


Figure 42. Comparison of transition piece aft bracket.

Hard Faced Cross Fire Tubes (FR1N)

This modification is for any customer with any older MS7001 unit not equipped with hard faced crossfire tubes. Installation of the new crossfire tubes helps to extend parts life. The hard facing on crossfire tubes consists of a flame-sprayed chrome-carbide wear coating being applied to the mating surfaces of the crossfire tubes. The hard faced crossfire tubes are then matched with hard faced crossfire tube collars on the combustion liner to complete the package. The hard facing on the crossfire tubes and collars helps to resist wear in the collar region, resulting in longer parts life.

Extendor Components Program for Increased Combustion Inspection Intervals (FR1V & FR1W)

For FR1V Retrofit Extendor Existing Components, and FR1W Purchase New Extendor Components, the applicable frames are MS7001B, C, E, and EA units.

All heavy-duty gas turbines undergo periodic combustion inspections due to material creep, thermal barrier coating erosion and wear. See *Figure 44* for component standard recommended inspection intervals with conventional and advanced technology parts.

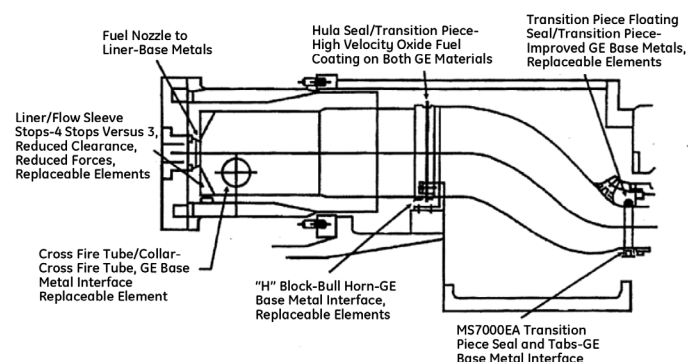


Figure 43. MS7001EA Extendor combustion wear system.

Maintenance Action	Maintenance Interval, Hours				
	7B	9B	7EA	9E	Extendor
Combustion Liner Inspection	3,000	3,000	8,000	8,000	24,000
Transition Piece Inspection					
Thin Wall	3,000	3,000	-	-	-
Thick Wall	8,000	8,000	8,000	8,000	-
Nimonic	-	-	12,000	12,000	24,000
Hot Gas Path Inspection	24,000	24,000	24,000	24,000	24,000
Major Inspection	48,000	48,000	48,000	48,000	48,000

Figure 44. Maintenance intervals for typical MS7001, MS9001, and for Extendor components.

GE’s recommended combustion inspection intervals are based on experience and a thorough understanding of the factors affecting combustion component life. For any combustion system, the duty cycle, fuel used and amount of water or steam injected are key factors in determining recommended intervals since they directly influence the operational characteristics of the combustion system and its components. Refer to *GER-3620, Heavy-Duty Gas Turbine Operating and Maintenance Considerations*, for more information relative to turbine maintenance inspections.

The MS7001 Extendor Components were developed to reduce the effects of wear at the following key wear interfaces: liner stops, fuel nozzle tip to combustion liner fuel collar, crossfire tube to combustion liner tube collar, combustion liner hula seal to transition piece forward sleeve, transition piece forward supports and bracket, and transition piece aft picture frame seal. *Figure 43* details these new combustion wear-resistant components included with the Extendor components.

The Extendor components are a combination of wear-resistant coatings, wear-resistant materials, enhanced clearances, and several mechanical design improvements. The Extendor components reduce combustion component wear by:

- Reducing the relative movement between combustion components
- Reducing forces and vibrations at wear interfaces
- Providing for critical clearance control at wear interfaces
- Using proven wear-resistant material couples developed by GE

The actual extension of combustion inspection intervals that Extendor components can provide will depend on the type of combustion system installed and unit operation. Continuous duty units operating dry or with steam injection can double or triple

combustion inspection intervals from 8,000 hours or 12,000 hours up to as many as 24,000 hours. Continuous duty units with breech-loaded style water injection fuel nozzles operating with water injection can extend combustion intervals from 6,500 or 8,000 hours to 12,000 hours.

The Extendor components improvements can be retrofitted into existing combustion hardware during routine maintenance (FR1V) or to new components using the same conversion package (FR1W). The Extendor components were initially introduced for Frame 7 gas turbines with single-body fuel nozzles, slot-cooled combustion liners, and Nimonic transition pieces. In the near future, the Extendor components will be applied to multi-nozzle Frame 7EA combustion systems. *Figure 44* illustrates the improved inspection intervals that can be realized with the installation of the improved combustion components.

Add Water Injection for Gas or Dual Fuel (FG1A)

This kit for MS7001A, B, C, E, and EA units will include the material necessary to add NO_x Water Injection to a unit. The modification kit will include replacement fuel nozzles containing water injection passages and connections, water injection skid, instrumentation, manifolding, on-base piping, fuel flow measurement system, and control changes to operate the NO_x system. This modification is not applicable to dual fuel units without atomized air. (*Reference FA6B*).

The water injection system provides water to the combustion system of the gas turbine to limit the amount of nitrogen oxides (NO_x) emitted in the turbine exhaust. This limit is site-specific and is dictated by the local regulating agency. Applicable federal, state, or local regulations will 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 federal standard. Based on these tests, a final control schedule is programmed into the control system that will regulate the water injection system.

Water injection will have a detrimental effect on the lives of the combustion system components. The combustion inspection intervals will be shorter with water injection and are also unit and fuel specific. In order to reduce thermal cracking of the fuel nozzles and liner cap/cowl assembly, a special breech-load fuel nozzle was

designed for MS6001B and MS 7001EA machines. These two frame sizes have the widest application of water injection and hence this design was first introduced for these models. The MS7001EA nozzle can also be applied to MS7001B/C units. In this design, the water is injected through an annulus in the center of the nozzle directly into the flame zone. This prevents water from impinging on the fuel nozzle or liner cap/cowl assembly. This eliminates the cracking of these components observed in the older designs and has allowed increased combustion inspection intervals. The breech-load nozzle also allows easy maintenance of the oil side of the nozzle. On units with oil operation, the application of breech-load fuel nozzle will require increasing the pressure ratio of the boost AA compressor (by increasing speed) and/or controls changes for proper ignition.

The main benefit of this modification is the reduction of the NO_x emissions level to meet EPA-required levels. In addition, a significant increase in power and heat rate will be experienced.

Fuel System Upgrades

For all MS7001A and EA units, 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 gas fuel. If the change in gas fuel 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 entire fuel system depending on the magnitude of the fuel change.

Universal Liquid Fuel (FA2L)

For MS7001A and B units, the universal liquid fuel system is designed to accommodate a wide range of petroleum-based fuels from the light distillates to crude and residuals. The modification kit is comprised of a main fuel pump, a stop valve, a free-wheeling or fuel-driven flow divider equipped with speed sensors, an electro-hydraulically controlled bypass valve, fuel filters, a control modification kit, and the necessary interconnecting piping.

The universal liquid fuel system provides the capability for use of a wide range of different fuels. A significant feature of the universal system is that it employs a rugged fixed-displacement pump and a flow divider that both divides and measures the fuel flow. This permits a comparison of the required fuel flow to the actual fuel flow, allowing for more accurate fuel control during the critical start-up period.

Convert to Gas Fuel Only (FA1A)

For MS7001E and EA units that are equipped with dual fuel DLN-1, the conversion to a gas-only fuel system from a dual fuel, liquid/gas system is designed to take advantage of the availability of gas fuel and to simplify the operation and maintenance of the gas turbine. This article addresses the conversion of MS7E/EA and MS9E DLN-1 units to Gas Only from a Gas and Distillate Dual Fuel configuration. This modification is for units that are equipped with a dual fuel, liquid and gas, DLN-1 system and are to be operated on gas only in the future. The conversion calls for a replacement of the primary and secondary fuel nozzle assemblies, elimination of the liquid fuel system, and controls modification to disable liquid fuel operation.

The primary benefits to converting to a gas-only system is that it eases maintenance and utilizes an available, generally less costly fuel. Gas fuel is a more easily handled fuel and has simplified emission controls.

Convert from Liquid to Dual Fuel by Adding Gas (FA3D)

There are many gas turbines in the family of MS7001B through EA units 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 continued to be available and liquid fuel is being used more often as a back-up fuel than as a primary fuel.

This modification will give the customer significant operational flexibility and potential fuel cost savings with the added gas fuel capability. There is no performance difference expected by adding gas fuel.

Hot Gas Path Improvements

The turbine hot gas path presents one of the greatest engineering challenges, and extensive efforts continually improve bucket and nozzle materials and designs. Advances in hot gas path technology,

including material improvements, coating developments, and design enhancements have led to the current MS7001 E-Class hot gas path. This section will provide details of the latest designs that have been incorporated into current production frame 7 E Class units, and that are available for retrofit on all the earlier MS7001 models now in use by operators. *Figures 45–47* give some examples of improved parts that are available to uprate the firing temperature to 2055°F.

Stage 1 Nozzle with Chordal Hinge (FS2J)

For MS7001A/B/C/E/EA units, the stage 1 nozzle has undergone several changes since the original design nozzle went into service. Over the years, cooling hole patterns have been resized and relocated, improved mounting arrangements have been introduced, and new vane airfoil designs have been developed. The 7EA improved universal nozzle (with a chordal hinge design) incorporates advanced cooling and sealing of the nozzle.

With the new nozzle the support ring design is altered, and thus a new improved stage 1 nozzle support ring is included with the conversion to the latest stage 1 nozzle.

The stage 1 nozzle is held in position by both the retaining and support rings. For machines with earlier style nozzles, the support ring usually must be replaced. The current mounting arrangement provides much greater support for the nozzle assembly. This improved tangential support lug with a milled radial slot was introduced to the stage 1 nozzle inner sidewall in each of the 18 segments that engages into the nozzle support ring. In conjunction with the support lug, an improved single piece bushing/tangential pin was added. A simpler flat plate retainer and lockplate is now used with two retainer bolts instead of one bolt previously used on the universal stage 1 nozzle. Adding inner side wall tangential support improves the overall reliability of the turbine and in certain situations, where fillet cracks have started along the airfoils, curtails the increasing frame stresses.

The latest production 71EA stage 1 turbine nozzle incorporates a new chordal hinge design and improved sidewall cooling that result in increased turbine performance and reduced maintenance, as well as the capability to burn heavy fuels as well as clean fuels.

GE Energy's newly designed improved cooling stage 1 nozzle illustrated in *Figure 48* offers advanced sidewall cooling and a new sidewall sealing design that allows operation at higher firing

7E and 7EA Stage 1 Parts

Part Name	Catalog Number	Quoted Life	Firing Temp
Perimeter Cooled Improved Cooling GTD-111 Stage 1 Bucket	314B7165G032	96,000	2055°F
Improved Cooling FSX-414 Stage 1 Nozzle	119E1722G002 (No TBC) 119E1722G016 (TBC) 119E1722G014 (ETBC*)	72,000	2055°F
HR-120™ Stage 1 Shroud	104C1547G001	48,000	2055°F

Figure 45. Stage 1 available parts.

7E and 7EA Stage 2 Parts

Part Name	Catalog Number	Quoted Life	Firing Temp
IN-738™ Improved Cooling Stage 2 Bucket	314B7166G038	72,000	2055°F
GTD-222+ Stage 2 Nozzle	116E4050G025	72,000	2055°F
SS-310 Honeycomb Stage 2 Shroud	339A9965G005	72,000	2055°F

Figure 46. Stage 2 available parts.

7E and 7EA Stage 3 Parts

Part Name	Catalog Number	Quoted Life	Firing Temp
IN-738™ Stage 3 Bucket	314B7167G029	72,000	2055°F
GTD-222 Stage 3 Nozzle	119E1539G005	72,000	2055°F
SS-410 Honeycomb Stage 3 Shroud	357B9978G003	72,000	2055°F

Figure 47. Stage 3 available parts.

Improved Cooling FSX-414 Stage 1 Nozzle

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

Offers:

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

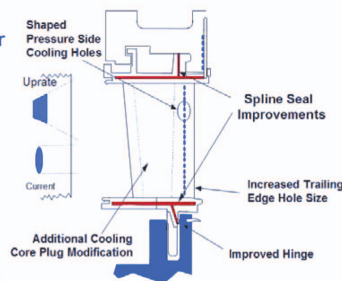


Figure 48. Improved stage 1 nozzle.

temperatures while maintaining component reliability and life cycle. The new design incorporates the following GE-proprietary features:

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

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

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

Increased High Temperature Capability. The GE-proprietary FSX-414 cobalt-based superalloy possesses superior strength (compared to most nickel-based superalloys) at very high temperatures allowing increased firing temperatures up to 2084°F. FSX-414 offers enhanced weldability, improved oxidation/corrosion resistance, and an increase in firing temperatures over previously used materials.

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

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

Heavy Fuel. For 7EA units, it is recommended to use the heavy-fuel stage 1 nozzle per FS2J, designed for units operating on heavy fuels, such as crude oil and residual oil. The cooling holes of the heavy-fuel stage 1 nozzle are larger than on the standard-fuel stage 1 nozzle. This serves to protect the heavy-fuel nozzle from clogging due to the increased combustion deposits associated with heavy fuels. Other than larger cooling holes, the standard fuel and heavy fuel nozzles are identical.

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

Stage 1 Nozzle with Enhanced TBC Coating (FS6E)

For MS7001E and EA units, the stage 1 nozzles can be coated with an enhanced thermal barrier coating. This ETBC can be applied to the leading edge, pressure side and outer wall of the stage 1 nozzle over the TBC. (See *Figure 49*.) ETBC provides a smoother surface finish to the stage 1 nozzle, which incorporates a slick, highly erosion-resistant

Enhanced Thermal Barrier Coating

eTBC, an advanced three layer coating system consisting of:

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

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

It reduces friction and erosion which yields performance.

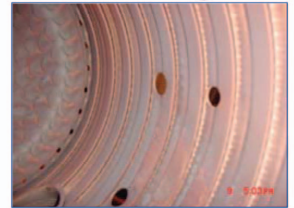


Figure 49. Stage 1 nozzle with enhanced TBC.

coating over the TBC. The smoother finish of ETBC makes it possible to increase the benefits of the thermal barrier coatings.

The overall benefits of enhanced thermal barrier coating for E-class stage 1 nozzles include:

- Enhanced erosion resistance 3X greater than porous TBC
- 5X smoother surface finish compared to TBC alone
- Reduced susceptibility to surface fouling
- Sustained smooth surface finish and unit operating performance
- Analytically predicted minor heat rate improvement over TBC alone
- Prolonged component life, durability, and increased maintenance intervals

The performance improvements are possible due to the sustained surface finish of the smooth coat over time. Improved surface finish reduces heat transfer—thus increasing part durability, improving erosion resistance (3X greater in laboratory testing), and reducing surface fouling.

Stage 2 Nozzle Introduction

GE offers two different nozzles for 7B through 7EA machines. (See *Figure 50*.) Both nozzles are made from GTD-222+ material with high creep resistance. The frame 7EA design enhancements allow an increase in firing temperatures up to 2055°F while the re-

Frames	Features
7B through 7EA	GTD-222+ alloy material Internal core plug Long chord vane length Up to 2055°F 72,000 hours
7B, 7C and early 7E	GTD-222+ alloy material Long chord vane length Up to 1850°F 72,000 hours

Figure 50. Stage 2 nozzles for E-Class.

introduced 7B stage 2 nozzle provides an affordable solution for 7B, 7C, and early 7E models operating at 1850°F or lower firing temperature.

Stage 2 Nozzle GTD-222+ (FS1P)

For MS7001A/B/C/E/EA units that shipped through 2005, the current stage 2 nozzle design includes a modified cooling pattern and use of an advanced alloy material (GTD-222+). (See Figure 51.) These improvements allow the unit to be operated at higher firing temperatures that provide for increases in efficiency and output. In addition, design improvements have resulted in less maintenance requirements that provide improved reliability and availability. Figure 53 gives the features and benefits of the improved Stage 2 nozzle.



Figure 51. Improved stage 2 nozzle.

GTD-222+ is inherently resistant to creep and oxidation, and the addition of an aluminide coating provides even greater resistance to high temperature oxidation. The internal core plug provides more efficient distribution of cooling air and reduces nozzle cooling requirements. The longer chord vane reduces stress level and

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

Reduced Cooling Flow
Controlled by Tuning Pin

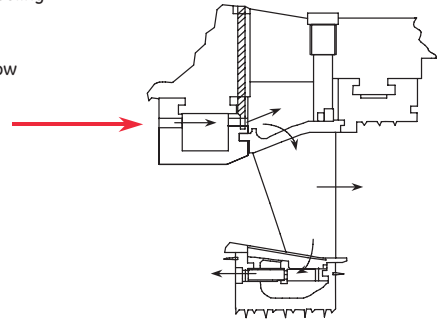


Figure 52. Reduced airflow in stage 2 nozzle.

increases part life. Figure 52 illustrates how tuning pins installed in the stage 1 shroud reduce cooling flow, thereby increasing performance.

The most significant problem with the stage 2 nozzle was tangential downstream deflection, indicating creep in the vane. To increase creep resistance, several important modifications have been introduced.

The original stage 2 nozzle on 7B units lacked air cooling, so impingement air cooling was added to the early 7E nozzle to reduce surface metal temperature. The nozzle chord length was also increased to reduce stress levels and prevent creep. On some earlier 7B units, a different design nozzle with a long outer sidewall was utilized. The present 7EA nozzle is of a short sidewall, long chord design. The difference in vane chord length is illustrated in Figure 54.

On machines with the long sidewall nozzle, stage 1 shroud blocks must also be replaced with a wider shroud block to accept the smaller sidewall design of the nozzle. The air-cooling pattern with the latest nozzle has been further improved compared to the original air-cooled designs. The nozzle core plug has been modified to further improve cooling effectiveness on the airfoil vanes.

GTD-222+ nozzles have performance benefits, heat rate benefits, and provide greater creep strength—thereby resisting downstream deflection:

- Performance and heat rate benefits are obtained as compared to FSX-414 nozzles. (See Figure 55.)
- Significant reduction in downstream creep deflection is obtained, a key life-limiting factor.
- Life increases to three HGPI (72,000 fired hours).

Feature Summary

	Previous Stage 2 Nozzle	GTD-222+ Stage 2 Nozzle for 7B-7EA
Material	FSX-414	GTD-222+
Internal Core Plug	Not Present	Present
Chord Van Length	Short	Long
Firing Temp	Up to 2020°F	Up to 2055°F

Benefits

- Reduced nozzle downstream stream creep deflection increases the life cycle of the nozzle.
- Design life expectancy of three hot gas path inspections (72,000 hours for gas only, dry, base loaded operation).
- Cooling airflow to the second stage nozzle is reduced on some units providing performance output increases up to 1%.
- Capable of increased firing temperatures, up to 2055°F.

Applicability

This offering is intended for use with Frame 7B, 7C, 7E, or 7EA gas turbines shipped through 2005.

Feature Summary

	Previous Stage 2 Nozzle	GTD-222+ Stage 2 Nozzle for 7B
Material	FSX-414	GTD-222+
Internal Core Plug	Not Present	Present
Chord Van Length	Short	Long
Firing Temp	Up to 1850°F	Up to 1850°F

Benefits

- A reduction in nozzle downstream stream creep deflection increases the life cycle of the nozzle.
- Design life expectancy includes three hot gas path inspections (72,000 hours for gas only, dry, base loaded operation).
- Cooling airflow to the second stage nozzle is reduced on some units and can provide performance output increases up to 1%.

Applicability

This offering is intended for use with Frame 7B gas turbines.

Figure 53. Features and benefits of improved second stage nozzle.

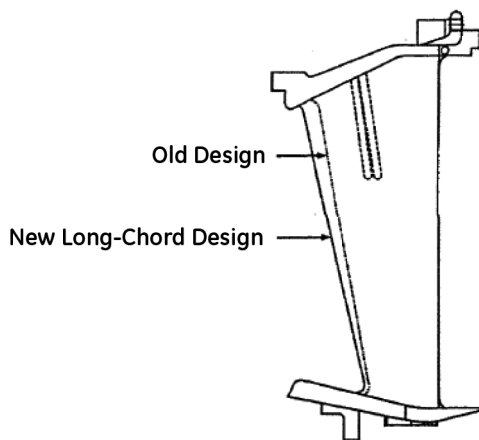


Figure 54. Long- and short-chord nozzle design comparison.

Downstream loading caused by axial pressure differential across the vanes associated with hot gas reaction forces—along with the cantilever design of the nozzle assembly—can contribute to a gradual downstream deflection of nozzles. Figure 55 illustrates the side view of a typical stage 2 nozzle segment indicating original position and resultant creep deflected position with the FSX-414

GTD 222 Stage 2 Nozzle Creep

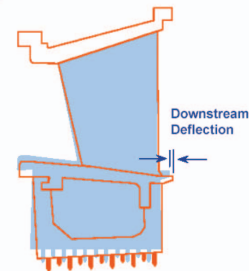
Improved Creep Resistance

Improved Nozzle Vane Cooling

- Redesigned Core Plug

Improved Performance

- Reduced Cooling Air Flow



GTD Stage 2 Nozzle Performance Improvement

Reduced Cooling Flow Controlled by Tuning Pin

Performance Improvement

	Output	Heat Rate
MS6001B	+1.0%	-0.4%
MS7001E/EA	+0.8%	-0.3%
MS9001E	+1.0%	-0.4%

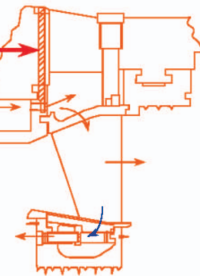


Figure 55. Benefits of GTD-222+ nozzles as compared to FSX-414 nozzles.

material. Downstream deflection can cause problems such as changing axial clearance between nozzle diaphragm and turbine wheel spacers—which alters cooling air flows to rotor wheelspaces; or when metal to metal contact occurs between components. Measurement of 2F1 (stage 2) and 3F1 (stage 3) clearances allows monitoring of deflection conditions. (See Figure 56.)

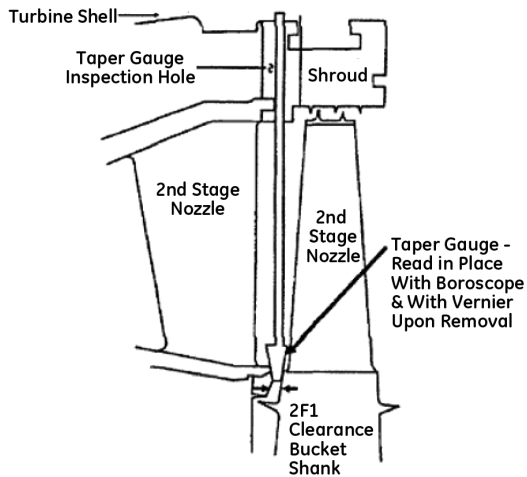


Figure 56. MS7001 stage 2 nozzle inspection.

GTD-222+ is a new nickel-based nozzle alloy that was developed and patented by GE in response to the need for greater nozzle creep strength. Figure 57 illustrates the relative improvement in nozzle creep resistance of GTD-222+ over the FSX-414 material originally used. When the nozzle material was changed to GTD-222+ along



Figure 57. GTD-222+ vs. FSX-414 nozzle creep deflection comparison.

with the improved internal core plug cooling design, such excellent results were observed with respect to creep resistance that cooling air flow to the nozzle was actually reduced to take full advantage of the GTD-222+ material properties. With this reduction in cooling air flow, the turbine experiences an increase in performance with the complete modification. Output increases on the order of +0.8% can be expected by installing the GTD-222+ nozzle with reduced cooling air on the 7EA and 7EA models. Cooling flow to the stage 2 nozzle is reduced by installing new longer tuning pins into new stage 1 shroud blocks with new smaller aft cooling air orifices. The stage 2 nozzle has an aluminide coating applied on the GTD-222+ to increase resistance to oxidation.

Coatings Available. This GTD-222+ nozzle includes an aluminide coating for increased high temperature oxidation resistance. It can be further enhanced by adding the following optional coatings:

- **Thermal Barrier Coating (TBC).** This rough-surfaced coating offers increased resistance to thermal fatigue, resulting in life extension and improved maintenance intervals.
- **Enhanced Thermal Barrier Coating (ETBC).** With a slick, highly erosion resistant coating, this TBC provides a smooth surface finish to the stage 2 nozzle. ETBC GE patented smooth finish increases the benefits of thermal barrier coatings.

Stage 3 Nozzle (FS1R)

Sourcebook article FS1R for improved stage 3 nozzles applies to MS7001A/B/C/E/EA units. In regards to the 7EA, a new stage 3 nozzle has been recently introduced. The changes are similar to those included in the new GTD-222+ stage 2 nozzle (described above). The stage 3 nozzle has experienced the same creep problem as the stage 2 nozzle, but to a lesser degree due to lower operating temperatures at its location. Like the stage 2 7EA nozzle, the chord length of the stage 3 nozzle also was increased for aerodynamic benefits; however, air cooling has not been added. An internal airfoil rib, similar to the design for the stage 1 nozzle, was introduced. As the airfoil chord length increases, the nozzle behaves less like a beam, which causes the suction and pressure panels to become more independent and buckle and/or warp with typical nozzle loading. With the addition of the internal airfoil rib, the structure continues to behave like a beam, even with the long chord design.

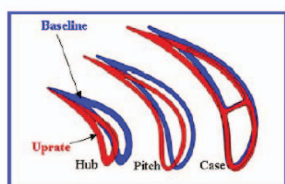
The 7B stage 3 nozzle, originally made from N-155™ material, an iron-based alloy, was changed to FSX-414 for earlier 7E/EA units. GTD-222+, the material now also used for the stage 2 nozzle, has been introduced as the latest stage 3 nozzle material to help prevent creep on the 7EA units. The benefits of the GTD-222+ nozzle can also be obtained with all earlier MS7001 turbines. (See Figure 57.)

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

FS4K Advanced Nozzle. To improve output and decrease heat rate for MS7001A through EA units, the advanced aero stage 3 nozzle is redesigned with improved airfoil aerodynamics. (See Figure 58.)

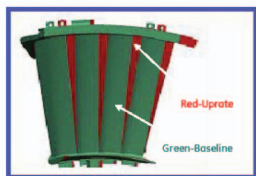
This improved design will allow for additional performance benefits when used in combination with the advanced aero stage 3 bucket (FS4L), as described in Figure 59. The modification includes the third stage nozzle and diaphragm plus required hardware.

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 58. Advanced Aero Stage 3 Nozzle.

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



Figure 59. New stage 3 bucket design.

The third stage nozzle was redesigned to improve aerodynamic performance. On the new airfoil, the inner and outer sidewalls are modified but the airfoil profile tolerances and wall thickness tolerances are the same. The flow path definition remains the same and the new nozzle design allows the use of the old machining fixtures in the hot gas path. There also is no reduction in transactional or contractual repair/replace intervals.

Dimensionally, the redesigned nozzle is interchangeable with the existing GTD-222+ nozzle. The latest stage 3 nozzle design is made out of GTD-241* material instead of GTD-222+ which offers similar creep resistant properties.

On those 7/1A/B and 9/1B units that are not already equipped with GTD-222+ or the advanced aero nozzle, the installation of the new design third stage nozzles provides an excellent time to install replaceable wheelspace thermocouples. More technical information can be found in FK5C.

FS4L Advanced Bucket. This modification for MS7001A through EA units replaces the existing stage 3 buckets with an advanced aerodynamic redesigned stage 3 bucket with an improved airfoil. (See Figure 59.) The high efficiency airfoil reduces stage losses and improves stage efficiency. This improved design allows for additional performance benefits when used in combination with the advanced aero stage 3 nozzle (reference FS4K). (See Figure 61.)

The latest stage 3 bucket design is made out of GTD-741* material instead of IN-738™ and offers similar hot corrosion resistance and outstanding strength at the high uprate temperature. For MS7001A-EA and the MS9001E, the advanced aero uprated bucket is dimensionally interchangeable with the existing bucket.

The advanced aero stage 3 bucket design includes “cutter teeth” on the bucket tip shroud rails, see Figure 60. The tip shrouds are re-scalloped for the new airfoil profile. The cutter teeth are designed to cut a slot in the honeycomb seal material on the stage 3 shroud block with no metal transfer to the bucket. This will allow new shroud blocks with honeycomb seals to be installed (reference FS2U). Since 1996, all new Frame 7E/EA, and 9E stage 2 and 3 buckets have been manufactured with cutter teeth on the bucket tip rails. High efficiency airfoil will reduce stage losses and improve stage efficiency. Performance benefit is available when used with the advanced aero stage 3 nozzle (Reference FS4K).

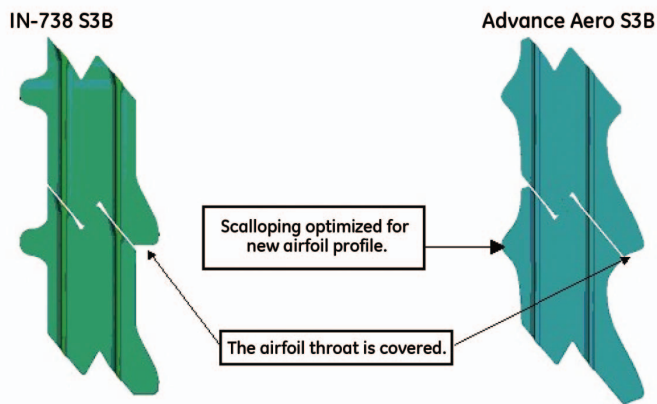


Figure 60. Advanced Aero Stage 3 Bucket.

Installation of Both Parts Provides the Greatest Benefit Significant Improvement in Output and Heat Rate

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

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

Figure 61. Performance benefit when Advanced Aero Stage 3 Bucket and Nozzle are combined on same unit.

Stage 1 Buckets Introduction

GE has designed several stage 1 buckets to meet each customer's specific needs. (See Figure 62.) Advanced materials and cooling features allow the current technology 12-hole blunt leading edge stage 1 bucket 314B7165G030—and the latest technology perimeter-cooled blunt leading edge GTD-111 directionally solidified stage 1 bucket 314B7165G032—to achieve firing temperatures up to 2055°F. The reintroduction of the IN-738™ stage 1 bucket for frames 7B 314B7165G031 provides a replacement solution for 7B, 7C, and early 7E models operating at 1985°F or lower firing temperature.

Stage 1 GTD-111 Buckets With Blunt Leading Edge and with 12-Hole Cooling (FS2G and FT6J)

This modification for MS7001B through EA units replaces either the existing sharp leading edge or the earlier version of the blunt

Frames	Part #	Features
7B through 7EA	314B7165G030	<ul style="list-style-type: none"> • 12 cooling holes • GT-33 IN Plus coating • Up to 2055°F • 72,000 hours
7B through 7EA	314B7165G032	<ul style="list-style-type: none"> • Perimeter cooling 16 radial cooling holes • GT-33 IN Plus coating • Up to 2055°F • 96,000 hours
7B, 7C and early 7E	314B7165G031	<ul style="list-style-type: none"> • 13 cooling holes • GT-33 coating • Up to 1985°F • 48,000 hours



Figure 62. Stage 1 buckets for E-Class.

leading edge (BLE) design stage 1 buckets with a modern design, directionally solidified BLE stage 1 bucket with 12-hole cooling, (See Figures 63 and 64.) The increased cooling results in a three-HGPI service life (up to 72,000 hours) by significantly reducing thermal gradients and associated thermally-caused cracks that occurred in the previous bucket along the leading and trailing edges.

Stage-1 BLE/DS Buckets

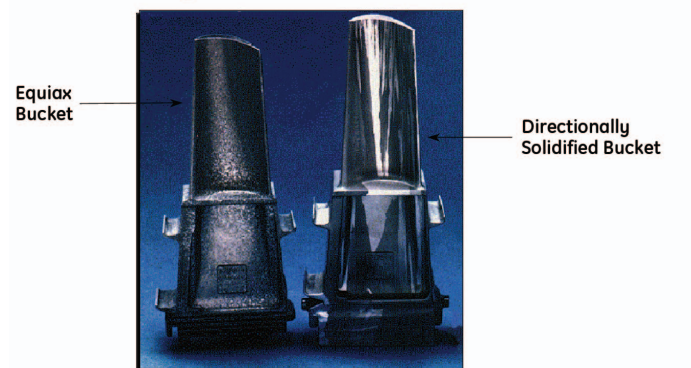
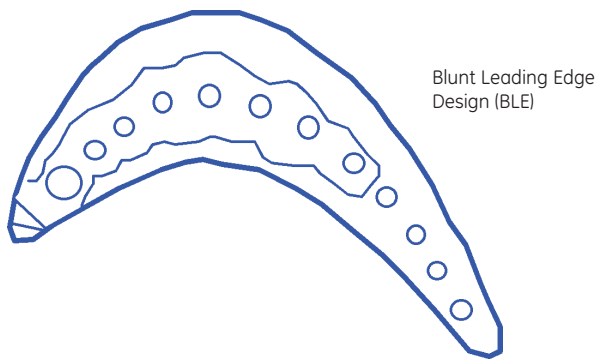


Figure 63. Improved stage 1 bucket cap capable of 2055°F firing temperature.



	All Previous Stage 1 Buckets	GTD-111 Stage 1 Bucket
Material	U700™/IN-738™/GTD-111 (E/A)	BLE DS GTD-111
Coating	Up to GT-29 IN Plus	GT-33 IN Plus
Cooling Holes	11 Cooling Holes	12 Cooling Holes
Firing Temp	Up to 2020°F	Up to 2055°F

Figure 64. Features of stage 1 advanced bucket.

The BLE stage 1 bucket design allows more cooling air to reach both the leading and trailing edges of the bucket. The increased cooling significantly reduces thermal gradients and associated cracks along the leading and trailing edges. Output performance is increased by 0.5% for 7/1 units that have the original (pre-1987) sharp leading edge bucket, output is not affected in other units.

Current production MS7121 units ship with BLE 12 cooling hole stage 1 buckets. The BLE stage 1 bucket incorporates and refines all the design advantages associated with the MS7/1E blunt leading edge bucket. These design advantages include:

- 1) *Directionally solidified (DS) GTD-111.* A precipitation hardened, nickel based super alloy with increased rupture strength provides greater low cycle fatigue strength while providing the industry standard in corrosion resistance.
- 2) *Plasmaguard* GT-33 coating.* This vacuum plasma spray coating further increases the corrosion and oxidation resistance of the bucket. (Note: The aluminide coating is still available as an option for possible spare parts consistency or interchangeability reasons.)

In 1983, Plasmaguard (GT-29*) coating was introduced, which had better corrosion resistance but lacked adequate oxidation resistance.

In 1989, Plasmaguard Plus (GT-29 Plus*) was developed, satisfying both criteria and is currently used on the 7EA stage 1 bucket.

More recently, Plasmaguard GT-29 IN Plus coating was introduced to allow coating of the internal air cooling passages with an aluminide coating to protect the internal surfaces from oxidation. Figure 65 shows a comparison of the older PtAl coating vs. GT-29 Plus currently in production. For further information on bucket materials and coatings, reference GER-3569E, *Advanced Gas Turbine Materials and Coatings*.

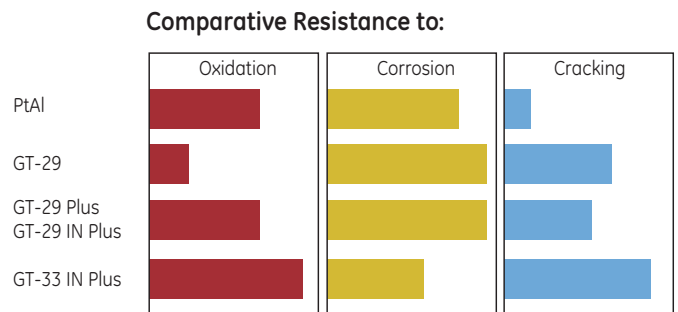


Figure 65. Types of bucket coatings.

- 3) A re-designed cooling hole pattern allows more air to the leading edge, resulting in a reduction in thermal gradients and associated cracks. The addition of a twelfth cooling hole is added, thereby extending the cooling hole pattern and providing better overall cooling, particularly in the trailing edge of the bucket.

16-Hole Perimeter Cooled GTD-111 Stage 1 Bucket (FS4A)

This modification for MS7001A through EA units that shipped through 2006 will replace the current stage 1 bucket with a redesigned directionally solidified (DS) stage 1 bucket, with advanced aerodynamics and cooling features that allow for operation at the higher 2055°F firing temperature associated with the 7EA Advanced Technology Uprate. These buckets (and all the improved components) are interchangeable with previous designs as complete kits.

These blunt leading edge, directionally solidified (DS) GTD-111 buckets possess an oriented grain structure that runs parallel to its major axis and contains no transverse grain boundaries. The elimination of the transverse grain boundaries results in improved creep life and rupture strength. The orientation of the grain structure provides a favorable modulus of elasticity in the longitudinal direction, increasing fatigue life.

The new bucket-cooling scheme includes a series of sixteen radial cooling holes located around the perimeter of the bucket. (See *Figure 66*.) Thirteen of the cooling holes include turbulators on the internal surfaces of the cooling holes (from 0 to 80% of bucket span) to increase the efficiency of heat transfer from the bucket metal to the cooling air. The locations of the cooling holes allow cooling air to reach both the leading and the trailing edges, significantly reducing thermal gradients and any associated cracks along these edges.

Stage-1 Perimeter/Turbulated Cooled BLE/DS Buckets

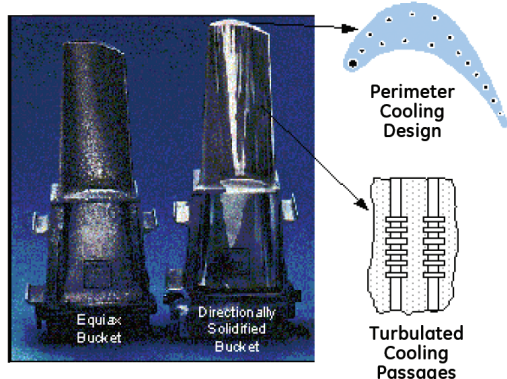


Figure 66. Stage 1 perimeter cooled 16-hole buckets.

In addition to the improvements in cooling, the new bucket has a new airfoil profile. The new airfoil profile has been designed with heat transfer characteristics appropriate for operation at the higher 2055°F firing temperature 7EA Advanced Technology Uprate. This included thinning of the leading edge and rotating the airfoil hub sections. With all of these improvements, the bulk metal temperature of the new first stage buckets operating at the higher firing temperature will be lower than the bulk metal temperature of the current buckets operating at the lower firing temperature.

GT-33 IN Plus is the standard coating applied to the buckets. (See *Figure 67*.) For units that burn corrosive fuels, GT-29 IN Plus coating can be provided upon request.

The re-designed bucket has a designed life expectancy of three Hot Gas Path Inspections (72,000 hours for gas only, dry, base loaded operation) for 6B gas turbines. With the new aerodynamic design of the perimeter-cooled 7EA stage 1 bucket, customers with 7B through 7EA gas turbines can expect an increase in bucket life from 72,000 to 96,000 hours.

Feature Summary

	Previous Stage 1 Buckets	Perimeter Cooled Stage 1 Bucket
Material	U700™/IN-738™/GTD-111	BLE DS GTD-111
Coating	Up to GT-33 IN Plus	GT-33 IN Plus
Cooling Holes	Up to 12 Smooth Holes	3 Smooth/13 Turbulator Holes
Firing Temp	Up to 2055°F	Up to 2055°F

Benefits

- Extended bucket life intervals
 - Designed life expectancy of four hot gas path inspections (96,000 hours for gas only, dry, base loaded operation)
- Improved cooling features
 - Increase heat transfer efficiency
 - Reduce thermal gradients
 - Reduce cracks along leading and trailing edges
- Improved aerodynamics
 - Better aerodynamic design and leading edge shape reduce the possibility of airflow separation that may result in loss of power
 - Newly designed leading edge meets variations in airflow between bucket's root and tip

Figure 67. Features and benefits of 16-hole perimeter cooled bucket.

Stage 1 Bucket with TBC Coating and 12-Hole Cooling (FS4G)

For frame MS7001EA units, thermal barrier coating (TBC) can be applied to new and in-service stage 1 turbine buckets to extend bucket life and increase maintenance intervals. Dense vertically cracked (DVC) TBC patented by GE is superior to coating applications offered by independent service providers due to the following:

- GE's bonding coat, GT-33, is superior to the thinner, smoother, and less adhesive ISP coatings
- GE's DVC TBC is more than twice the thickness of ISP TBC, and resists spallation to provide a more robust thermal gradient barrier than the competition
- Extensive GE lab data produced at GE Global Research Center, design engineering modeling, and program development have been used to insure the optimum application, thickness, composition, and product performance of DVC TBC

Coating the first stage buckets with TBC increases hot gas path parts life and maintenance intervals at a small cost to performance. Based on fleet leader data and extensive testing, it has been

determined that 32,000 hour inspection intervals can be obtained. However, gains in inspection intervals are impacted by other factors such as firing temperature, base load vs. peaker duty, fuel and fuel quality, ambient temperatures, and number of hard starts (see GER-3620K) and this will need to be considered on a case-by-case basis. According to design predictions, TBC also has the potential of increasing bucket life from 72,000 hours to 96,000 hours of total life. However, this life expectancy increase should not be quoted to the customer until there is sufficient field data to validate the design analysis. There is no emissions impact from this change.

Stage 1 IN-738™ Bucket

The IN-738™ stage 1 bucket is a direct replacement for the 7B, 7C, and early 7E models operating at 1985°F or lower firing temperature. The bucket was constructed using a leading-edge airfoil shape and an equiaxed IN-738™ material. First used in Frame 7 models built between 1971 and 1987, this superalloy was the first cast bucket material used by GE gas turbines. This bucket is well suited for units for which low cost, elevated temperature strength, corrosion resistance, and proven reliability are critical. GT-33 coating increases the corrosion and oxidation resistance.

Stage 2 Bucket

The air-cooled design GTD-741 stage 2 bucket for frames 7B through 7EA 214B7166G039 can achieve firing temperatures. The re-introduced IN-738™ stage 2 bucket 314B7166G033 for frame 7B provides a low cost direct replacement solution for units operating at 1840°F or lower.

Stage 2 Improved Bucket (FS1L)

The stage 2 bucket was revised for MS7001A and B units that shipped prior to 1979. (See Figure 68.) The first major change was the addition of air-cooling to the stage 2 bucket that was absent for the

Frames	Part #	Features
7B through 7EA	314B7166G039	GTD-741 10 cooling holes Shrouded design Cutter teeth Up to 2055°F 72,000 hours
7B shipped prior to 1979	314B7166G033	IN-738™ Shrouded design Cutter teeth Up to 1840°F 72,000 hours

Figure 68. Stage 2 buckets.

7B. This improvement requires replacement of the 1-2 spacer (found between the stage 1 and 2 turbine wheels) to allow cooling air from the compressor extraction to flow to the stage 2 bucket. Figure 69 illustrates the cooling airflow to the stage 2 bucket coming up through the 1-2 turbine spacer. With air-cooling introduced to the stage 2 bucket, higher firing temperatures can be achieved.

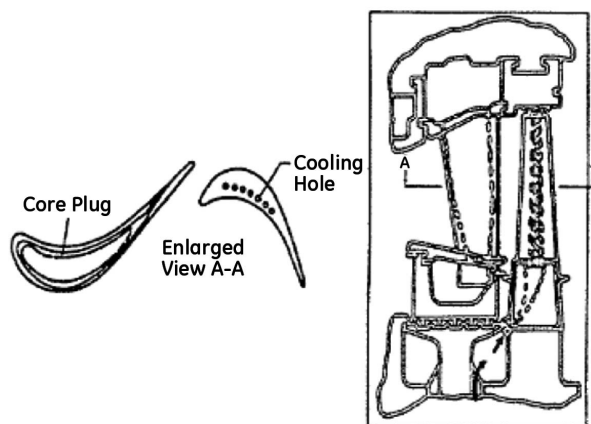


Figure 69. MS7001 stage 2 air-cooled bucket.

The second area of redesign involved the interlocking tip shroud on the bucket top to reduce operating stress levels and increase creep life. To achieve these objectives, the shroud leading edge was machined to remove excess material (see Figure 70 scalloping process), the area between the seal teeth was thickened, and the underside of the shroud was tapered. The final configuration, which employs a lighter and more robust design is illustrated in Figure 71. The new shrouded tip design reduced stress levels by more than 25% and increased creep life 80% over the original design.

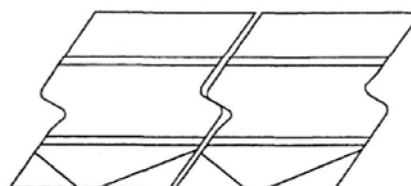


Figure 70. Scalloping of the bucket shroud.



Figure 71. Final configuration of bucket shroud.

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

*Refer to GER3571 for information about cutter teeth applications.

Benefits

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

Figure 72. Improved stage 2 bucket.

Another important improvement made to the stage 2 bucket was a change in material. (See Figure 72.) Originally, the 7B turbines had stage 2 buckets made of U700™, a precipitation-hardened, nickel-based alloy; the 7A had U500™ material buckets. The current model 7EA buckets are made of IN-738™, also a precipitation-hardened nickel-based alloy that had been used on the 7B model stage 1 buckets. IN-738™ is a better choice as it was specifically designed for land-based gas turbines, as opposed to use in aircraft. Combining elevated temperature strength and hot corrosion resistance, IN-738™ has lasted longer and, in tests comparing it to U700™, was in better condition even after four times testing duration.

IN-738™ Material. The new bucket material combines elevated temperature strength and hot corrosion resistance while the new tip shroud design reduces stress sufficient to increase creep life of the bucket by 80% over the previous bucket. IN-738™ has an excellent balance of strength and corrosion resistance thereby making it optimal for units operating at lower firing temperatures where corrosion occurs. This bucket is meant for firing temperatures of 1840°F.

Improved Shroud Tip Design. The shrouded tips have been improved to increase creep life. The leading edge of the bucket was scalloped, the shroud tip was thickened between the seal teeth, and the underside was tapered. These re-designs reduced stress and decreased creep rates, extending the life by 80% over the original design.

Stage 2 Buckets with Turbulated Ten-Hole Cooling (FS4B)

This modification for MS7001B/C/E/EA units that shipped through 2006 replaces the stage 2 bucket with a re-designed stage 2 bucket having improved cooling features (ten-hole cooling and turbulation) that allow for operation at the higher firing temperature associated with the 7E/EA 2055°F uprate. (See Figure 73.) The material for the new stage 2 buckets is GTD-741, considered as an improvement over previous U500™ and IN-738™ materials. GTD-741 material has an outstanding combination of elevated temperature strength and hot corrosion resistance.

	Previous Stage 2 Bucket	GTD-741 Stage 2 Bucket
Material	IN-738™	GTD-741
Cooling Holes	8	10
Shrouded Design	Present	Present
Cutter Teeth*	Present	Present
Firing Temp	Up to 2035°F	Up to 2055°F

Figure 73. Stage 2 bucket rated to 2055°F.

These buckets are capable of achieving three hot gas path inspections up to 72,000 hours at the uprated 2055°F firing temperatures. These buckets are suitable for gas turbines that may have or not have honeycomb stage 2 shrouds fitted. The tip shroud was scalloped and the material between the seal teeth thickened to reduce stress by 75% and increase life by 80% over the original design.

This new technologically advanced design incorporates the following GE features:

- Airfoil profile with enhanced cooling passage arrangement
- Turbulated cooling passages
- Operating life of 72,000 hours at 2055°F for gas only
- Improved hot corrosion resistance
- Increased performance with honeycomb seals
- Capable of operation at 2084°F

GE Proprietary Cooling Design: The new cooling design has ten radial, turbulated cooling holes. A new airfoil profile allows a reduction in cooling airflow close to the trailing edge of the bucket.

Cutter Teeth: The new stage 2 bucket design includes cutter teeth on the bucket tip shroud rails. These cut a slot in the honeycomb seal material on the stage 2 shroud block with no metal transfer to or from the bucket.

Stage 3 Bucket IN-738™ (FS2K)

This modification for MS7001A through EA units replaces the existing U500™ stage 3 buckets with the IN-738™ stage 3 buckets. The latest stage 3 bucket design is made of IN-738™ material instead of U500™. IN-738™ material offers superior hot corrosion resistance compared to U500™, and has outstanding strength at the high uprate temperature. 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 honeycomb seal material on the stage 3 shroud block with no metal transfer to the bucket. This modification improves the third stage buckets parts lives for the higher firing, uprate temperatures.

Improved Stage 1 Shroud with Cloth Spline Seals (FS2Y)

The new shroud design for MS7001E and EA units includes several improved sealing features that increase performance (output and efficiency) by reducing leakage between shroud segments and between the stage 1 shrouds and stage 1 nozzles. The improved stage 1 shrouds are made of a one-piece design from Haynes® HR-120™ alloy—a solid solution strengthened iron-nickel-chromium alloy that improves low cycle fatigue life, allows operation at higher 2055°F firing temperatures, and increases performance and heat rate¹. (See Figure 74 and 75.)

GE Proprietary Spline Seal Arrangement. The new cloth seal arrangement illustrated in Figure 75 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™ alloy. This solid-solution strengthened iron-nickel-chromium alloy offers improved low cycle fatigue life and allows operation at higher firing temperatures up to 2055°F. The new stage 1 shroud material provides a 3X improvement in LCF life in comparison to the current 310SS 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.

The improved sealing features increase performance as tabulated below:

- Frame Size 7/1E/EA: +0.70% output; -0.30% heat rate

Stage 1 Shroud

This shroud has a life expectancy of up to 72,000 fired hours and is capable of 2035°F firing temperature. It is made of forged 310 or 316 stainless steel with an oxidation resistance coating. It has a pumpkin tooth seal to interlock with each shroud segment that, along with the bus bar shroud seal, reduces leakage between shroud segments, resulting in optimum airflow. (See Figure 76.)

“Pumpkin-Tooth” Design vs. New Shroud

First Stage Shroud Cloth Seals

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

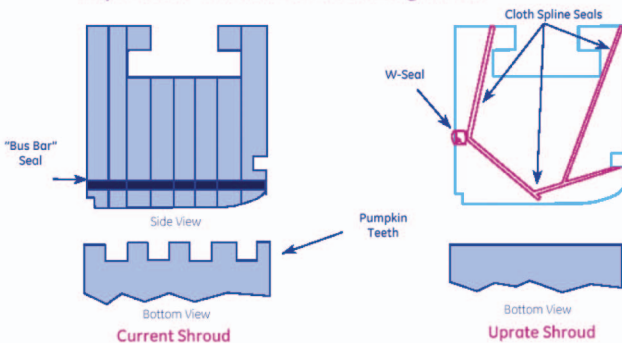
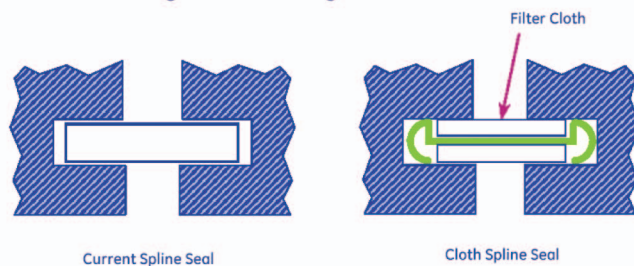


Figure 74. First stage shroud with cloth seals FS2Y.

Bar Type Spline vs. Cloth Seal Design

New Intersegment Seal Design



¹ Haynes HR-120™ is a registered mark of Haynes International, Inc., which is not affiliated with the General Electric Company.

HR-120™ Stage 1 Shroud

Features & Benefits

- New Material and Improved Sealing
- Improved Performance

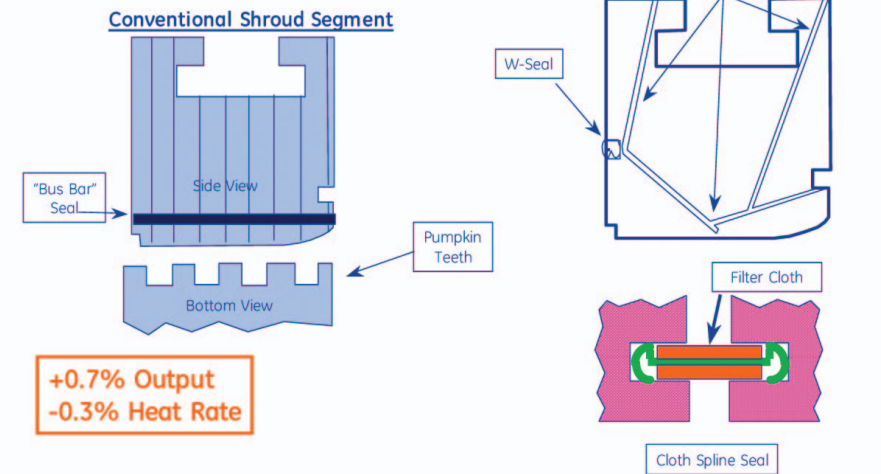


Figure 75. HR-120™ Improved Stage 1 Shroud.

Abradable Coating for Stage 1 Shroud Blocks (FS6A and FS2O)

The stage 1 shroud blocks on MS7001E and EA units can be coated with an abradable coating on the inner diameter surface. (See Figure 77.) The abradable coating on the stage 1 shroud allows for improved airflow control. The improved clearance and associated reduction in tip leakage creates a performance benefit. The abradable coating is designed to preferentially wear away in the event of a bucket tip rub, greatly reducing wear on the bucket tips. It also allows tighter clearances between the bucket and shroud leading to performance improvements.

The abradable coating on the Stage 1 shroud blocks will increase turbine section efficiency for increased output power and improved heat rate as given below:

- Frame Size 7E/EA: +0.5% output; -0.5% heat rate

Stage 2 and Stage 3 Inner Shroud Blocks With Honeycomb Seals (FS2T & FS2U)

For FS2T stage 2 shroud blocks and FS2U stage 3 shroud blocks in Figures 78 and 80, the applicable frames are MS7001A through EA units. In addition to providing damping, the stage 2 and stage 3 bucket tip shrouds increase the turbine efficiency by minimizing tip leakage. Radial teeth on the bucket shrouds combine with mating

teeth on the stationary shroud blocks (mounted in the turbine shell) to provide a labyrinth seal against the hot gas leakage past the bucket tips.

The introduction of a “honeycomb seal” to the stage 2 and 3 shroud block arrangement allows for an even tighter clearance interface than a labyrinth seal, resulting in reduced leakage and improved performance.

Figure 79 illustrates a typical cross section view of a stage 2 shroud block with the honeycomb seal design. Honeycomb seal technology has been proven in aircraft engine design to provide much tighter steady state and transient clearances. A typical design uses honeycomb material that incorporates a small cell structure made of a high temperature, oxidation-resistant alloy that is softer than the bucket material. Strips of honeycomb material are mounted between the teeth on the casing shrouds. (See Figure 79.) In the past, clearances between bucket tips and shroud blocks were designed based upon expected transients that tend to close clearances. With the previous bucket/shroud block interface design, the clearances needed to be large enough to allow these transients to occur without permitting contact between the bucket tip and the shroud block (i.e., “rubs”).

With the installation of the tighter clearance honeycomb seal

Order parts based on existing stage 2 nozzle configuration

For this Existing Nozzle Configuration...	Order these Parts...
Long sidewall	<i>Narrow Shroud Design:</i> 10 of part #: 678D0446P002 38 of part #: 678D0446P006
Short sidewall Wide turbine shell interface	<i>Wide Shroud Design:</i> Kit #: 329A3481G002 Shroud Seal Keys: 46 of part #: 172C9090P001 2 of part #: 172C9091P001
Short sidewall Narrow turbine shell interface	<i>Hybrid ("Guppy") Shroud Design:</i> Kit #: 329A3444G002 Shroud Seal Keys: 46 of part #: 172C9090P001 2 of part #: 172C9091P001

Note: All three designs are interchangeable with advanced technology HR-120™ Stage 1 Shrouds. Refer to GER3571 for information about the new HR-120™ material shrouds.

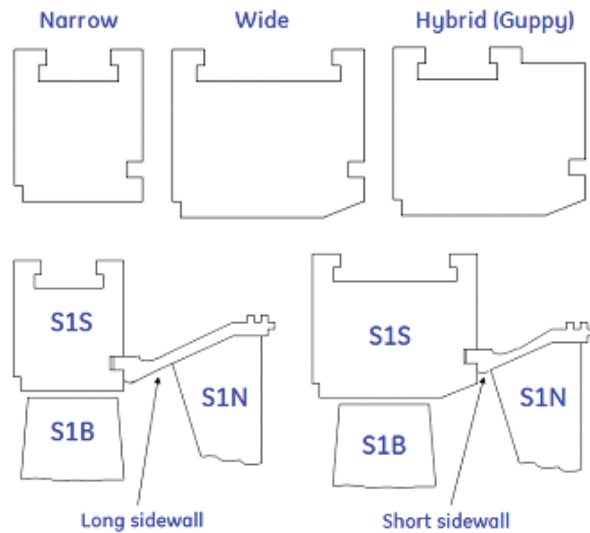


Figure 76. Stage 1 shrouds for 7B gas turbines.

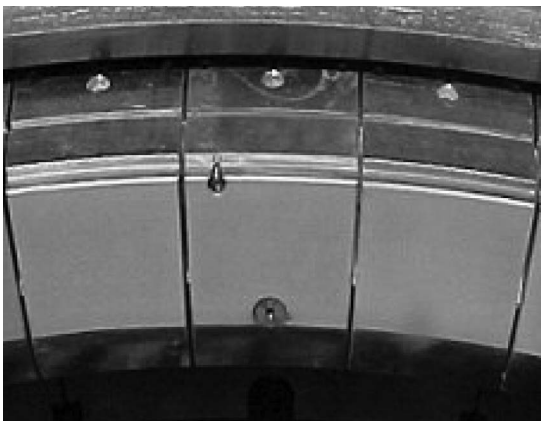


Figure 77. Stage 1 shrouds coated with abrasion-resistant coating.



Figure 78. Stage 2 and three hot gas path showing shroud blocks.

Honeycomb Seal Insert

Honeycomb Shroud Blocks

Honeycomb Shrouds

- Reduces Leakage
- Greater Rub Tolerance

Requires Buckets with
Cutter Teeth

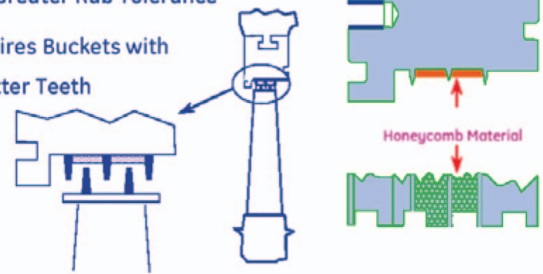


Figure 79. 7EA stage 2 honeycomb inner shroud design.

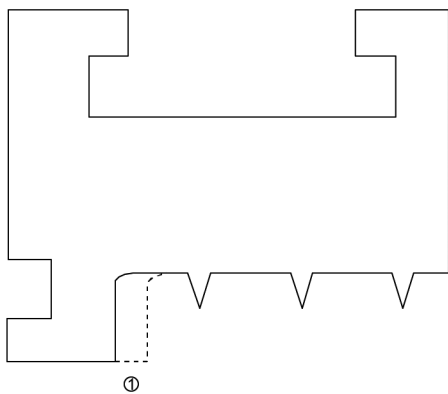


Figure 80. Shroud block with honeycomb sealing.

design shroud blocks, the buckets must also be modified. “Cutter teeth” must be added to the shrouded tip bucket rails leading edge in order to “cut” the honeycomb material away if contact occurs during transient conditions. The bucket seal teeth, which remain unharmed after cutting a passage in the honeycomb material, maintain a tight clearance. This design produces an effective clearance that is actually tighter than the absolute clearance since the resulting groove in the honeycomb provides a tighter labyrinth seal than is obtainable with the solid materials currently used.

This modification includes a new set of shroud blocks with the honeycomb seal material installed, as well as a new set of buckets with the new cutter teeth design.

Note that before installing 7E stage 3 buckets in a 7B unit, the stage 3 shrouds must be modified. See *Figure 81* for illustration of the modification.



① Modify Existing Third Stage Shrouds as Shown Above.

Figure 81. Modification of stage 3 shrouds when installing 7E buckets in a 7B unit.

The honeycomb stage 2 shroud design, when combined with cutter teeth, provides the following performance gains:

- *Frame Size 7/1A-EA*: +0.35% output; -0.35% heat rate

The expected performance gain in output and efficiency due to the improved sealing characteristics of the honeycomb seals on new honeycomb stage 3 shrouds with cutter teeth stage 3 buckets is:

- *Frame Size 7/1A-EA*: +0.15% output; -0.15% heat rate

Interstage Brush Seal (FS2Z)

For MS7001B/C/E/EA units, 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. (See *Figure 82*.) When added to a unit, the interstage brush seal further reduces this leakage. (See *Figure 83*.) Since the hot gas in this leakage performs no useful work, any reduction in this leakage will result in an increase in performance. Cooling airflow to the 2nd stage forward wheel space will be reduced, but this flow is currently larger than required.

In testing, the sealing efficiency of a single brush is found to be about 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 to give the following performance benefits:

- *Frame Size 71B*: +0.5% output; -0.3% heat rate
- *Frame Size 71C/E/EA*: +1.0% output; -0.5% heat rate

Number #2 Bearing Brush Seals (FS2X)

For MS7001E and EA units, brush seals installed in the #2 bearing enhance performance by reducing leakage past the #2 bearing air seals. (See *Figure 84*.) Since any air that leaks past these seals into the bearing housing does not perform additional work in the turbine, any reduction in this flow will result in an increase in performance.

This option will utilize brush seals in two of the air seals in the #2 bearing housing. Since the brush seals provide tighter clearances than the original labyrinth seals the leakage flow into the bearing housing is reduced. This leakage flow is typically vented to exhaust and therefore does not perform useful work in the system. By reducing the leakage, the brush seals result in an improvement in performance, both in output and heat rate.

The No. 2 bearing brush seal should be installed in conjunction with the HPP brush seals (reference FS2V) to increase performance gains.

The brush seal maintains tighter clearances than the previous labyrinth design. The expected performance gain from the

Stage 2 Nozzle with a Brush Seal

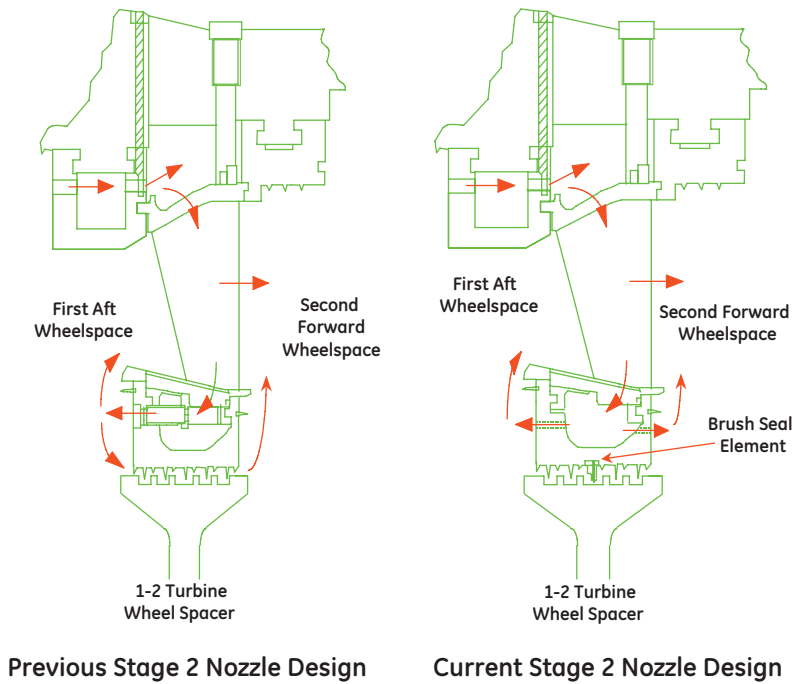


Figure 82. 7EA stage 2 honeycomb inner shroud design.

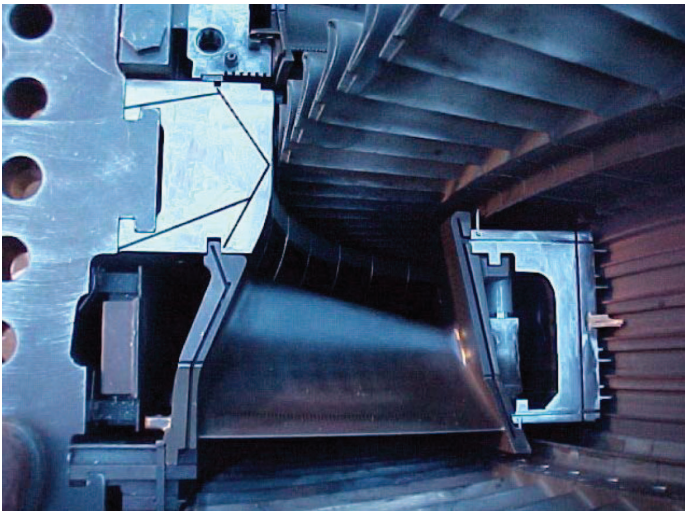


Figure 83. Installed interstage brush seal.

improved sealing characteristics (reduced leakage) due to the brush seal design at the #2 Bearing is estimated as follows:

- Frame Size 71E/EA: +0.3% output; -0.2% heat rate

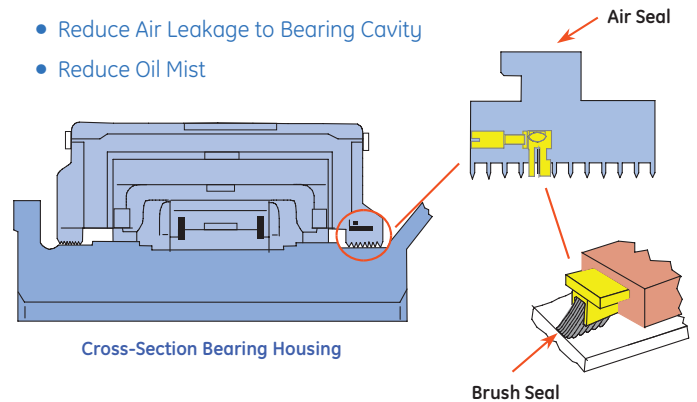


Figure 84. #2 Bearing brush seal.

Add Turbine Water Wash (FC4C)

For all MS7001A through EA units, turbine water wash is used to remove ash deposits from turbine sections left by the burning of low-grade liquid fuels. These deposits will gradually reduce the thermal efficiency and output of the turbine. Water washing must take place

while the turbine is off-line, the wheelspace temperatures are cool, and with the unit at crank speed. For machines burning other types of fuels, the turbine water wash will probably not be necessary. Compressor water wash should also be used in conjunction with turbine wash. The compressor water wash removes dirt and deposits from the compressor sections and is described in FC4A.

The turbine water wash system will allow the customer to remove ash deposits from the turbine sections, thereby recovering lost output and efficiency in machines using low-grade liquid fuel.

MS7001 Turbine Uprate Packages

Firing Temperature Uprate (FT5X)

This modification will raise the firing temperature in older MS7001A and B units to up to the MS7001E to 2020°F.

As all the components described herein are today's production MS7001EA parts, they are all integrated to form the complete 7EA turbine. Once it was verified that all components physically fit in older design turbines (with little or no modification) it was important to package component options together to devise the best offering to customers. By applying standard current production MS7001EA parts to older MS7001 units, GE can increase output as detailed in the four possible uprate options listed in *Figure 85*.

Similar to the MS7001B to E uprate, MS7001A units could be uprated with EA components and utilize the options as outlined in *Figure 85*. Since the 7A units are the original MS7001 design, and there are only two units, a detailed review would need to be performed to evaluate any special concerns that might exist for uprating the MS7001A with EA parts. The MS7001C and E units can also be uprated with

MS7001EA hot gas path components. The material required would be similar to B/EA Option 3 in *Figure 85*. The uprate for 7C and 7E models is discussed next in more detail since a slightly different offering exists for these models.

Figure 86 provides a summary of the individual design improvements for each MS7001EA component involved in the "B to E" uprate (each of the components was described in detail). One of the most significant design improvements for the uprate of an MS7001B unit is the stage 1 turbine nozzle. As illustrated in *Figure 10*, the E unit has a higher airflow than the B unit, but it has a smaller "throat area" for the stage 1 nozzle. This design provides a significant increase in compressor pressure ratio. When the MS7001EA stage 1 nozzle is applied to MS7001B units, there is a 6% increase in compressor pressure ratio. Extensive evaluation indicated the increase in pressure ratio was acceptable on MS7001B units. The first application of this uprate was applied to a utility unit in Alaska. Extensive field testing, completed in August 1988, proved that this uprate was a success.

The Option 1 uprate in *Figure 87* involves new reduced camber IGVs and MS7001EA stage 1 buckets and nozzle. Due to increased efficiency, the actual exhaust temperature decreases for this option, while firing temperature is maintained at the same level.

Option 2 in *Figure 88* is intended to increase firing temperature as much as possible to keep exhaust temperature at pre-uprate levels. This option might be desirable for heat recovery unit applications, where exhaust temperature decreases could be detrimental to combined-cycle efficiency and exhaust temperature increases might not be compatible with the HRSG or cycle design.

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

* Generator and station electrical equipment uprate may be required.

** Non air-cooled bucket for MS9001B applications.

*** Blades must be replaced in the 17th EGV1 and EGV2 stator rows for low ambient applications, water or steam injection applications, or modulating inlet guide vane applications. A new stage 17 wheel is also recommended if replacement with a curved impeller has not been made for MS7001B applications.

**** Exhaust diffuser may be required for option 3 for high ambient temperature applications.

Figure 85. MS7001A and B uprate using current production EA hardware.

Sourcebook Codes	Component	Design Improvements
FS2J	Stage 1 Nozzle	2 Vane/segment, 6% higher pressure ratio, chordal hinge with improved sidewall sealing, improved sidewall cooling
FS2G	Stage 1 Bucket	DS GTD-111, GT-29 Plus, blunt leading edge airfoil and coating on cooling holes
FS1P	Stage 2 Nozzle	Air cooled, long chord, GTD222 for increased creep resistance, aluminide coating, reduced cooling
FS1L	Stage 2 Bucket	Air cooled, IN-738™, scalloped tip shroud
FS1R	Stage 3 Nozzle	Long chord, GTD222 for increased creep resistance
FS1M	Stage 3 Bucket	Increased firing temperature design, U500™, scalloped tip shroud
-	Combustion	Slot cooled liners (FR1H), Nimonic thick wall transition pieces (FR1D) and thermal barrier coated liners (FR1G)
FS2T, FS2U	Stage 2/3 Shrouds	Honeycomb seal shroud design
FS2V	HPP Brush Seal	Brush seal on compressor inner barrel replaces labyrinth seal design (currently in development)

Figure 86. Individual design improvements for each MS7001EA component involved in the “B to E” uprate.

Option 3 in Figure 89 is based upon reaching the maximum exhaust temperature with the existing MS7001B exhaust frame and diffuser assembly. This option would increase the MS7001B rating at ISO conditions to approximately 70 MW. Turbines that

operate in high ambient temperature locations may consider an optional exhaust diffuser section replacement. A new stainless steel exhaust diffuser will allow the turbine to operate at elevated exhaust temperatures and achieve maximum performance during

Frame 7 Advanced Technology Uprate

MS7001B to E Uprate Option I

Features & Benefits

- Increased Output (+5.8%)
- Decreased Heat Rate (-2.9)
- Improved Cooling Features
- Improved Materials
- Includes GTD-450 IGVs (not shown)
- No Firing Temperature Increase

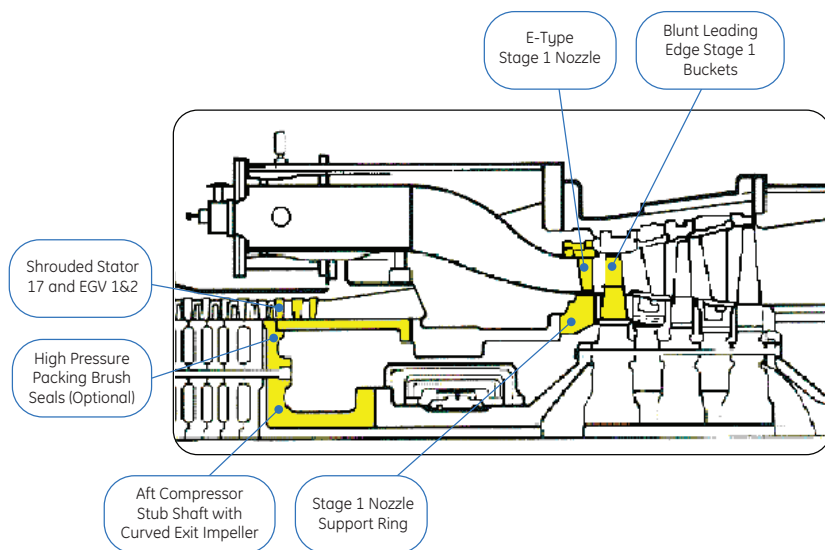


Figure 87. Option I uprate package without firing temperature increase.

Frame 7 Advanced Technology Uprate
MS7001B to E Uprate Option II

Features & Benefits

- Increased Output (+10.3%)
- Decreased Heat Rate (-2.8)
- Improved Cooling Features
- Improved Materials
- Includes GTD-450 IGVs (not shown)
- Firing Temperature Increase to 1905°F

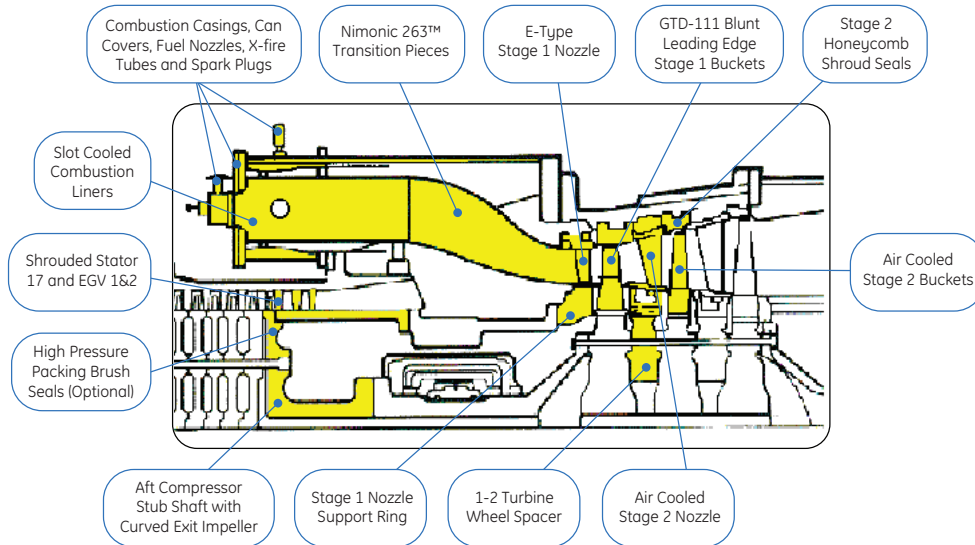


Figure 88. Option II uprate package to increase firing temperature to 1905°F.

Frame 7 Advanced Technology Uprate
MS7001B to E Uprate Option III

Features & Benefits

- Increased Output (+16.7%)
- Decreased Heat Rate (-3.9)
- Improved Cooling Features
- Improved Materials
- Includes GTD-450 IGVs (not shown)
- Firing Temperature Increase to 1965°F

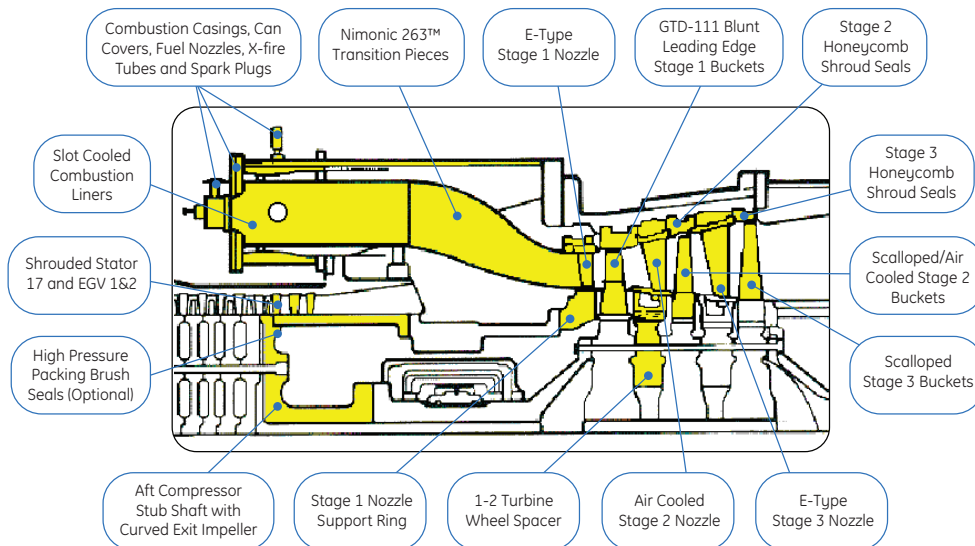


Figure 89. Option III uprate package to increase firing temperature to 1965°F.

Frame 7 Advanced Technology Uprate
MS7001B to E Uprate Option IV

Features & Benefits

- Increased Output (+22.6%)
- Decreased Heat Rate (-4.6)
- Improved Cooling Features
- Improved Materials
- Includes GTD-450 IGVs (not shown)
- Firing Temperature Increase to 2020°F
- New Exhaust Frame (not shown)

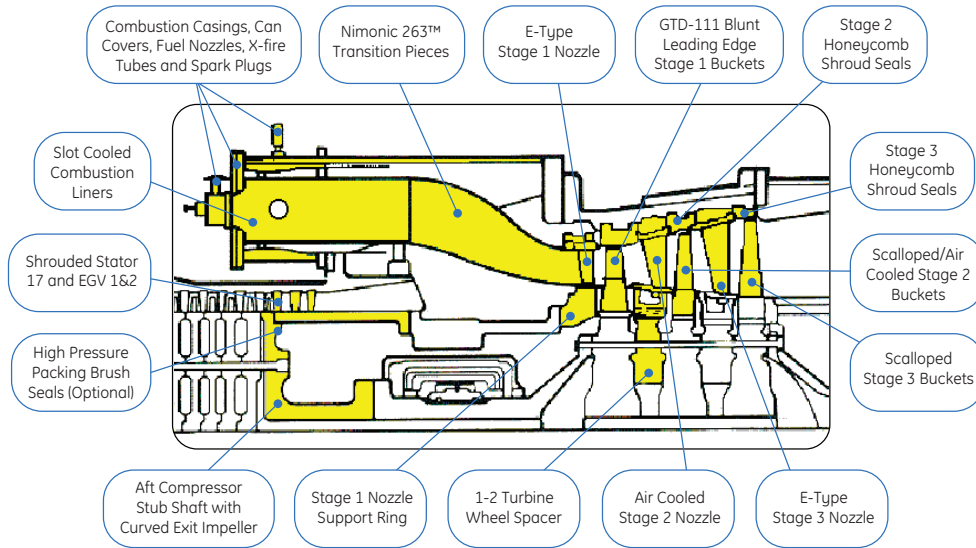


Figure 90. Option III uprate package to increase firing temperature to 2020°F.

hot ambient temperature operation. Many 7B turbines are currently limited to a 1000°F/538°C exhaust temperature due to the current exhaust system configuration and material. Replacement of the exhaust system components with an improved stainless steel design will raise the exhaust isothermal limit to allow increased performance.

Option 4 in *Figure 90* involves increasing the firing temperature for an MS7001B unit to the full 2020°F/1104°C MS7001E/EA firing temperature by also changing to the MS7001EA exhaust frame and diffuser assembly. As discussed with uprate option 3 (exhaust diffuser optional), the benefits of the new exhaust system are included in the option 4 package. The exhaust frame replacement results in the maximum gas turbine performance particularly for hot climate applications.

In addition to the output increases, a significant improvement in maintenance/inspection intervals is achieved by using the higher firing temperature MS7001EA parts. *Figure 44* detailed the expected extensions in maintenance intervals using 7EA hot gas parts. Each of the MS7001EA components listed in *Figure 86* can be applied to MS7001B units with minor modification. A

turbine/generator performance comparison will be required in each case to determine the capability of the load equipment to accept the uprating. This review may also result in suggested modifications to the generator and electrical auxiliaries. A typical performance comparison study between gas turbine output and generator capability is illustrated in *Figure 91*. In many cases higher generator operating power factors will allow a gas turbine uprate with little or no generator modifications required.

Tabulated performance for each uprate package, as well as for individual component upgrades, is listed in *Figure 92*. These figures provide an understanding of the individual component performance benefits and show how the package performance is compiled. In cases where a complete uprate may not be justified, these figures show individual component values.

Uprate to 2020°F Firing Temperature (FT5C)

This modification will raise the firing temperature in older MS7001E units (pre-1982 approximately) to 2020°F. The critical changes include upgrades in material and design.

One of the design changes is the addition of scalloping to the second and third stage turbine bucket shrouds. Scalloping decreases the over hung weight of the shroud tip thus decreasing the stress at the top of the fillet.

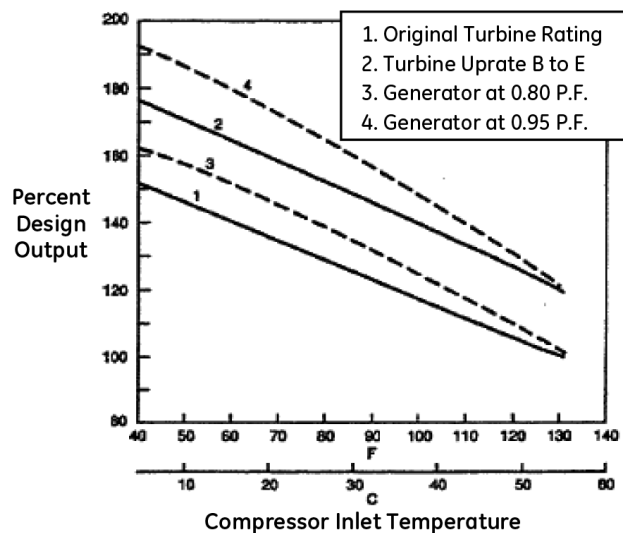


Figure 91. Typical MS7001B to E uprate performance study.

Frame 7 Advanced Technology Uprate MS7001B to E Advanced Technology Uprate

	MS 7B-E Uprate Options				MS 7B-E Uprate Options			
	I	II	III	IV	I	II	III	IV
Original Tf (°F/°C)	1840/1004	1840/1004	1840/1004	1840/1004	1840/1004	1840/1004	1840/1004	1840/1004
Up-rated Tf (°F/°C)	1840/1004	1905/1041	1965/1074	2020/1104	1840/1004	1905/1041	1965/1074	2020/1104
	Increase in Output				Increase in Heat Rate			
	%	%	%	%	%	%	%	%
Increase in Firing Temperature and Controls Modifications (FT5C/FT5Y)	-	6.7	12.8	18.2	-	-1.1	-2.0	-2.6
Improved Cooling Stage 1 Nozzle	-	-	-	-	-1.9	-1.9	-1.9	-1.9
GTD-450 IGVs (84°) (FT5B)	4.3	4.3	4.3	4.3	-0.7	-0.7	-0.7	-0.7
Additional 2° IGV (86°)	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2
GTD-222 S2N (FS1P)	-	-1.0	-1.0	-1.0	-	0.4	0.4	0.4
Exh. Frm. Motor Blowers (FS2D)	-	-	-	0.2	-	-	-	-0.1
Air-Cooled S2B (FS1L)	-	-1.65	-1.65	-1.65	-	1.1	1.1	1.1
Stage 2 Bucket Shrouds with Honeycomb Seals (FS2T)	-	0.35	0.35	0.35	-	-0.35	-0.35	-0.35
Stage 3 Bucket Shrouds with Honeycomb Seals (FS2U)	-	-	0.15	0.15	-	-	-0.15	-0.15
HPP Brush Seals (FS2V)	1.0	1.0	1.0	1.0	-0.5	-0.5	-0.5	-0.5
Total Effect on Output*	5.8	10.3	16.7	22.6	-2.9	-2.8	-3.9	-4.6

Figure 92. MS7001 uprate options: effects on output and heat rate.

The transition pieces will receive an upgrade in material to thermal barrier coated Nimonic. (Reference FR1D.) The combustion liners will also receive an upgrade in design by receiving a thermal barrier coating. (Reference FR1G.) An upgrade to GTD-222+ material is highly recommended for the second and third stage nozzles. During this uprate, the Stage 1-2 spacer discourager seals should be inspected and/or replaced due to the deteriorating aluminum bronze seal material. The new material is 410 stainless steel. (Reference FW3E and TIL 1260-2.)

With the above changes implemented, the firing temperature can be raised to 2020°F. With this uprate, the customer will receive a benefit of approximately 3.0% increase in output and a 0.3% decrease in heat rate at base load ISO conditions on natural gas fuel.

Uprate to 2035°F Firing Temperature (FT5Y)

This modification will raise the firing temperature in MS7001C/E/EA units to up to 2035°F. This uprate offers all earlier vintages of MS7001C, E, or EA turbines to be uprated to the 2035°F firing temperature by upgrading with the latest MS7001EA hardware. The major hot gas path components changed for this uprate are illustrated in Figure 93.

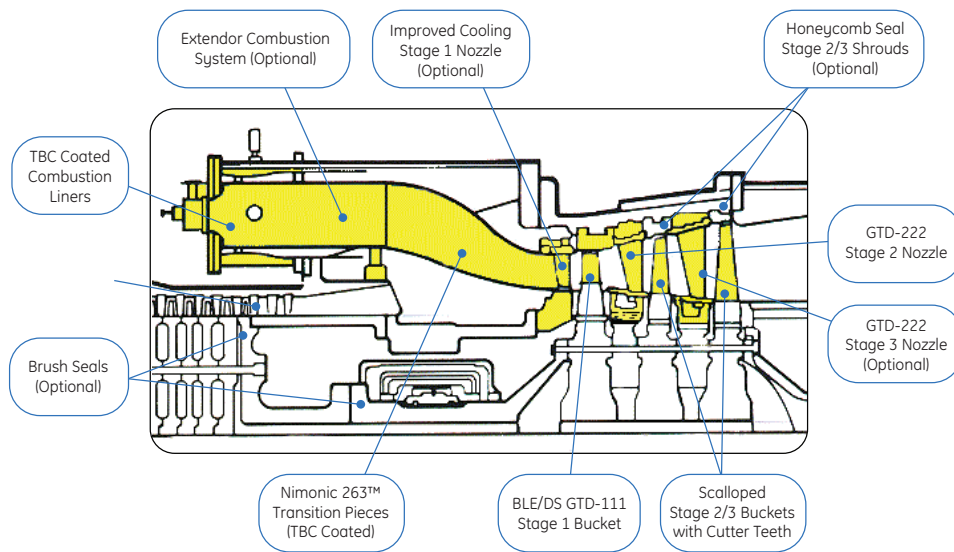


Figure 93. MS7001E/EA uprate hot gas path changes for 2035°F firing temperature.

The turbine uprate to 2035°F firing temperature involves changes to a majority of the hot gas path components. The uprate of pre-1988 units may involve an inlet guide vane change.

Required Components:

- GTD-111, Directionally Solidified, 12 Cooling Holes, BLE Stage 1 Buckets (FS2G)
- Stage 2 Buckets with Scalloped Interlocking Shroud Tips and Cutter Teeth (FS1L)
- GTD-222 Stage 2 Nozzle with reduced cooling flow (FS1P)
- Stage 3 Buckets with Scalloped Interlocking Shroud Tips and Cutter Teeth (FS2K)
- First Stage Shroud Set (FS1P Option A)
- Stage-17 Compressor Exit Guide Vane (EGV) Modification (FS2B)
- Nimonic 263™ Transition Pieces with TBC Coating (FR1D)
- Slot Cooled Combustion Liners with TBC Coating (FR1H)
- GTD-450 Reduced Camber IGVs (FT5B)
- Firing Temperature Increase

Optional Components:

- Improved Cooling Stage 1 Nozzle (FS2J)
- GTD-222 Stage 3 Nozzle (FS1R)

- Stage 2 Shroud Blocks with Honeycomb Shroud Seals (FS2T)
- Stage 3 Shroud Blocks with Honeycomb Shroud Seals (FS2U)
- High Pressure Packing Brush Seals (FS2V)
- #2 Bearing Brush Seals (FS2X)
- Turbine Section Interstage Brush Seal (FS2Z)
- HR-120™ Stage 1 Shrouds (FS2Y)
- Extensor Components (FR1W/FR1V)
- Exhaust Isotherm 1100°F

Additional Scope. The 71C and early 71E units will require additional advanced technology parts since some of the improved technology is already incorporated in the newer original units.

These changes include:

- All 71C model turbines MUST upgrade their compressor to a model 71E design for the resultant improved thermal efficiency and increased air flow, by replacing the first eight (8) stages of compressor stator blading.

If desired, new spacers for stages 1-2 and stages 2-3 may be supplied. The new spacers provide an improved high pressure seal to mate with the new second and third stage diaphragms provided with the GTD-222 nozzles resulting in improved interstage sealing. The new spacers are available as option A.

This uprate provides improved heat rate and increased output due to the increase in firing temperature and the reduction in turbine wheel space cooling flow. Additionally, since the material supplied is designed for the 2035°F firing temperature, the hot gas path inspection interval will remain at 24,000 hours. The combustion interval may be extended due to incorporating the Extendor components (i.e., 24,000 hours for gas fuel/base load/dry or steam injection for NO_x.)

Due to the higher operating temperatures and the design airflows desired, this uprate option does not apply to the 7B model. For the model E and EA turbines, the estimated performance improvements

will vary depending on the present machine configuration. Figures 94 and 95 illustrate typical performance gains in output and heat rate that could be achieved with the 2035°F Advanced Technology Uprate as a complete package or as individual parts replacements.

The 7C and early 7E models require updating of the compressor to the latest “E” design (FT5D), as discussed in the compressor section. In addition, units without the latest design Nimonic transition pieces (FR1G) and TBC coated combustion liners (FR1D) must add these components. For 7C/E units the inlet guide vane angle can also be increased from 84 to 86 to improve turbine performance for the complete uprate configuration. For the 7C model, it would first be

Decrease in Heat Rate

Feature	Frame				
	MS7001C	MS7001E	MS7001E	MS7001EA	MS7001EA
Original Tf (°F/°C)	1950/1066	1985/1085	2020/1104	2020/1104	2035/1113
Max Uprated (°F/°C)	2035/1112	2035/1124	2035/1124	2035/1124	2035/1124
Fleet IBs	12	137			478
	Decrease in Heat Rate (%)				
2035 & Control Modes (FT5Y)	-0.7	-0.4	-0.1	-0.1	-
S1B w/ 12-Hole Cooling Design (FS2G)	0.00	0.00	0.00	0.00	0.00
S2N GTD-222 w/ int. Core Plus Cooling	-0.30	-0.30	-0.30	-0.30	-0.30
S1S Tuning Pin Mod (FS1P)					
S3B w/ IN-738™ (FS2K)	0.00	0.00	0.00	0.00	0.00
GTD-450 Reduced Camber IGVs (FT5B)	-0.10	-0.30	-0.30	-0.30	0.00
Shrouded Stator Blades (S17 + EGV) (FS2B)	<i>To prevent aerod. vane stall under certain operating cond.</i>				
71C Compressor Upgrade to 71E model (FT5E)	0.00	0.00	0.00	0.00	0.00
Nimonic 263™ Transition Pieces	0.00	0.00	0.00	0.00	0.00
Stage 1-2 and 2-3 Spacers (FS1L)	0.00	0.00	0.00	0.00	0.00
OPTION: S1N w/ Chordal Hinge Design (FS2J)	-0.25	-0.25	-0.25	-0.25	-0.25
OPTION: S3N GTD-222 w/o Air-Cooled (FS1R)	0.00	0.00	0.00	0.00	0.00
OPTION: S2S w/ HoneyComb Seals (FS2T)	-0.35	-0.35	-0.35	-0.35	-0.35
OPTION: S3S w/ HoneyComb Seals (FS2U)	-0.15	-0.15	-0.15	-0.15	-0.15
OPTION: HPP Brush Seals (FS2V)	-0.50	-0.50	-0.50	-0.50	-0.50
OPTION: Number 2 Bearing Brush Seals (FS2X)	-0.20	-0.20	-0.20	-0.20	-0.20
OPTION: Interstage Brush Seals (FS2Z)	-0.50	-0.50	-0.50	-0.50	-0.50
OPTION: SIS HR-120™ Cloth Seal (FS2Y)	-0.30	-0.30	-0.30	-0.30	-0.30
OPTION: Extendor Components (FS1V)	0.00	0.00	0.00	0.00	0.00
Max Output Increase*	-3.35	-3.25	-2.95	-2.95	-2.55

* Total effect = compounding effects of all the performance improvements above with 71C/E/EA for Tf2035°F

Sourcebook codes are provided in parentheses

All performance improvements apply at ISO condition (59°F/15°C, 14.7 psia/1.013 bar)

Figure 94. Efficiency increases with 2035°F firing temperature increases.

required to uprate the machine to the early 7E rating illustrated in Figure 9, including the compressor modification (FT5D).

Exhaust system modifications may allow the customer to increase the benefits of a 2035°F uprate. Many turbines have exhaust temperature (isothermal) limits set in the control system to protect the gas turbine. Isothermal units may be set for several reasons, including overall plant limits, HRSG limits, control protection limits, and turbine material temperature limits. The maximum exhaust temperature limit that the current MS7001EA gas turbine is presently designed for is 1100°F.

Figure 96 illustrates the effect at base load of raising the isothermal exhaust temperature limit to obtain increased base load turbine output. Typical exhaust isothermal settings of 1020°F to 1040°F could be raised to 1100°F to increase turbine uprate performance at high ambient temperature sites. Figure 97 illustrates the additional gain in exhaust temperature that can be realized to increase steam production and part load combined-cycle efficiency when lower inlet guide vane angles are utilized and the 1100°F isotherm is implemented. To reach the elevated exhaust temperature capability, some units may require an upgrade to the latest stainless steel 7EA conical style exhaust diffuser section,

Increase in Output

Feature	Frame				
	MS7001C	MS7001E	MS7001E	MS7001EA	MS7001EA
Original Tf (°F/°C)	1950/1066	1985/1085	2020/1104	2020/1104	2035/1113
Max Uprated (°F/°C)	2035/1112	2035/1124	2035/1124	2035/1124	2035/1124
Fleet IBs	12	137		478	
	Increase in Output (%)				
2035 & Control Modes (FT5Y)	8.7	5.4	2.3	1.8	-
S1B w/ 12-Hole Cooling Design (FS2G)	0.00	0.00	0.00	0.00	0.00
S2N GTD 222 w/ int. Core Plus Cooling	0.80	0.80	0.80	0.80	0.80
S1S Tuning Pin Mod (FS1P)					
S3B w/ IN-738™ (FS2K)	0.00	0.00	0.00	0.00	0.00
GTD-450 Reduced Camber IGV's (FT5B)	4.10	1.50	1.50	1.40	0.00
Shrouded Stator Blades (S17 + EGV) (FS2B)	<i>To prevent aerod. vane stall under certain operating cond.</i>				
71C Compressor Upgrade to 71E model (FT5E)	0.00	0.00	0.00	0.00	0.00
Nimonic 263™ Transition Pieces	0.00	0.00	0.00	0.00	0.00
Stage 1-2 and 2-3 Spacers (FS1L)	0.00	0.00	0.00	0.00	0.00
OPTION: S1N w/ Chordal Hinge Design (FS2J)	0.00	0.00	0.00	0.00	0.00
OPTION: S3N GTD-222 w/o Air-Cooled (FS1R)	0.00	0.00	0.00	0.00	0.00
OPTION: S2S w/ HoneyComb Seals (FS2T)	0.35	0.35	0.35	0.35	0.35
OPTION: S3S w/ HoneyComb Seals (FS2U)	0.16	0.16	0.16	0.16	0.16
OPTION: HPP Brush Seals (FS2V)	1.00	1.00	1.00	1.00	1.00
OPTION: Number 2 Bearing Brush Seals (FS2X)	0.30	0.30	0.30	0.30	0.30
OPTION: Interstage Brush Seals (FS2Z)	1.00	1.00	1.00	1.00	1.00
OPTION: SIS HR-120™ Cloth Seal (FS2Y)	0.70	0.70	0.70	0.70	0.70
OPTION: Extendor Components (FS1V)	0.00	0.00	0.00	0.00	0.00
Max Output Increase*	+17.11	+11.21	+8.11	+7.51	+4.31

* Total effect = compounding effects of all the performance improvements above with 71C/E/EA for Tf2035°F

Sourcebook codes are provided in parentheses

All performance improvements apply at ISO conditions (59°F/15°C, 14.7 psia/1.013 bar)

Figure 95. Output increases with increases in firing temperature to 2035°F.

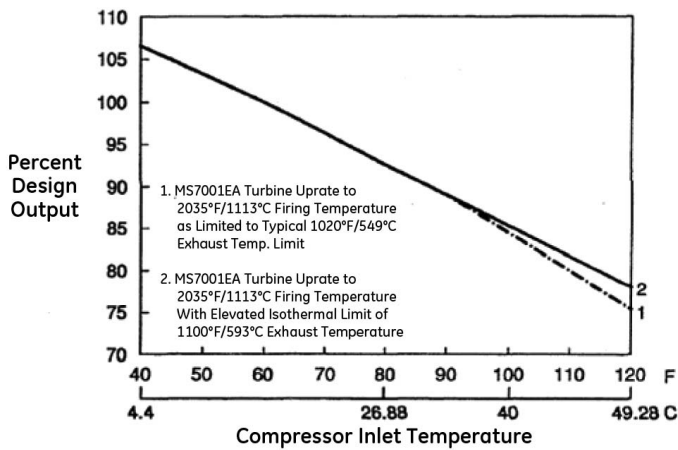


Figure 96. MS7001EA exhaust temperature limit impact on advanced technology uprate.

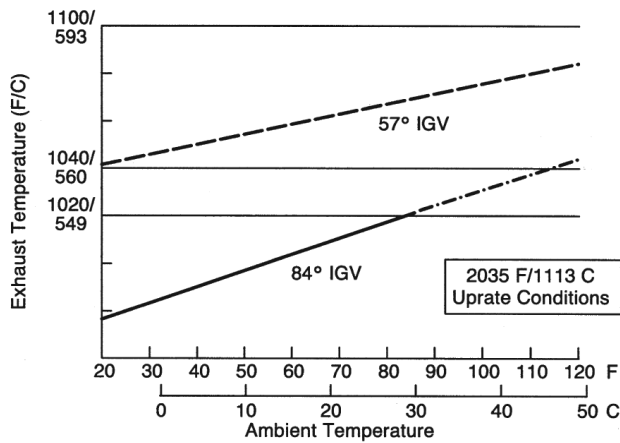


Figure 97. Improved operational flexibility & increased heat recovery when modulating IGVs with isotherm increase to 1100°F.

replacement current production exhaust frame blowers with a 100 horsepower rating, and modified control system settings. Units with the latest design exhaust diffuser may just require the 100 horsepower blowers and the modified control settings.

Additionally, for all models, new stage 1-2 and 2-3 turbine wheel spacers may be supplied along with the uprate as an option. The latest design spacers incorporate improved high-pressure seals to mate with the new stage 2 and 3 diaphragms with redesigned teeth provided with the GTD-222+ stage 2 and 3 nozzle sets, resulting in improved interstage sealing. To obtain the maximum output and efficiency increases with the uprate, new turbine wheel spaces could be supplied to reduce interstage leakage. The improved space design incorporates an extra tooth added to the

end of each land for the 1-2 space, and wider lands for the 2-3 spacer to reduce wheelspace flow by providing a flow path that is harder to travel. Since installation of the new spacers involves unstacking the turbine rotor, this option is not included as part of the uprate requirements. Optionally, the spacers can be installed to increase output and efficiency gains with the hot gas path uprate.

This uprate provides improved heat rate and increased output due to the increase in firing temperature and the reduction in turbine wheel space cooling flow. This will result in an approximate 2.3 to 3.9% increase in output. Additionally, since the material supplied is designed for the 2035°F firing temperature, the hot gas path inspection interval will remain at 24,000 hours. The combustion interval may be extended due to incorporating the Extendor components (i.e., 24,000 hours for gas fuel/base load/dry or steam injection for NO_x).

For a unit that currently has DLN combustion, a mechanical liner re-tune is required to maintain the current emissions. The scope and cost of a re-tune can be found in Sourcebook FG2B, option E. Quality pre-outage data including performance, emissions and fuel analysis data is required to ensure that the sizing of the liner dilution holes can be accurately determined and to mitigate the need for additional liner re-tunes to meet emissions compliance. **(Note:** For quotations that contain several options that impact emissions, only one liner re-tune is required for an uprate outage if all purchased options are to be installed during the same outage. If purchased options are to be installed during different outages, multiple liner re-tunes must be purchased.)

For a unit that currently has DLN combustion, staged dilution for the transition pieces is required if the transition pieces do not have staged dilution.

Aft frame cooling for the transition pieces (all combustion systems) is required for operation at 2035°F firing temperature.

The Extendor components are now applicable to units with a standard or DLN or multi-nozzle quiet combustion (MNQC) system. Currently only available for Frame 71B, 71EA units with slot cooled diffusion combustion liners and slotted end frame Nimonic transition pieces.

Heavy fuel units may only increase their firing temperature to 2000°F. 71EA customers must upgrade their shrouded stage 17/EGV

arrangement per TIL-1140-2R1, before the firing temperature increase may be performed. (Reference Necessary Addition 5.)

For units containing a Mark IV or earlier vintage control system, a control modification or 2-part control curve may be needed at an additional charge.

This Sourcebook article does not provide details on generator capability. It is suggested that a GE Generator Applications Engineer perform a generator study to determine the generator capability before this uprate is sold to a customer.

For the 71EA units, the 2035°F Tfire uprate will require that the current production R17 rotor compressor blades be installed during the upgrade outage unless the unit is already configured with the Gen1, Gen3-678 Hz or Gen3-squealer tip blades as described in TIL 1346-1. If the unit uses water or steam injection or if water and steam injection will be quoted with the Tfire uprate, the current production R17 rotor blades will be required to be installed during the upgrade outage and at each subsequent Major Inspection as described in TIL 1346-1. Refer to Sourcebook FW3V for replacement 71EA rotating compressor blades.

Uprate to 2055°F Firing Temperature (FT5Q)

This modification will uprate any MS7001C, E or EA unit to a firing temperature of 2055°F. The turbine uprate to 2055°F firing temperature involves changes to a majority of the hot gas path components. (See Figure 98.) The uprate of pre-1988 units may

involve an inlet guide vane change. The uprate provides current production new unit Advanced Technology components. The objectives of this uprate are improved performance, increased reliability and availability, and reduced maintenance intervals. The scope involves changes to most of the hot gas path components, which allows for increased firing temperature and airflow, thus resulting in improved output and heat rate.

Required Components:

- GTD-111, Directionally Solidified, 12 Cooling Holes, BLE Stage 1 Buckets (FS2G)
- Improved Cooling Stage 1 Nozzles (FS2J)
- HR-120™ Stage 1 Shrouds (FS2Y)
- Stage 2 Buckets with Scalloped Interlocking Shroud Tips and Cutter Teeth (FS4B)
- GTD-222+ Stage 2 Nozzles with Reduced Cooling Flow (FS1P)
- Stage 3 Buckets with Scalloped Interlocking Shroud Tips and Cutter Teeth (FS2K)
- GTD-222+ Stage 3 Nozzles (FS1R)
- GTD-450 Reduced Camber IGVs (FT5B)
- Nimonic 263™ Transition Pieces with TBC Coating with Aft Frame Cooling (FR1D)

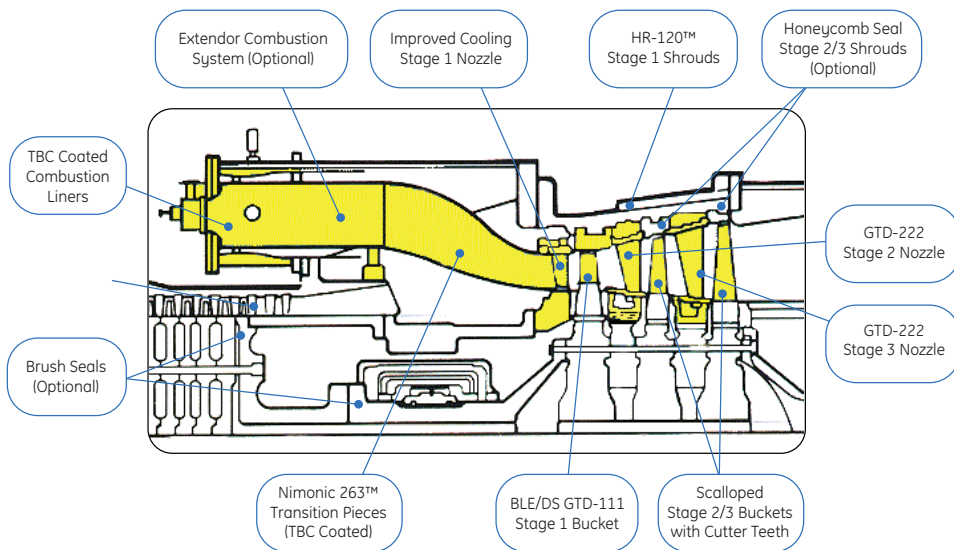


Figure 98. Hot gas path configuration after increasing firing temperature to 2550°F.

- Slot-Cooled Combustion Liners with TBC Coating (FR1H)
- Firing Temperature in Increase to 2055°F

Additional Required Components:

DLN, 71C, 71E, and early 71EA units will require additional advanced technology parts, including:

- DLN Units
 - Liner Re-tune (FG2B Option E)
 - Unified Liners
 - Staged Dilution for Transition Pieces
- 71C Units
 - Upgrade 71C Compressor to a Model 71E Design
 - Stage 1-2 Spacer Discourager Seal Inspection and Replacement (Pre-96)(TIL 1260-2/FW3E)

(This uprate is required for Frame 71C and 71E/EA units shipped prior to 1996.)

- 71C, 71E and early 71EA units:
 - Transition Pieces Aft Frame Cooling
 - Stage 17 Rotor Blades (FW3V)
 - Exhaust Frame Blower Upgrade (FS1W)
 - Stage 17 Stator Blades and Compressor Exit Guide Vane (EGV) Modification (FS2B)

Optional Components:

To achieve the highest possible performance gain, the following are recommended:

- Stage 1 Shroud Abradable Coating (FS6A)
- 2nd and 3rd Stage Honeycomb Shrouds (FS2T & FS2U)
- HPP Brush Seals (FS2V)
- Number 2 Bearing with Brush Seals (FS2X)
- Interstage Brush Seals
- Extendor Components (FR1V/FR1W)

- Stage 1-2 and 2-3 Spacer (FS1L/FW3E)
- Stage 1-2 Spacer Discourager Seal Inspection and Replacement (FW3E – TIL 1260-2)
- ETBC Stage 1 Nozzle (FS6E)
- Stage 1 Shroud Abradable Coating (FS6A)
- IGVs Angle Increase from 84 to 86 Degrees

This uprate provides improved heat rate and increased output due to the increase in firing temperature and the reduction in turbine wheel space cooling flow. (See *Figures 99 and 100*.) Please take into consideration that estimated performance improvements will vary depending on the present machine unit configuration. Additionally, since the material supplied is designed for the 2055°F firing temperature, the hot gas path inspection interval will remain at 24,000 hours. The combustion interval may be extended due to incorporating the Extendor components (i.e., 24,000 hours for gas fuel/base load/dry or steam injection for NO_x).

- As noted above, the output and heat rate for the MS7001 varies, depending on the unit's current firing temperature. Therefore, all 71EA 2055°F uprate proposals for units that have shipped since January 1996 must have an evaluation of the current firing temperature to determine the increase in firing temperature that can be applied. Because of the special tuning associated with DLN combustion systems, evaluation of the firing temperature will require that the exhaust temperature control constants be obtained from the site for 71EA units with DLN combustion.
- Emissions will be affected by this uprate due to the increase in firing temperature and airflow. The material changes necessary to reach EPA (or other) requirements are not included in this quote. Since most 7C, E and EA units already have an emissions control system, this may only require retuning of the existing system.
- For a unit that currently has DLN combustion, a mechanical liner re-tune is required to maintain the current emissions. The scope and cost of a re-tune can be found in Sourcebook FG2B, option E. Quality pre-outage data including performance, emissions and fuel analysis data is required to ensure that the sizing of the liner dilution holes can be accurately determined and to mitigate the

Decrease in Heat Rate

Feature	Frame				
	MS7001C	MS7001E	MS7001E	MS7001EA	MS7001EA
Original Tf (°F/°C)	1950/1066	1985/1085	2020/1104	2020/1104	2035/1113
Max Up-rated (°F/°C)	2055/1124	2055/1124	2055/1124	2055/1124	2055/1124
Fleet IBs	12	137		478	
	Decrease in Heat Rate (%)				
2055 & Control Modes (FT5Q)	-0.70	-0.40	-0.10	-0.10	-
S1N w/ Chordal Hinge Design (FS2J)	-0.25	-0.25	-0.25	-0.25	-0.25
S1B w/ 12-Hole Cooling Design (FS2G)	0.00	0.00	0.00	0.00	0.00
S2N GTD-222 w/ int. core plus cooling	-0.30	-0.30	-0.30	-0.30	-0.30
S1S Tuning Pin Mod (FS1P)					
S3N GTD-222 w/0 Air-Cooled (FS1R)	0.00	0.00	0.00	0.00	0.00
S2B w 10 radial cooling holes (FS4B)	0.00	0.00	0.00	0.00	0.00
S3B w/ IN-738™ (FS2K)	0.00	0.00	0.00	0.00	0.00
S1S HR-120™ Cloth Seal (FS2Y)	-0.30	-0.30	-0.30	-0.30	-0.30
GTD-450 Reduced Camber IGVs (FT5B)	-0.10	-0.30	-0.30	-0.30	0.00
Shrouded Stator Blades (S17 + EGV) (FS2B)	<i>To prevent aerod. Vane stall under certain operating cond.</i>				
71C Compressor Upgrade to 71E model (FT5E)	0.00	0.00	0.00	0.00	0.00
Nimonic 263™ Transition Pieces	0.00	0.00	0.00	0.00	0.00
Liner Retune for DLN Units (FG2B)	0.00	0.00	0.00	0.00	0.00
Unified Liners for DLN Units	0.00	0.00	0.00	0.00	0.00
Staged Dilution for DLN Units	0.00	0.00	0.00	0.00	0.00
R17 Blades	0.00	0.00	0.00	0.00	0.00
OPTION: Stage 1-2 and 2-3 Spacers (FS1L)	0.00	0.00	0.00	0.00	0.00
OPTION: ETBC for S1N (FS6E)	0.00	0.00	0.00	0.00	0.00
OPTION: SIS Abradable Coating Seal (FS6A)	-0.50	-0.50	-0.50	-0.50	-0.50
OPTION: GTD-450 IGV, open from 84° to 86° (FT5B)	0.20	N/A	N/A	N/A	N/A
OPTION: S2S w/ HoneyComb Seals (FS2T)	-0.35	-0.35	-0.35	-0.35	-0.35
OPTION: S3S w/ HoneyComb Seals (FS2U)	-0.15	-0.15	-0.15	-0.15	-0.15
OPTION: HPP Brush Seals (FS2V)	-0.50	-0.50	-0.50	-0.50	-0.50
OPTION: Number 2 Bearing Brush Seals (FS2X)	-0.20	-0.20	-0.20	-0.20	-0.20
OPTION: Interstage Brush Seals (FS2Z)	-0.50	-0.50	-0.50	-0.50	-0.50
OPTION: Extendor Components (FS1V)	0.00	0.00	0.00	0.00	0.00
Max Heat Rate Decrease*	-3.65	-3.45	-3.15	-3.15	-2.75

* Total effect = compounding effects of all the performance improvements above with 71C/E/EA for Tf2550°F

Sourcebook codes are provided in parentheses

All performance improvements apply at ISO conditions (59°F/15°C, 14.7 psia/1.013 bar)

Figure 99. Heat rate benefits after increasing firing temperature to 2550°F.

Increase in Output

Feature	Frame				
	MS7001C	MS7001E	MS7001E	MS7001EA	MS7001EA
Original Tf (°F/°C)	1950/1066	1985/1085	2020/1104	2020/1104	2035/1113
Max Up rated (°F/°C)	2055/1124	2055/1124	2055/1124	2055/1124	2055/1124
Fleet IBs	12	137		478	
	Increase in Output (%)				
2055 & Control Modes (FT5Q)	10.30	7.00	3.90	3.40	1.60
S1N w/ Chordal Hinge Design (FS2J)	0.00	0.00	0.00	0.00	0.00
S1B w/ 12-Hole Cooling Design (FS2G)	0.00	0.00	0.00	0.00	0.00
S2N GTD-222 w/ int. core plus cooling	0.80	0.80	0.80	0.80	0.80
S1S Tuning Pin Mod (FS1P)					
S3N GTD-222 w/0 Air-Cooled (FS1R)	0.00	0.00	0.00	0.00	0.00
S2B w 10 radial cooling holes (FS4B)	0.00	0.00	0.00	0.00	0.00
S3B w/ IN-738™ (FS2K)	0.00	0.00	0.00	0.00	0.00
S1S HR-120™ Cloth Seal (FS2Y)	0.70	0.70	0.70	0.70	0.70
GTD-450 Reduced Camber IGVs (FT5B)	4.10	1.50	1.50	1.40	0.00
Shrouded Stator Blades (S17 + EGV) (FS2B)	<i>To prevent aerod. vane stall under certain operating cond.</i>				
71C Compressor Upgrade to 71E model (FT5E)	0.00	0.00	0.00	0.00	0.00
Nimonic 263™ Transition Pieces	0.00	0.00	0.00	0.00	0.00
Liner Retune for DLN Units (FG2B)	0.00	0.00	0.00	0.00	0.00
Unified Liners for DLN Units	0.00	0.00	0.00	0.00	0.00
Staged Dilution for DLN Units	0.00	0.00	0.00	0.00	0.00
R17 Blades	0.00	0.00	0.00	0.00	0.00
OPTION: Stage 1-2 and 2-3 Spacers (FS1L)	0.00	0.00	0.00	0.00	0.00
OPTION: ETBC for S1N (FS6E)	0.00	0.00	0.00	0.00	0.00
OPTION: SIS Abradable Coating Seal (FS6A)	0.50	0.50	0.50	0.50	0.50
OPTION: GTD-450 IGV, open from 84° to 86° (FT5B)	0.40	N/A	N/A	N/A	N/A
OPTION: S2S w/ HoneyComb Seals (FS2T)	0.35	0.35	0.35	0.35	0.35
OPTION: S3S w/ HoneyComb Seals (FS2U)	0.16	0.16	0.16	0.16	0.16
OPTION: HPP Brush Seals (FS2V)	1.00	1.00	1.00	1.00	1.00
OPTION: Number 2 Bearing Brush Seals (FS2X)	0.30	0.30	0.30	0.30	0.30
OPTION: Interstage Brush Seals (FS2Z)	1.00	1.00	1.00	1.00	1.00
OPTION: Extendor Components (FS1V)	0.00	0.00	0.00	0.00	0.00
Max Heat Rate Decrease*	19.61	12.51	9.41	8.9	5.61

* Total effect = compounding effects of all the performance improvements above with 71C/E/EA for Tf2550°F

Sourcebook codes are provided in parentheses

All performance improvements apply at ISO conditions (59°F/15°C, 14.7 psia/1.013 bar)

Figure 100. Performance benefits after increasing firing temperature to 2550°F.

need for additional liner re-tunes to meet emissions compliance. (**Note:** For quotations that contain several options that impact emissions, only one liner re-tune is required for an uprate outage if all purchased options are to be installed during the same outage. If purchased options are to be installed during different outages, multiple liner re-tunes must be purchased).

- For a unit that currently has DLN combustion, staged dilution for the transition pieces is required if the transition pieces do not have staged dilution. Please contact GE's Gas Turbine Application Engineering group for further details.
- For a unit that currently has DLN combustion, unified liners are required for operation at 2055°F firing temperature. Please contact GE's Gas Turbine Application Engineering group for further details.
- Aft frame cooling for the transition pieces (all combustion systems) is required for operation at 2055°F firing temperature.
- The addition of Extendor components is now applicable to units with a Standard, DLN and Multi-Nozzle Quiet Combustor Combustion System. It is currently only available for Frame 71B-EA units with slot-cooled diffusion combustion liners and slotted end frame Nimonic transition pieces.
- Heavy fuel units may only increase their firing temperature to 2000°F. 71EA customers must upgrade their shrouded stage 17 EGV 1-2 arrangement per TIL-1140-2R1, before the firing temperature increase can be performed. Reference *Necessary Addition 5*.
- For units containing a Mark IV or earlier vintage control system, a Control MOD or 2-Part Control Curve is needed at an additional charge. Please contact GE's Gas Turbine Application Engineering group for further details.
- For uprates of significant performance improvement, GE will evaluate generator capability. This includes a graph of turbine uprate capability versus generator capability, at different power factors. *Figure 91*, as an example of the power factor approach, illustrates that increasing power factor provides for sufficient generator capability to handle the proposed performance increase. Using the power factor increase approach, GE has been able to uprate units without needing to uprate generators.

GE does offer uprates for generators, and will offer such uprates after a generator study is completed. These studies typically are performed for units that may receive large uprate in output.

- During this uprate, the Stage 1-2 spacer discourager seals should be inspected and/or replaced due to the deteriorating aluminum bronze seal material. The new material should be 410 stainless steel. For further information, please reference *Sourcebook code FW3E and TIL 1260-2*.
- Due to the complexity and scope of this uprate, the major components involved, which are all current production items, are available as independent kits which allow incremental improvements to be realized. Refer to the Sourcebook articles mentioned above.
- GE Energy has confidence in the gas turbine performance improvements identified for individual uprate components. However, customers may not experience the rated performance benefit of an individual component upgrade if other components, either refurbished or third party, are replaced at the same time. Benefits associated with any GE Energy improvement package cannot be assured without a complete audit of all of the turbine's installed hot gas path components. In addition to replacement of parts, the parts need to be installed using recommended procedures to fully realize the rated performance benefit.
- Special attention is required for the turbine stage 1 nozzle due to its significant impact on the overall gas turbine performance. Document TIM 00-S-566 provides details of critical levels of clearance needed after installation of the nozzles to realize the performance benefit. GE cannot guarantee performance if the stage one nozzle used in the uprate was repaired by a third party.
- For the 71EA units, the 2055°F Tfire uprate will require that the current production R17 rotor compressor blades be installed during the upgrade outage, unless the unit is already configured with the Gen1, Gen3-678 Hz or Gen3-squealer tip blades as described in TIL 1346-1. If the unit uses water or steam injection or if water and steam injection will be quoted with the Tfire uprate, the current production R17 rotor blades will be required to be installed during the upgrade outage and at each subsequent Major Inspection as described in TIL 1346-1.

Control System Upgrades

For a great variety of control systems, enhancements and upgrades are available for all vintages of gas turbine control systems. The MS7001 turbines are controlled by the Speedtronic Mark I-through-Mark VI control panels. Today's control technology is superior to previous control systems because it offers more reliable operation.

Turbines with older control systems are excellent candidates for a Mark V control panel replacement. When a complete control panel replacement is desired, GE can replace the existing control system with a complete Speedtronic Mark V panel with either simplex or triple redundant processors. Complete details of available control and instrumentation upgrades are available in the GE publication, *GER-3659E: Control System Upgrades for Existing Gas Turbines in the 1990s*.

When considering a control system uprate to an existing MS7001 gas turbine, a control system retrofit can help provide maximum benefits to operators.

Compartment and Exhaust Upgrades

Dual 100 HP Fans for Turbine Compartment (FF1E)

This modification for all MS7001 units involves adding two centrifugal ventilation fans, enclosed in box-type casings and driven by AC motors, to the top of the turbine compartment. The fans provide ventilation by drawing air up through several ducts in the turbine and accessory compartments and exhausting it to atmosphere through a horizontal discharge. A dual vent fan arrangement is used to supply symmetrical airflow throughout the turbine compartment.

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 that are 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 will employ a damper housing. The damper blades will be held in a normally open position with a CO₂/Halon

pressure-actuated spring release latch. This latch is operated by the fire-extinguishing agent. When the fire protection system is activated, the latch will release and the damper blades will close by gravity. The damper housing and CO₂ latch will be bolted to the fan outlet and shipped as a unit. It should be noted that the CO₂ latch can 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. Interconnecting cable from the fan motors to the MCC is to be supplied by the customer. Other options that can be incorporated into this uprate include limit and differential pressure switches, as well as back draft dampers.

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.

Upgrade to 100 HP Exhaust Frame Motor Blowers (FS2D)

For frame MS7001EA and vintage 71E units (see below), cooling of the turbine exhaust casing and frame is accomplished by motor driven blowers. These fans are mounted externally to the turbine. The replacement kit will include 100 HP exhaust frame blowers, interconnection piping arrangement modifications, motor control center modifications and exhaust frame cooling circuit tuning. The current design exhaust frame is cooled with two motor-driven centrifugal blowers. The 100 HP exhaust frame blowers help to reduce the temperature of the frame, helping to reduce cracking, reduce the general repair costs and provide a durable exhaust frame.

Upgrading the exhaust frame blowers is applicable to units with the modern design exhaust frame that do not have 100 HP rated blowers. All 71EAs and 91Es have the modern design. Some later vintage 71E units also have the modern design exhaust frame and cooling circuit. Some of these units have blowers with lower horsepower ratings than the latest design. The latest design for combined cycle machines is 100 HP exhaust frame blowers for both 71EA and 91E units. For simple cycle, the latest design is 60 HP blowers for 71EA units and 30 HP blowers for 91E units. Simple cycle units generally have lower horsepower blowers because the gas path pressure is relatively low for simple cycle.

However, for simple cycle units, an upgrade to exhaust frame blowers with 100 HP rating may be required to obtain the elevated exhaust temperature capability that is needed to get the full benefit of a 2055°F firing temperature increase.

See FS1W for a modification kit for 71EA and 91E units that contain the latest enhancements and recommended plenum upgrades. For 71B, 71E (except as noted above), and 91B units, see FS1W for exhaust frame blower addition/upgrade and exhaust frame upgrade.

Exhaust Extended Thermocouple (FK5C)

For frame MS7001A and B units, the removable wheelspace thermocouples modification provides thermocouples that can be replaced upon failure without removing the turbine shell. The new thermocouples are also extended, which provides greater reliability by moving the termination junction from the turbine compartment to outside of the compartment. The modification will include all wheelspace thermocouples, necessary hardware, and on-base junction boxes.

The extended externally replaceable wheelspace thermocouple increases turbine availability through the reduction in downtime. The reliability of the thermocouple increases with the increased shielding and removal of the termination point from the turbine compartment

Exhaust Frame Upgrade (FS1W)

For frame MS7001B/C/E/EA units, the exhaust frame diffuses high temperature exhaust gas through the exhaust plenum. The frame consists of an inner forward diffuser, an outer forward diffuser, an aft exhaust diffuser and a turning vane sub-assembly.

The modification packages illustrated in *Figures 101 and 102* include the following, as appropriate: a change of cooling air circuit; an increase or addition of exhaust frame blower capacity; covers/upgraded gaskets for horizontal joints; new forward flex seals; stress relief scallops; and turning vane enhancements. These modifications improve exhaust frame cooling, reduce general repair costs and address load tunnel over-temperature issues by reducing exhaust gas leakage.

The benefit of these upgrade packages is to provide an enhanced exhaust frame for 71B/C/E (Reference FT5X, FT5Q or FT5Y) or 91B/E (Reference FT6X, FT6Y) firing temperature upgrades. These modifications

enhance exhaust frame cooling, reduce repair costs, and address load tunnel over-temperature issues by reducing exhaust gas leakage.

Exhaust Diffuser Horizontal Gasket (FW1L)

For MS7001E units, several problems have occurred in the exhaust diffuser inner barrel flange area. Incidents included loss of gasket material between horizontal flanges, bolt failures/loosening, and flange distortion causing leakage. To resolve these problems, several modifications have been developed and are available.

Issue #1: Loss of gasket material

Recommendation: The thin waveform sheet metal gaskets originally used on the horizontal flanges should be replaced with a new ceramic fiber gasket.

Issue #2: Failures and/or loosening of exhaust diffuser bolts

Recommendation: Modification that upgrades the bolt strength with a material change to an A286™ series bolt.

Issue #3: Distortion of the flange, resulting in gaps in the flange that will not pull back together with the stronger bolts

Recommendation: The modification drawing illustrated in *Figure 103* includes a sheet metal channel, which may be utilized to reduce leakage across the joint. Note that minor leakages do not pose a danger to machine operation. The use of the high temperature sealant with the channel section as illustrated on the modification drawing will significantly reduce leaks.

The benefit to applying this Sourcebook is improved maintenance and reliability.

Exhaust Diffuser Doubler Plate (FW2E)

This Sourcebook is a pre-engineered kit for MS7001E units that may be ordered through standard spare and renewal parts channels. Therefore, this modification does not require further engineering input.

Exhaust Plenum Replacement

To ensure that customers have access to high quality gas turbine exhaust plenums, GE Energy provides retrofit, re-designed exhaust plenums as part of its product offering. (See *Figure 103*.) Over time, exhaust plenums having fixed, non-floating inner liners will develop extensive liner cracking caused by thermal stresses arising from the non-floating designed liner. Excessive thermal movement contributes

MS7001B to E Advanced Technology Uprates Exhaust Frame Modification

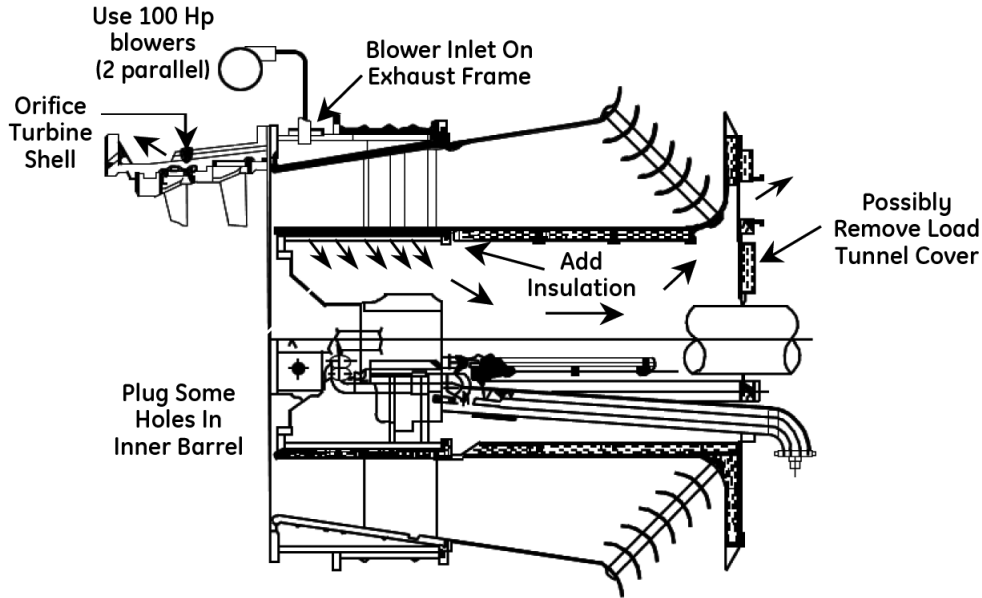


Figure 101. Exhaust frame modification and 100 HP blowers.



Figure 102. Improved exhaust frame.

toward destruction of control cables and severe turbulence that can cause liner damage. GE offers plenums with full-floating liners that decrease stress due to thermal movements. The flexible seal is normally replaced whenever the exhaust plenum is replaced.

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



Figure 103. Improved Exhaust Frame.

Summary

GE has an Advanced Technology Uprate Package available to uprate all of the 800 GE designed MS7001 heavy-duty gas turbines. (See Figure 104.) These Advanced Technology Uprate packages provide significant savings to our customers due to reduced maintenance, improved efficiency and output, and improved reliability. Changes in emission levels associated with a gas turbine uprate may also make it necessary to add/change emission controls due to

- GE Energy has Advanced Technology Uprate Packages available to uprate all of the quantity of 800 GE-designed MS7001 heavy-duty gas turbines to improve their performance, efficiency, and reliability
- Uprates are available to increase maintenance intervals and reduce repairs

Figure 104. Summary for GER-3808C.

regulatory requirements. It is frequently desirable to also consider a control system upgrade or replacement in conjunction with a turbine uprate to achieve the best overall improvement in reliability. GE's current technology and production components allow customers to bring their aging turbines back to excellent condition based upon today's offerings.

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