Advanced Gas Turbine Guidelines: Hot Gas Path Parts Condition and Remaining Life Assessment for GE 7FA in Baseload Operation

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ABSTRACT

Advanced Gas Turbine Guidelines: Hot Gas Path Parts Condition And Remaining Life Assessement ForBaseload Operation

The Guideline on Hot Gas Path Parts Condition and Remaining Life Assessment provides results of monitoring and inspection of four General Electric ("GE") MS 7221 FA Advanced Gas Turbines, in baseload service at Florida Power & Light's ("FP&L") Martin Station, Indiantown, Florida.

EPRI's Durability Surveillance Project Team, along with EPRI materials consultants, participated with FP&L and GE in a series of Combustion Inspections and Hot Gas Path Inspections on Martin CC Advanced Gas Turbine Units 3A, 3B, 4A and 4B. The inspections were performed in 1994 and 1995.

The purpose of this guideline is to assist utilities in obtaining long term monitoring/analysis information applicable to GE 7221 FA advanced gas turbines. The effects of baseload service on the integrity and life of hot gas path components are evaluated and assessed. The status of the buckets, nozzles, combustors and other hot path components are presented as found during various inspections.

The information provided in this Guideline will enable utility operators to make educated decisions regarding baseload operation of advanced gas turbines, as well as to plan the maintenance inspections, reduce forced outages, and minimize overall maintenance cost.

This Report is the eighth (8) in the series of AGT Guidelines Reports, which describe the results from the Durability Surveillance Project. The published EPRI Guidelines described the following subjects:

- Rotating Blade Temperature Measurements (peaking service)
- EPRI Performance Operation and Maintenance Management System
- Hot Gas Path Condition and Remaining Life Assessment (peaking service)

- Data Acquisition System and Baseline Data (peaking service)
- Vibration Monitoring and Analysis (peaking service)
- Rotating Blade Temperature Measurements (baseload service)
- Performance Retention (peaking service)
- Performance Retention (baseload service)

REPORT SUMMARY

Based on two years experience operating four advanced gas turbines (AGT) General Electric MS 7221 FA at Martin CC of Florida Power & Light (FP&L), this guideline describes the operating and maintenance philosophy used for baseload AGT units and the integrity of the hot path components and their remaining life. The guideline will assist utilities operating the GE MS 7221FA class AGT plan inspections and comparisons with other units in this class.

Background

Advanced high-temperature materials and blade-cooling techniques have allowed for the construction of industrial gas turbines with firing temperatures up to 2350°F (1287.8 °C). These turbines are designed to provide greater fuel efficiencies, extended availability, and lower maintenance costs. In 1991 EPRI launched a durability surveillance project to assess the ability of advanced gas turbines to meet expectations about durability and performance. A blade surface temperature measurement system using optical pyrometers was designed to determine the performance of cooled rotating turbine blades and to establish an operational database. The database then became the source for establishing unit baseline and trending data over the operating life of the advanced gas turbines. This report describes EPRI's materials inspections and associated maintenance practices for FP&L's General Electric MS 7221 FA.

Objectives

To assess the condition of hot gas path parts of AGTs in baseload service through on-site gas turbine inspections during scheduled and forced outages; to develop a historical database and assess the hot path components' life expenditure; to develop a reliable system for measuring the operating blade surface temperatures of cooled turbine rotating blades and use the results in AGT blade predictive maintenance.

Approach

Focusing on the General Electric Frame 7FA advanced gas turbine because of its deployment worldwide, durability surveillance investigators monitored four GE MS 7221 FA gas turbines at FP&L’s Martin CC plant. The EPRI project team participated in all gas turbine inspections from the turbine’s initial operation, using a comprehensive data acquisition system to collect and evaluate turbine blade temperature data and to collect unit operations data.

Results

EPRI’s AGT guidelines provide database and operational information for operating units similar to those at the Martin CC plant. The guidelines address the effects of baseload service on the hot gas path components, which are the most important and expensive parts to be replaced during scheduled and forced inspections. The status of the inspected parts and assessments of part ability to provide further service are included in the discussion.

EPRI Perspective

These AGT guidelines are designed to help the user become a low- cost power producer. Other guidelines published by EPRI to help utilities select advanced gas turbines that meet their expectations are TR-103895 on rotating blade temperature measurement, TR-103937 on data acquisition and baseline data, TR-104019 on performance, operation, and maintenance management, TR-104101 on hot gas path parts condition assessment and remaining life assessment for peaking operation, TR-104100 on vibration analysis at Station H - GE 7F, and TR-105069 on blade temperature measurement at Martin CC.

Other EPRI Guidelines are being planned. The Institute has arranged for investigators to study the first ABB GT24 advanced cycle unit at Jersey Central Power & Light's Gilbert Station. Investigators will also study additional advanced gas turbines manufactured by Siemens Power Corporation and Westinghouse/Mitsubishi Heavy Industries.

TR-106329

Interest Category

Advanced combustion turbines and cycles
Combustion turbines and combined cycle plants

Keywords

Gas turbines
Advanced gas turbines
Gas turbine materials
Cooled gas turbine blades
Remaining life assessment of gas turbine materials
Peaking service of gas turbines
Advanced gas turbines maintenance

EXECUTIVE SUMMARY

HOT GAS PATH PARTS CONDITION AND REMAINING LIFE ASSESSMENT FOR ADVANCED GAS TURBINES (BASELOAD OPERATION) GUIDELINE

Introduction

This Hot Gas Path Parts Condition Assessment Guideline pertains to General Electric ("GE") 7FA advanced gas turbines operating in baseload service. Inspections referenced are based on EPRI's work at FP&L Martin Station on four (4) GE MS 7221FA advanced gas turbines.

EPRI has provided contracted expert materials consultants to inspect each gas turbine at site during planned and unplanned outages. Combustion and hot gas path inspections have been made via borescope or, if the combustion system or casing was opened, by direct inspection of the units.

Objectives and Benefits of this Hot Gas Path Parts Condition Guideline

The objective of this Guideline is to provide the status of the hot gas path components for the GE MS 7221 FA advanced gas turbines used in combined cycle baseload service.

The results of the durability surveillance inspections by EPRI, FP&L, and GE, and their impact on FP&L's operation and parts replacements, is described. Conclusions are made regarding the durability of the hot gas path components operated in baseload service. The use of EPRI specialized instrumentation, in detecting component wear, is also described.

The objectives and benefits related to this guideline are as follows:

Objectives	**Benefits**
Provide an understanding of the basic maintenance inspections required.	The utility plant staff will have a summary of the combustion and hot gas path parts condition over the monitoring period.
Provide an understanding of the replacement parts requirements.	The utility plant staff will have a summary of parts required during maintenance outages.
Provide information on the frequency of planned and unplanned unit inspections.	The record of inspections at Station H shares with the utility owners the experience of first units.
Provide information on the operating life of combustion and hot gas path parts.	Owner will be able to determine the actual hot gas path parts life under peaking operating service.

FP&L MARTIN CC STATION COMBINED CYCLE

Florida Power and Light's ("FP&L") Martin CC Station is located in Indiantown, Florida. Martin CC Station is a combined cycle plant consisting of two power blocks, unit 3 and unit 4.

Each power block consists of two General Electric 7221 FA advanced gas turbines, two Vogt, three pressure non-supplementally fired heat recovery steam generators (HRSG) and one GE reheat steam turbine (ST) generator. **The two power blocks operate at total net plant output of 898 MW** (ISO design rating).

The Turbines were first synchronized in latter 1993, and went commercial in early 1994. The units have natural gas/distillate dual fuel capability and provision for steam power augmentation, but neither distillate fuel or power augmentation has been used as of November, 1995.

These units operate at, or near, full load (140-165 MW, depending on the ambient temperature) for 80% of the time. Electric power output is generally reduced in the early morning hours, commonly to 100-130 MW but occasionally as low as 40 MW.

The first 40 MW of power reduction is handled entirely by closing the inlet guide vanes which reduces airflow, increases exhaust temperature slightly, and keeps firing temperature and bucket temperatures relatively constant. Power reductions beyond 40 MW are handled by reducing the firing temperatures, which lowers both bucket and exhaust temperatures.

The compressors are cleaned by on-line and off-line techniques. On-line cleaning is done twice a week with demineralized water. Off-line cleaning is done with detergent demineralized water at the annual inspection, and occasionally during other machine shutdown. On-line cleaning restores about 3 MW of power when it is done shortly after an off-line cleaning - but this restoration becomes less as the months go by.

Infrared Pyrometers are installed on each Martin gas turbine as a means of monitoring bucket temperatures. Together with an extensive Data Acquisition System (DAS), they were installed by EPRI as part of the Durability Surveillance Program.

Description of Durability Surveillance Project

Worldwide pressures for reducing power generation costs have encouraged manufacturers to build high-efficiency gas turbines with firing temperatures up to 2350°F (1288°C). One manufacturer recently announcing a firing temperature of 2600°F (1427°C) for a new model gas turbine, due to ship in 1996. To assess the staying power of these gas turbines in utility peaking, intermediate, and base load service, EPRI has undergone a multi-year project for the Durability Surveillance of Advanced Gas Turbines, which focuses on new-marketed advanced gas turbines.

Project Objectives

- To determine hot gas path parts condition by providing materials consultants contracted by EPRI for on-site gas turbine inspections during outages.
- To develop a reliable system to measure the operating temperatures of cooled turbine rotating blades.
- To develop a historical data base of condition monitoring data.
- To develop performance and other analysis screens for use by the plant staff.
- To create Baseline Data against which to compare gas turbine performance over the unit's operating life.
- To develop and implement a maintenance and reliability/availability tracking system.

DESCRIPTION OF MS 7221 FA

The MS 7221 FA's installed at Martin CC Station were introduced by General Electric in 1990. It is an uprated version of the MS7221F which was introduced in 1986. The MS 7221 FA (**Figure 1**) consists of an 18 stage axial compressor, 14 cross-connected combustion chambers and a 3 stage reaction turbine directly coupled to a 2 pole 3600 RPM generator and is rated 159 MW (ISO) at base load operation.

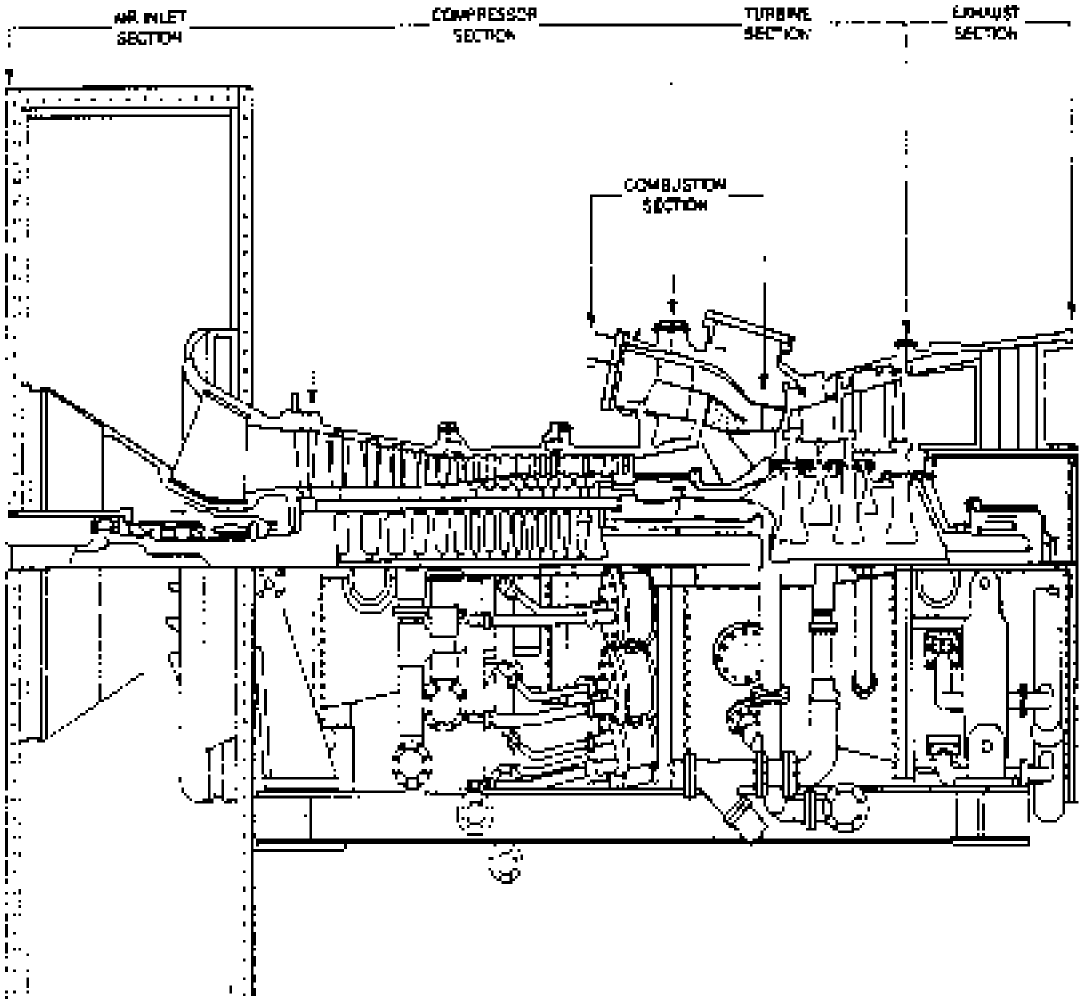


Figure 1
General Electric MS 7221 FA Advanced Gas Turbine

The MS 7221 FA is an advanced design machine utilizing a rotor inlet temperature of approximately 2350°F (1288°C). The temperatures of hot gas path components (including turbine blades) is proportionate to the firing temperature. As a result, the high firing temperature of the MS 7221 FA requires application of new technologies for the turbine blades. To survive at these harsh conditions the first and second stage buckets are air-cooled. The first stage buckets are convectively cooled via serpentine passages and second stage buckets are cooled via convective heat transfer through drilled radial holes. The MS 7221 FA, achieves improved efficiency through higher inlet gas temperature which was made possible by the introduction of better blade cooling **(Figure 2)**. If not properly cooled, these blades are exposed to temperatures well above their operating limit. Turbine blade cooling is critical for effective operation of advanced combustion turbines with turbine inlet temperature above 2300°F (1260°C). Since most superalloys begin to melt at about 2200°F (1204°C), hot gas components (including turbine blades) must be cooled to maintain metal temperatures well below this temperature.

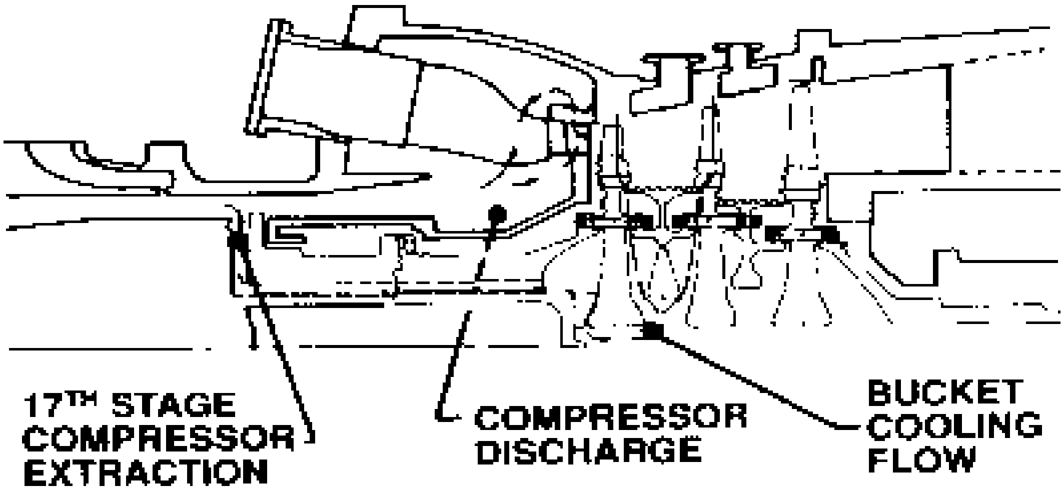


Figure 2
Blade Cooling Air of First Stage Bucket via
Extraction Air from 17th Compressor Stage

Gas turbine buckets (particularly 1st and 2nd stage) are the most burdened components of the gas turbine due to high heat, intense stress and the harsh environment. The first stage turbine bucket must withstand the most severe combination of temperature, stress and environment. and is generally the limiting item on the machine. Blades must be designed to successfully address the following areas:

- Thermal Fatigue (cracking)
- Alloy Hot Corrosion
- High Temperature Oxidation
- Blocked Cooling Passages/Loss of Cooling
- Loss of Material

OPERATION OF GAS TURBINES

The FP&L - Martin Station is currently the MS 7221 FA gas turbine site having logged the greatest number of operating hours. The site has four gas turbines operating in a base load combined cycle mode with a DLN-2 combustion system that has used natural gas exclusively to date.

The current operating statistics for the four Martin CC Station machines are shown in **Table 1**. The most operated machine (Unit 3A) has accumulated 16352 hours of service, with 88 fired starts and 38 trips as of November 1995. The four machines have accumulated a collective total of 56906 hours of service with 278 fired starts and 108 trips as of November 1995. Operation prior to May 1994 was characterized by numerous shutdowns, largely due to the new dry low-NOx combustor, DLN-2, (typically running at 10 to 18 ppm NOx levels); technology that was being introduced. Since that time, however, it has been the more typical base load operation. Overall, operation has averaged 198 fired hours per start since installation, and about 480 hours/start from latter 1994 to the end of 1995.

All four machines were inspected on a scheduled basis, or as a result of the installation of new technology hardware or other events. There have been 5 Combustion, 1 Hot Gas Path, and 2 Major Inspections on the Martin machines since their installation in late 1993, and all are shown in **Table 2**.

Table 1
Operating Statistics As Of 11/14/95

	Unit 3A	Unit 3B	Unit 4A	Unit 4B
Turbine Number	295810	295851	295854	295855
Installation				
First Synchronized	Late 1993	Late 1993	Late 1993	Late 1993
Commercial	Early 1994	Early 1994	Early 1994	Early 1994
Last Inspected	Nov. 1994	June 1995	Feb. 1995	Nov. 1995
Inspection Type	Comb'n	Comb'n	Major	Comb'n
Fired Hours	16352	16062	10228	14264
Fired Starts	88	66	64	60
Trips	38	22	27	21
Total Starts	93	73	74	71
Normal Starts	116	101	79	85
Manual Starts	90	64	56	62
Compressor Surge Indications	9	9		0
Primary Mode Fired Hrs.-Gas	17	6	19	8
Primary Mode Fired Hrs. - Oil	0	0	0	0
Lean-Lean Mode Fired Hours	796	452	114	361
Secondary Mode Fired Hours		0		
Premix Mode Fired Hours	6768	11643	10082	4295
Premix Transfers	54	64	0	0

Table 2
Significant History

Unit	Date	Fired Hours	Fired Starts	Trip s	Comments
3A	6/93	0	0	0	First synchronized
	12/93	~450			Combustion and 1st shroud modifications
	2/94	~1200			Commercial operation
	4/13/94	3549	64	27	Combustion Inspection
	5/15/94	~4300			Load swings, (a)
	11/14/94	8079	74	32	Combustion Inspection
	7/18/95	~13600			Firing temp. readjusted from 2384 to 2365°F (1307 to 1296°C)
	11/14/95	16352	88	38	Latest status
3B	6/93	0	0	0	First synchronized
	12/93	~450			Combustion and 1st shroud modifications
	2/94	~1200			Commercial operation
	3/4/94	2295	40	16	Borescope Inspection
	5/15/94	~3500			Load swings, (a)
	5/21/94	~4000			Peak load test demonstration of about an hour
	5/23/94	4082	47	17	Hot Gas Path Inspect.- nozzle tip loss, (a)
	6/11/95	12586	60	21	Combustion Inspection
	7/28/95	~13500			Firing temp. readjusted from 2384 to 2365°F (1307 to 1296°C)
	11/14/95	16062	66	22	Latest status
4A	12/93	0	0	0	First synchronized
	2/94	~100			Combustion modifications
	4/94	~300			Commercial operation
	5/15/94	~1000			Load swings, (a)
	11/7/94	4867	42	21	Major inspection - rotor vibration - (a)
	2/16/95	6120			Major Inspection - compr. blade failure - (a)
	6/21/95	~6700			Firing temp. readjusted from 2384 to 2365°F (1307 to 1296°C)
	11/14/95	10228	64	27	Latest status
4B	12/93	0	0	0	First synchronized
	2/94	~100			Combustion modifications
	4/94	~300			Commercial operation
	5/15/94	~1000			Load swings, (a)
	9/14/94	4402	41	21	Combustion Inspection
	7/15/95	~11500			Firing temp. readjusted from 2384 to 2365°F (1307 to 1296°C)
	11/14/95	14264	60	21	Combustion Inspection. Latest Status

(a) Described in Section 4.

INSPECTION INTERVALS

GE has traditionally recommended three types of inspections. These are Combustion Inspections, Hot Gas Path Inspections, and Major Inspections in increasing order of machine disassembly and inspection coverage. Combustion hardware only is removed at Combustion Inspections, while turbine upper casings are removed at Hot Gas Path Inspections and all upper casings and the rotor are removed at Major Inspections.

The reference Maintenance Interval is the one for the most favorable case - that of a base load machine, fired on natural gas with no water/steam injections. The FP&L-Martin Station is therefore an example of a reference case. The GE recommended inspection intervals for the MS 7221E/EA/F/FA reference case are as follows:

Type of Inspection	Designation	Interval Hours
Combustion Inspection	CI	8000
Hot Gas Path inspection	HGPI	24000
Major Inspection	Maj	48000

The reference Maintenance Interval is calculated according to the following formula:

$$\text{Maintenance Interval (in hours)} = \frac{24000}{\text{Maintenance Factor}}$$

where —

$$\text{Maintenance Factor} = \frac{\text{Factored Hours}}{\text{Actual Hours}}$$

and —

Factored Hours = G + 1.5D
Actual Hours = G + D

and —

G = annual base load operating hours on gas fuel
D = annual base load operating hours on distillate fuel

Nothing in these inspections suggested that the inspection intervals should be lowered for the reference case of a base loaded FP&L-Martin machine fired at 2350°F (1288°C). There might, in fact, be some optimism for increasing the Combustion Inspection interval sometime in the future (Unit 4B just completed a 9624 hour interval). Inspection intervals for the current hardware might, however, be lowered because these machines were actually fired at 2384°F (1307°C) for a significant part of their life.

A shorter Combustion Inspection interval was occasionally used to get a preliminary assessment of a new hardware design. This practice was good, and should be considered for any significant innovations in the future.

LIFE OF HOT GAS PARTS

GE references the life of parts as multiples of the recommended standard Maintenance Intervals mentioned above. The philosophy for any new machine is to use appropriate design tools as tempered by past field experience, and then follow the fleet leaders to verify that design - as is currently being done for the MS 7221 FA. GE has presented the following lives for the MS 7221E model which, at 70000 hours, is a more mature design than the MS 7221 FA:

	Repair Interval	Replacement Interval
1st Stage Buckets and Shrouds	HGPI	2 HGPI/3 HGPI (a)
2nd, 3rd Stage Buckets and Shrouds	HGPI	3 HGPI
1st , 2nd, 3rd Stage Nozzles	HGPI	3 HGPI
Combustion Liners	CI	5 CI
Fuel Nozzles, Cross Fire Tubes	CI	3 CI
Transition Pieces	CI	6 CI

(a) Bucket Only: 3 HGPI with refurb/recoat

It is anticipated that the lives of some current FP&L parts, particularly the 1st stage bucket, will be shorter than these because of the higher firing temperature used initially.

It is impossible to project the results of the current 4000-14000 hour visual inspections out to the 48000-72000 hour level, certainly without the benefit of destructive analyses. Most observations were encouraging, however, and didn't *disprove* the use of the above MS 7E table for an FP&L MS 7221 FA fired at 2350°F (1288°C). The 1st stage bucket, however, may be the item that is most in question (see Condition of Parts).

SUMMARY OF OPERATIONAL INCIDENTS

The machines have basically run quite well, but have not been without several incidents which are described below:

Units 3A, 3B, 4A, 4B (5/15/94). Load Swing

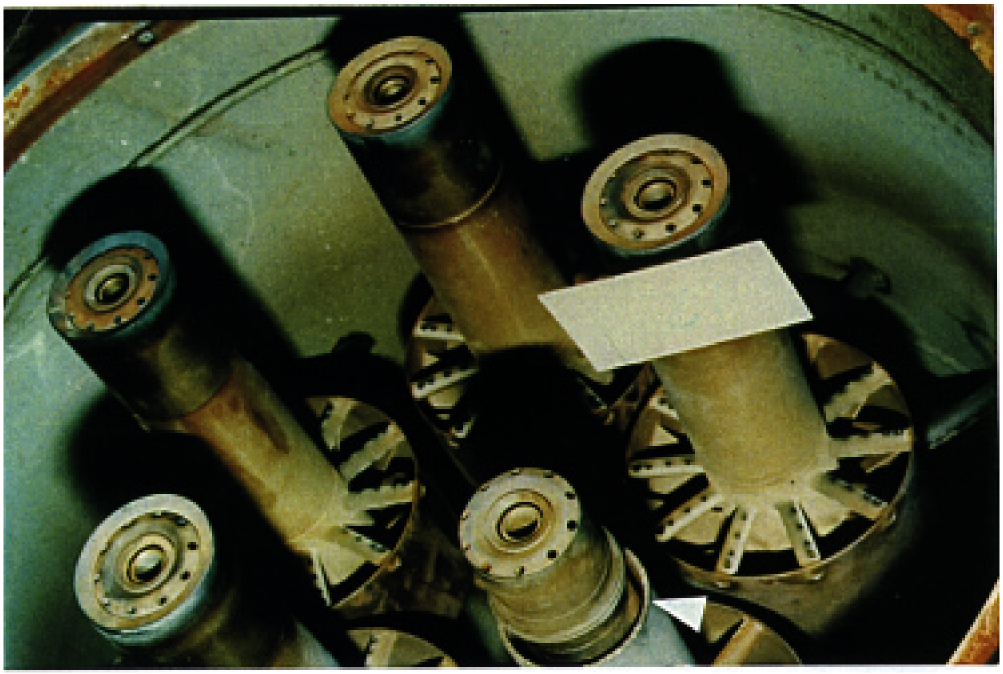
All units experienced unique load swings which were suspected to be caused by a fuel gas delivery malfunction. The machines went from a fully loaded 150 MW to about 25 MW in a few seconds, reestablished at full load, possibly repeated, and then tripped. Control modifications were made as protection against possible repeat occurrences.

Unit 3B (5/94, 4082 hours). Loss of Fuel Nozzle Tip

Loss of a fuel nozzle tip (**See Figure 3 & 4**) was discovered at the scheduled inspection of 5/23/94 (there have been no subsequent tip losses). This is a 2″x2″ (50.8 x 50.8 mm) cylinder of 60-120 mil (1.524 - 3.048 mm) wall thickness and 4 ounce weight. No defects were found in metallurgical examination and the observations were consistent with a fuel flashback. Exhaust temperature spreads were normal two months before, but were skewed within two weeks of, the inspection (no interim data was available). It is believed that the tip loss triggered the exhaust temperature shift, and both occurred from combustion flashbacks. The downstream damage was surprisingly little. The 1st stage nozzle partitions and buckets were both removed for repair; while 2nd and 3rd stage nozzles and buckets were left in the machine. Leading edges on three 2nd stage buckets and two 3rd stage buckets were carefully blended in the machine.

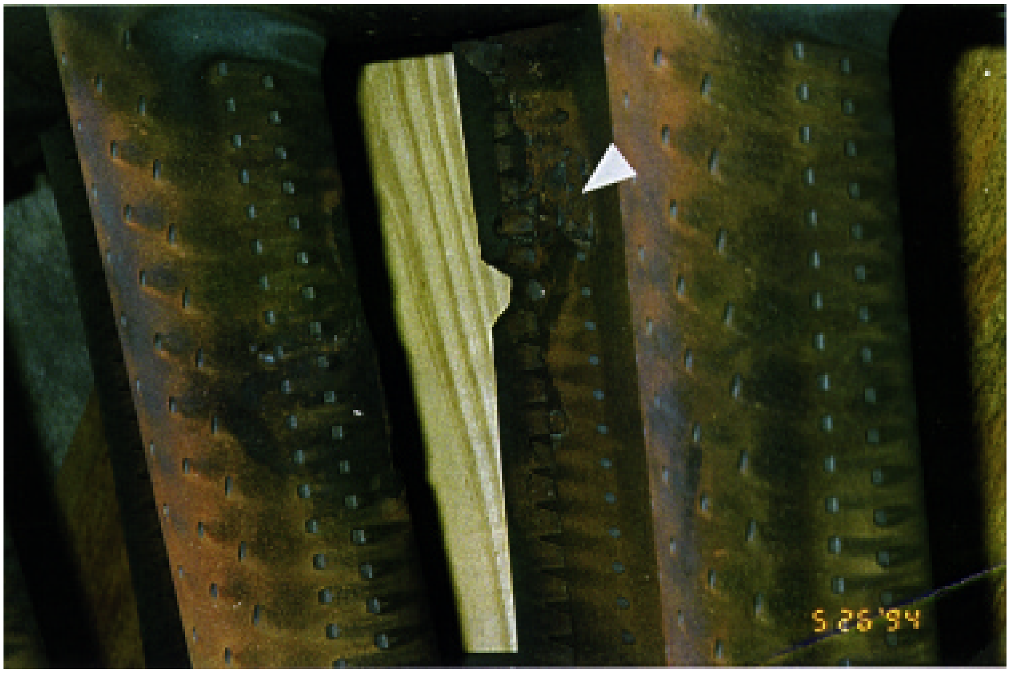
Unit 4A (2/95, 6120 hours). Compressor Blade Failure

The compressor rotor developed significant vibration and was replaced with a compressor rotor section from another site. The rebuilt rotor then experienced a compressor blading failure in early February 1995. There had been a loss of output (8 MW) and the compressor discharge pressure dropped about 6% approximately sixteen (16) hours prior to the high vibration trip. Portions of three compressor blades (**See Figure 5**) went downstream (stator 4, rotor 4, stator 14), and most blades downstream of stage 3 were dented and bent. Combustion parts were essentially intact; 1st and 2nd stage nozzles and buckets (**See Figure 6 & 7**) and some 3rd stage buckets were removed for refurbishment, and the 3rd stage nozzle was quickly refurbished and reinstalled in the same machine. The rotor is under investigation by the OEM. Interestingly, station instrumentation indicated that the machine had been producing about 7 MW more power than the other three for at least part of it operation.



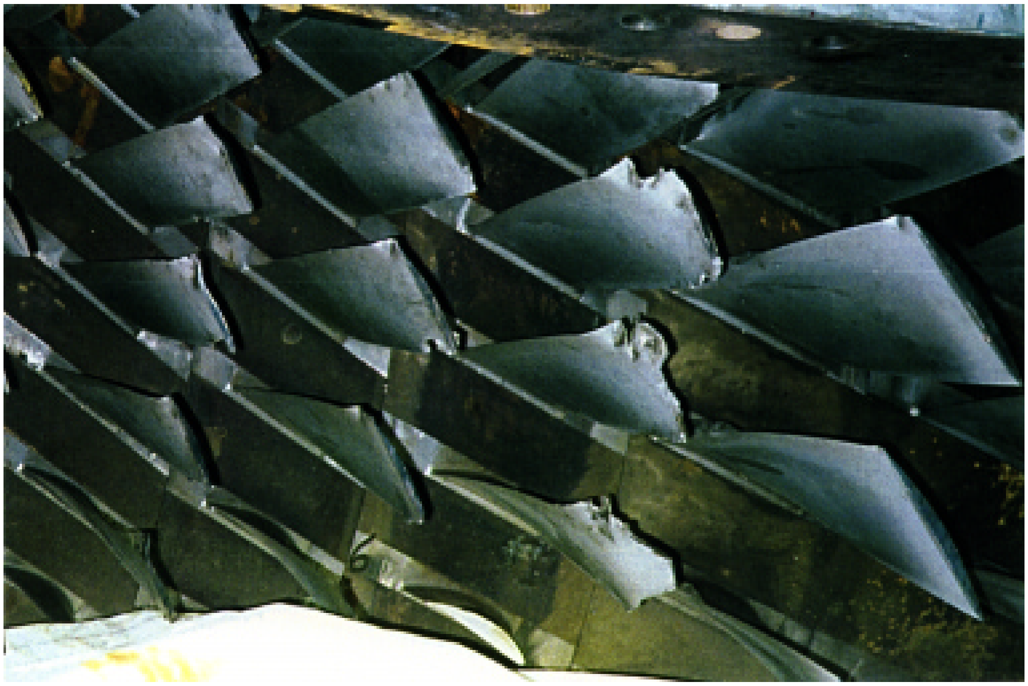
The fuel nozzle tip was lost after 2,500 hours. This failure was attributed to a fuel flashback.

Figure 3 Unit 3B 5/94, 4,082 Hrs. Fuel Nozzle Tip.



1st stage nozzle showing heavy oxidation in the single throat where the fuel nozzle tip lodged temporarily. The other nozzle throats were unaffected.

Figure 4 Unit 3B 5/94, 4,082 Hrs. 1st Stage Nozzle.



Compressor rotor section blade failures.
Figure 5 Unit 4A 2/95, 6,120 Hrs. Compressor Rotor

The 1st stage buckets are shown after the impactions from the compressor blades.
Figure 6 Unit 4A 2/95, 6,120 hrs. 1st Stage Buckets.

1st stage buckets showing convex side damage from compressor blade impactions.
Figure 7 Unit 4A 2/95, 6,120 hrs. 1st Stage Buckets.

CONDITION OF PARTS

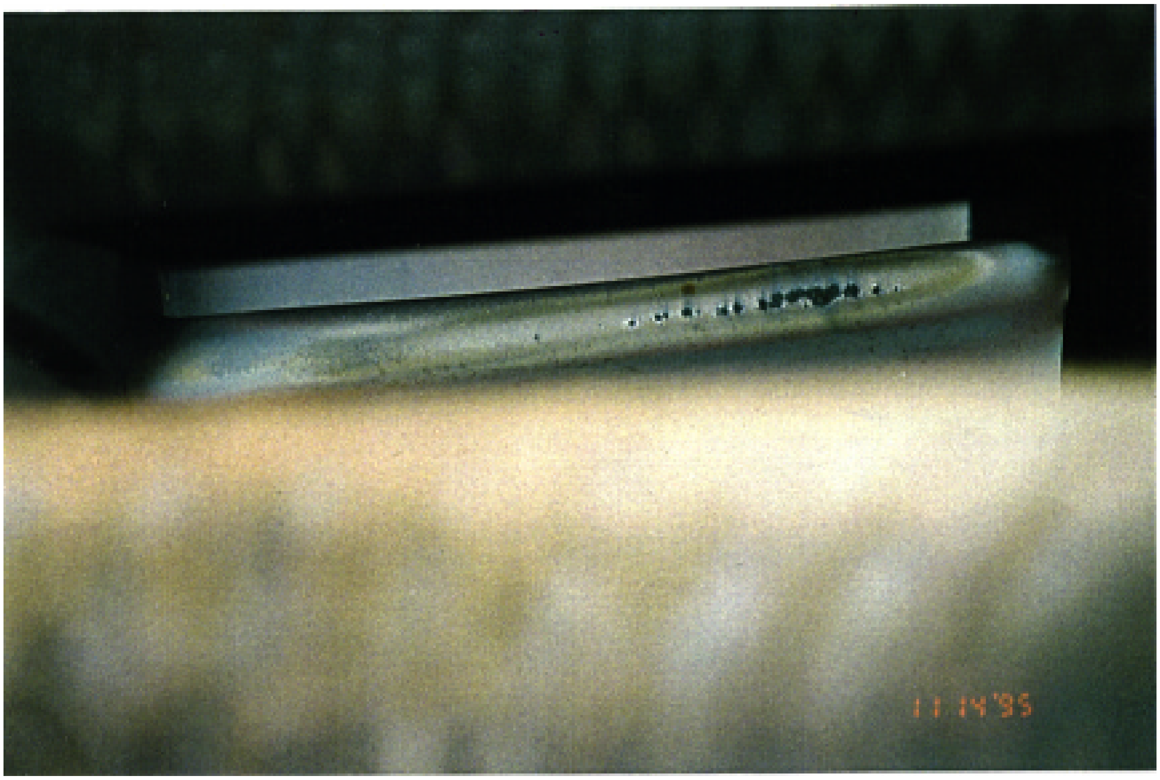
To date, impactions due to foreign object damage (FOD) have been the cause of most of the damage to, and limited the life of, hot gas parts. This has been a factor on three machines, and particularly affects the first stage parts.

1st Stage Buckets

First stage buckets are the parts most sensitive to firing temperature changes. Moderate increases in metal temperature deplete blade life more rapidly. All four machines have operated for substantial time with elevated firing temperatures (about 20°F (11.1°C) elevation at the bucket). Potential concerns the wear at the leading edges and the squealer tips.

a) Leading Edges:

The coatings have been universally protective through all 8000 hours inspections, FOD excepted. The most recent inspection of Unit 4B did show localized leading edge attack (breach and 2-10 mils (0.05-0.25 mm) metal attack) at 14264 hours. (**See Figure 8**) The higher firing temperatures certainly contributed, to his oxidation. Additionally, traces of sand-like foreign material were ingested into this machine, but the deposit pattern was not necessarily associated with the oxidation. It would imply that the coating breach life for a 2350°F (1288°C) fired machine might be somewhere between 14000 and 24000 hours, but this can only be verified by future inspections.



1st stage bucket shows localized oxidation attack has breached the coating at the leading edge.
Figure 8 Unit 4B 11/95, 14,264 hrs. 1st Stage Buckets.

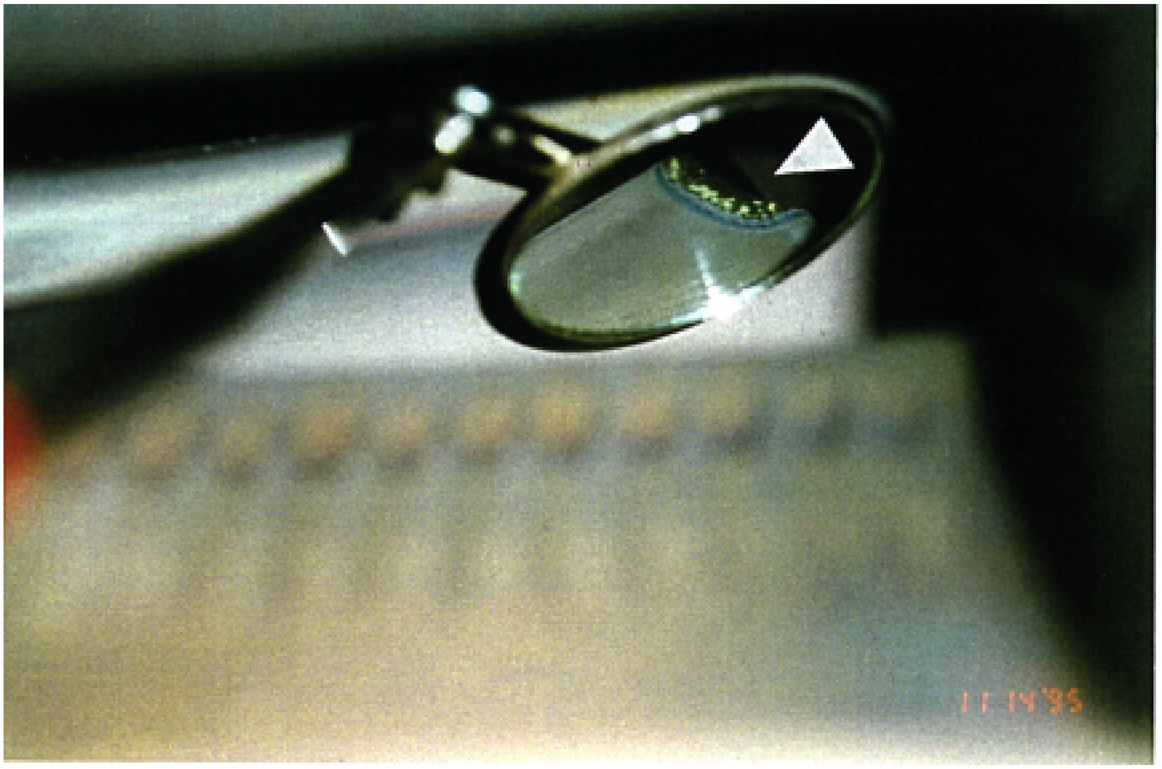
b) Squealer Tips (trailing edge):

Trailing edge tip oxidation has been noted on all MS 7221F/FA to date and appears to be almost linear with time. It removed 120-150 mils (3.05-3.81 mm) of the trailing edge tip by 14,000 hours (**See Figure 9**). It is still felt that this oxidation will be self-limiting by virtue of the nearby trailing edge cooling holes. Both the cavity floor.

The tip cavity plate oxidize original design, and the newer slotted tip design, oxidized at about the same rate.

Tip rubs varied from light, 5-20 mils (0.13-0.51 mm) to heavier, 30-60 mils (0.76-1.52 mm), and virtually all came from the shrouds at the horizontal joint. Squealer tip cracks were not significant at FP&L - they were seen in only one machine and did not go below the cavity floor.

The tip cavity plate oxidized significantly when part of the squealer tip wall was damaged by FOD. Hot combustion gases then entered that cavity.



One 1st stage bucket viewed through a mirror, shows oxidation at the tip of the trailing edge.
Figure 9 Unit 4B 11/95, 14,264 Hrs. 1st Stage Buckets.

2nd and 3rd Stage Buckets

The 2nd and 3rd stage buckets (**See Figure 10**), including the tip shrouds, appeared to be in good condition after some 14000 hours of service except for occasional impactions/FOD. The 2nd stage vane coating appear to have at least 24000 hours capability at this site. Significant parts of the 3rd stage coating (~ 25%) were no longer in place, but it may have been thin as originally installed. This, however, is of little significance at FP&L in that the coating was only applied for hot corrosion protection which has not been a factor at this site.

1st Stage Nozzles

The nozzles and the aft side thermal barrier coatings (TBC) were in good condition after some 14000 hours of service other than for any impactions/FOD. Some minor potential limitations seen to date are sidewall oxidation (**See Figure 11**) and sidewall cracking. The high time machine also had a 2.5″ (63.5 mm) crack on two vanes. All of these have been seen on the MS 7221E. It is felt that the nozzle will satisfactorily reach the 24000 hour refurbishment point

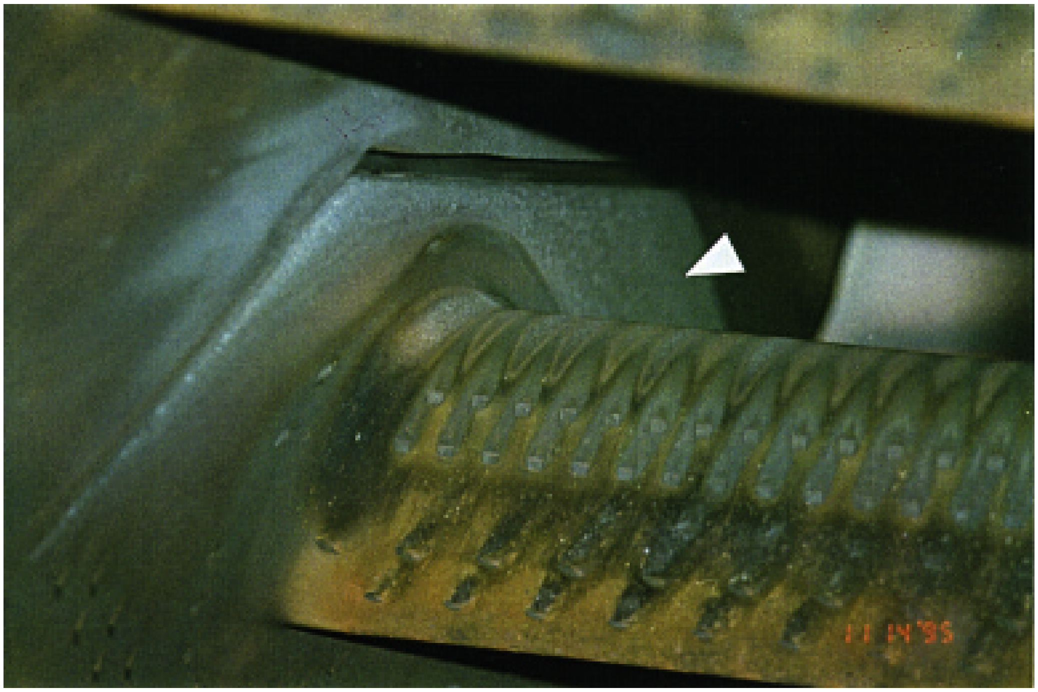
Overall view of 2nd and 3rd stage buckets.
Figure 10 Unit 3B 5/94, 4,082 hrs. 2nd and 3rd Stage Buckets.

2nd and 3rd Stage Nozzles

The nozzles appear to be in very good condition after some 14000 hours of service other than for any impactions/FOD. The 2nd stage coating should have at least 24000 hours capability at this site, the 3rd stage is uncoated.

Stationary Shrouds and Seals

First, second and third stage stationary shrouds were all in good condition in inspections up to 14000 hours and had considerably more life potential. The only exception was 1st stage shrouds. 39 of the 384 1st stage shrouds have been replaced to date - all specifically due to rubs on those that were located near the horizontal joint, and variously between 10 and 50 mils (0.254 and 1.27 mm). Rubs on the discourager, angel wing, and labyrinth seals were infrequent in inspections to 6000 hours, and were more frequent on the 2nd stage than on the 3rd stage.



First Stage Nozzle shows Significant Sidewall Oxidation.
Figure 11 Unit 4B 11/95, 14,264 hrs. lst Stage Nozzle

Combustion System

Combustion hardware, particularly with the more recent modifications, was in generally good condition and has been successfully refurbished a number of times. The coatings were still intact, the cooling holes were effective, and there generally wasn't much hardware deterioration. The areas that are more potentially limiting are distortion and wear.

Distortion (inward bulging) was seen on all liners. (**See Figure 12**) It was in identical locations near the head end and varied in maximum depth from 0.1″ - 0.8″ (2.54-20.3 mm). Distortion at the two recent 8000^+ hour inspections was similar to that in previous 4000 hour inspections, so there is a possibility it will stabilize over time.

Three liners (of the 112 liners examined) also had a crack, (**See Figure 13**) but all were in completely different locations. Although of concern, the cracks suggested isolated manufacturing problems as opposed to a generic design problem. One was at an exit end weld, one was in the body, and the other was at a cross fire tube collar weld.

Combustion liner shows typical inward bulging distortion after 9682 hours of operation. (Seen on all liners.)

Figure 12 Unit 4B 11/95, 14,264 hrs. Combustion Liner.

Combustion liner showing body crack, after 4868 hours. (Seen in one liner only).

Figure 13 Unit 4A 11/94, 4,868 hrs. Combustion Liner.

Life of the original transition pieces was limited by wear. It has virtually been eliminated in newer designs by two approaches - each of which had some potential side effects.

Two machines with wear strips had virtually no wear, but two (of the many) strips had cracks in the attachment weld. Neither caused the strip to be lost or damaged, and the cracks didn't look like they were propagating. They should be monitored because of their potential for downstream bucket damage.

One machine with FSX-414 end frames (the same alloy used for the 1st stage nozzle) had even less wear. Two of the 14 end frames, however, developed 1-2" (25.4-50.8 mm) cracks - but in completely different locations. Propagation looked as if it was very slow.

Small Impactions (< 60 mils diameter)

Many gas turbines, including some Martin machines, have small impacts on the 1st stage buckets leading edges (<60 mils or 3.048 mm diam. x 5-20 mils or 0.127-0.508 mm deep). The source of these impacts is generally not known, but comparable ones have not limited life in the earlier MS 7221E model machines. The MS 7221 FA, even though of a more sophisticated design, appears to be equally tolerant to these very small impactions. They have not grown in size or oxidized significantly with 9000 hours of additional service in one FP&L MS 7221 FA machine. This will be monitored as service time increases.

Larger Impactions/FOD (> 120 mils diameter)

There have been three instances where larger parts have gone through the FP&L machines, at least two of which were known to be failed upstream components. This has been the most significant cause of damage to date, and the only reason for removal/refurbishment of the FP&L blading so far.

The damage varied between the three machines. Unit 3A experienced small impacts on one 1st stage bucket leading edge which was left in service; Unit 3B (lost fuel nozzle tip) required that the 1st stage nozzles and buckets be removed; Unit 4A (compressor blade failure) required that essentially all three stages be removed for refurbishment. Earlier stages were generally more heavily damaged than the latter, but the reverse has occasionally happened on the MS 7221E due to ricocheting and secondary damage.

Most damaged parts were "nicked and scraped". The coating was typically breached - locally on the leading edges and the convex vane surfaces downstream of the throat. These parts were candidates for refurbishment. A few parts, however, were damaged more seriously, such as with tip loss or projectiles piercing the wall. Nozzles in this category were repairable, but buckets were more probably replaced.

Overall, the MS 7221F hot gas parts were felt to be quite robust, considering the size of some parts to which they were exposed. They may not, in fact, be markedly more sensitive to initial impact than the earlier MS 7221E parts. However, the bare metal that is exposed would oxidize more rapidly, so that the parts would have to be refurbished sooner.

Other Items of Interest in the Inspections were:

Unit 3B successfully *demonstrated peak load operation* in a one hour test in May 21, 1994, see Section 8.5. *Firing temperatures were increased 50°F (27.8°C)* (2384 to 2434°F or 1307-1334°C) and there was a *corresponding increase in the surface temperature of the 1st stage bucket leading edge of about 25-30°F (13.9-16.7°*C), as anticipated. Not all operating parameters were completely reestablished after the test, possibly by virtue of the different ambient temperatures.

Parts have generally looked very similar to each other within, and between, stages of machines with equivalent service. The only difference was the 1st stage buckets in Unit 3B, which looked slightly whiter and of a lighter hue than other buckets. This probably resulted from either the 1 hour peak load test or the loss of a fuel nozzle tip that occurred on that particular machine.

Most blade and combustion coatings have held up well so far at the Martin Station of FP&L.

Distortion of the combustion liners was originally thought to be caused by a series of severe load swings on May 21st, 1994. That, however, did not turn out to be the case because liners that have been installed subsequently had equal degrees of distortion.

1st stage bucket tip rubs were virtually all caused by rubbing with the inner shroud blocks at the horizontal joints, and less so from foreign objects that might have come downstream. The rub lips that build up on the tips are no indication as to the amount of rub - more dependable measure seems to be the degree of coating deterioration in the area close by the rub.

Some MS 6B/7E/9E machines had oxidation undercuts on the outer sidewall of the 1st stage nozzle. This has been seen on only two segments of one FP&L MS 7221 FA machine (Unit 4B, 11/95, 14,264 hours). Even there, oxidation was less than seen on the MS6B/7EA and should not limit nozzle life, but will increase the difficulty of refurbishment.

The compressor blading failure (Unit 4A, February 1995) brought out a point of interest. The compressor balding is made from GTD-450 alloy in the forward stages, and AISI 403Cb in the latter. The newer GTD-450 material was more resistant to impact damage than was the 403Cb - which has long been regarded as the tough, ductile workhouse alloy of the industry.

CONCLUSIONS AND RECOMMENDATIONS

It is recommended to continue the Turbine Manufacturer's (OEM) Maintenance Interval Schedules for the FP&L Martin Station involving hot gas path parts that have been fired at 2350°F (1288°C):

Combustion Inspection	every 8000 hours
Hot Gas Inspection	every 24000 hours
Major Inspection	every 48000 hours

It may be possible to increase the Combustion Inspection interval somewhat, in the future (Unit 4B has completed a 9624 hour interval). Also, an intermediate 4000 hour mini-Combustion Inspection should be considered if new technology hardware is introduced in to service. Quite possibly this could be done borescopically with little, or no, hardware disassembly.

Life Inspection of Parts

Estimating life of parts into the very distant future is not possible from these inspections, certainly not without destructive analyses. However, most observations were encouraging and were in concurrence with the use of the MS 7001E life table for a 2350°F (1288°C) fired FP&L MS 7221FA. The 1st stage bucket may be the most critical. It would be appropriate for GE, as OEM, to monitor these buckets. The Recommendation above shouldn't imply that all parts are perfect. Those items that might be more likely to limit eventual life are:

Impactions/FOD	From upstream pieces, and particularly to 1st stage parts.
1st Stage Buckets	Leading edge oxidation. Squealer tips - trailing edge tip oxidation, and cavity plate oxidation (when squealer walls are lost by FOD)
Combustion Liners	Distortion (inward bulging).

These items should be investigated, and monitored at future inspections.

Life of Parts and Inspection Intervals

The inspection intervals and the life of parts, currently in the machines, have been reduced because they operated at 2384°F (1307°C) firing temperatures until mid 1995. This primarily relates to the 1st stage bucket.

Destructive Evaluation

It is suggested that a program for periodic destructive evaluation of selected hot gas path parts be conducted. From a technical standpoint, this would best involve the OEM since they know the interaction between design and operating conditions. It is also suggested that any destructive analyses be done on the hottest bucket in a set as identified by pyrometer measurements. This recognizes the strong influence that operating temperature has on bucket life.

Evaluate/Implement

Evaluate/Implement the following:

Evaluate a cutback of twelve 1st stage inner shrouds at either horizontal joint (of the 92 total). The shrouds at this location have a history of rubbing, most probably due to a small distortion in the casing.

Continue inspecting future long time 1st stage buckets to determine whether the localized oxidation seen on Unit 4B (11/95, 14264 hours) was largely attributable to the higher firing temperatures and/or foreign material ingested into that machine.

Metallurgically examine the combustion liner crack recently found on Unit 4B (11/95, 14264 hours, Liner #4). Although these cracks are rare and seemingly not propagating fast, this one was next to a seam weld.

Evaluate a thermal barrier coating (TBC) for the perforated plate of the combustor end cap to minimize the mild oxidation and occasional distortion that is seen on this part. Increase the resistance of the liner to distortion (inward bulging) such as by different material, fins, etc.

The turbine manufacturer should be requested to evaluate the design/procedure for weld-attaching the wear strips on the transition piece end frames - unless the intent is to move to FSX-414 end frames. The (very few) cracks seen in these strips to date were all associated with these welds.

CONTENTS

FIGURES

Figure **Page**

Exeuctive Summary

Section

1

INTRODUCTION

The year 1990 saw the advent of a new generation of land base gas turbines - with a 300°F (166.7°C) increase in firing temperatures over previous machines. This was the "F" generation first installed as GE's MS 7001F gas turbine at Virginia Power.

The EPRI Durability Surveillance Program tracks the performance of selected machines of this new generation. This Hot Gas Path Parts Condition Assessment Guideline pertains to the GE 7F (7FA) advanced gas turbine program, and covers the four machines at Florida Power and Light's Martin Station in Indiantown, FL., as shown in Figure 1.1. These machines are notable in that they are the fleet leading MS 7221FA and DLN-2 dry low-NOx gas turbines, with a nominal 2350°F (1288°C) firing temperature in the base load mode.

The scope of this report is strictly address these FPL MS 7221FA gas turbines and, particularly, the condition of the hot gas path components over their first two years of service. Comments and observations may, or may not, apply to other sites.

All operating hours are as of November 14, 1995 unless otherwise stated, which was the date of the most recent gas turbine inspection (Unit 4B). Parts hours shown are those since they were last installed, unless otherwise indicated. The parts were new in most cases, but some (combustion parts mostly) may have been refurbished after having seen prior service in another machine.

This guideline aims to provide utility plant operators, engineers and maintenance staff the following benefits:

- An understanding of the type and frequency of planned gas turbine maintenance inspections resulting from base-load operation
- An understanding of wear phenomenon for individual hot path components such as combustors, buckets, nozzles, seals, and shrouds.

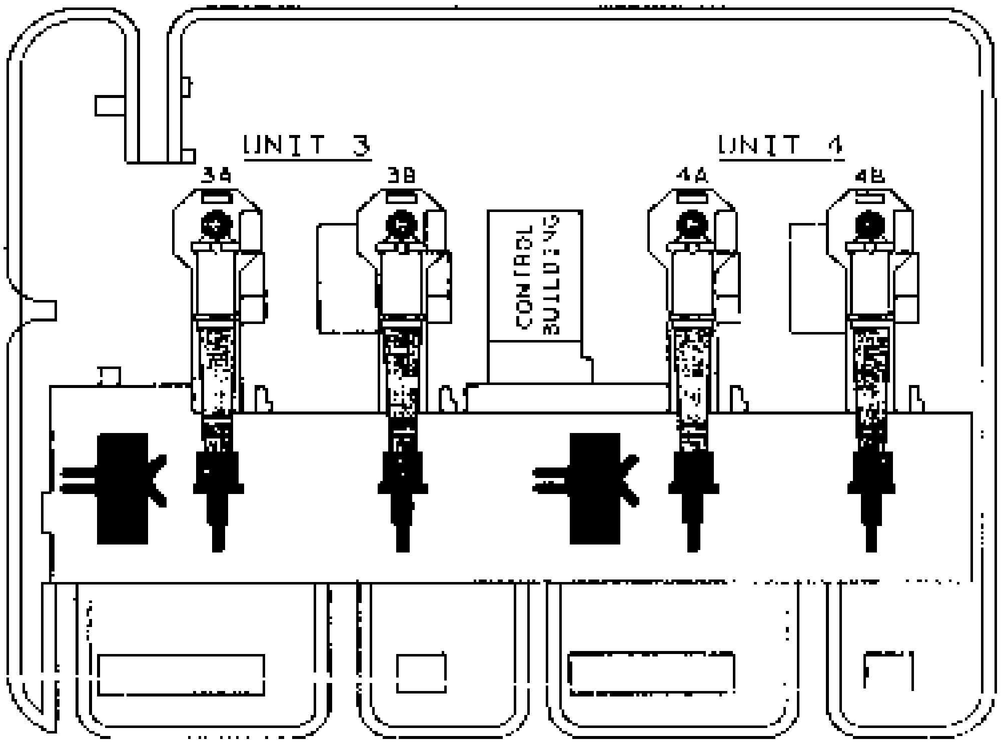


Figure 1.1 Martin Station CC Plot Plan

2

ADVANCED INDUSTRIAL GAS TURBINES

2.0 INTRODUCTION

A discussion on various features and characteristics of currently marketed advanced industrial gas turbines is presented in this section. A comparison of the key design and performance parameters for advanced gas turbines in 60 Hz and 50 Hz power generation service is provided. The GE MS7001F gas turbine was the first unit monitored by this EPRI Project. A brief description of GE MS7001F main components identifying use of the latest technological advances important from the monitoring and analysis point of view is included.

2.1 BACKGROUND OF ADVANCED INDUSTRIAL GAS TURBINES

Advanced industrial gas turbines are machines developed in the last decade with features and characteristics which take advantages of the latest technological advances. The latest gas turbine technological advances have taken place in different areas such as materials, manufacturing processes, aerodynamics, blade cooling techniques, new and powerful analytical capabilities, and better understanding of the combustion process. These technological advances in combination with increased use of the gas turbines in power generation and the dynamics of the changing and competitive power generation market has led to the development of high performance and high thermal efficiency advanced industrial gas turbines.

2.2 CURRENTLY MARKETED ADVANCED INDUSTRIAL GAS TURBINES

Tables 2.1 and **2.2** provide comparison of important design and performance parameters of advanced gas turbines marketed for the 60 Hz and 50 Hz power generation markets. Some common features of gas turbines marketed by domestic and foreign manufacturers for the 60 Hz market are the turbine inlet temperature of 2300°F (1260°C) and higher, ISO power rating on natural gas fuel of 150 -165 MW, and maximum thermal efficiency (LHV) approaching 38% as is evident from **Table 2.1**. For the 50 Hz power generation market common features of newly developed advanced gas turbines are similar to the 60 Hz machines as far as turbine inlet temperature and thermal efficiency are concerned. 50 HZ power rating on natural gas fuel ranges from 220 - 240 MW (see **Table 2.2**).

Table 2.1 Currently Marketed 60 Hz Advanced Gas Turbines

Manufacturer	ABB	GE	GE	Siemens	Siemens	Westing-house	Westing-house
Model	GT 24	MS7001F	MS7001FA	V84.3	V84.3A	501F	501G
Base Load Output, MW	165	156	159	153.5	170	163	230
TIT/RIT, °F TIT/RIT, (°C)	2255 (1235)	2300 (1260)	2350 (1288)	2120 (1160)	2390 (1310)	2462 (1350)	2600 (1427)
Heat Rate, Btu/kWh Heat Rate, (kJ/kWh)	9075 (9600)	10390 (10962)	9500 (10023)	9412 (9930)	8980 (9474)	9469 (9991)	8860 (9346)
Efficiency %, LHV	37.5	32.84	35.92	36.3	38.0	36.04	38.5
Pressure ratio	30.0	13.5	15.0	16.1	16.5	14.0	19.2
Mass Flow Rate, lbs/sec Mass Flow Rate, (kg/sec)	829 (376)	955 (433)	941 (426.8)	955 (433)	1000 454	990 (449.0)	1200 (544)
Exhaust Temperature, °F Exhaust Temperature, (°C)	1130 (610)	1100 (593)	1092 (589)	1022 (550)	1044 (562)	1076 (580)	1100 (593)
Combustor System	EV Low No_x Sequential	Quiet Combustors Can - annular	Dry Low NO_x, can-annular	Horizontal cylinder, ceramic tile liner	Hybrid burner ring	Premix lean-burn hybrid, can-annular	Dry Low NO_x, Can - annular
No. Of Combustor	2,(30, 24 Burners)	14	14	2	1,24 Burners	16	16
First Site	JCP&L	PEPCO Station H (2nd Site)	FP&L Martin Plant	Met Ed Portland Station	KCP&L		
Startup Date	4Q 1995	2Q 1992	4Q 1993	4Q 1994	Ship 1996	3Q 1993	Ship 1996

Notes:

1. *All the data presented here refers to ISO conditions.*
2. *The rated values given here are for the machines fired with the natural gas fuel.*
3. *A significant amount of data presented here is excerpted from Turbomachinery International [5] and various other sources [6-12].*

Table 2.2 - Currently Marketed 50 Hz Advanced Gas Turbines

Manufacturer	ABB	GE	Siemens	Siemens	Westing-house	Westing-house
Model	GT 26	MS9001FA	V94.3	V94.3A	701F	701G
Base Load Output, MW	240	226	222	240	235	up to 300
TIT/RIT, °F TIT/RIT, (°C)	2255 (1235)	2350 (1288)	2120 (1160)	2390 (1310)	2462 (1350)	
Heat Rate, Btu/kWh Heat Rate, (kJ/kWh)	9029 (9526)	9500 (10096)	9412 (9930)	8890 (9474)	9469 (9790)	
Efficiency %, LHV	37.8	35.66	36.3	38.0	36.78	
Pressure ratio	30.0	15.0	16.1	16.5	15.6	
Mass Flow Rate, lb/sec Mass Flow Rate, kg/s	1195 (542)	941 (614.5)	1375 (624)	1375 (624)	990 (665.0)	
Exhaust Temperature °F Exhaust Temperature (°C)	1130 (610)	1092 (589)	1022 (550)	1044 (562)	1076 (547)	
Combustor System	EV Low No_x Sequential	Dry Low Nox, can-annular	Horizontal cylinder, ceramic tile liner	Hybrid burner ring	Premix lean-burn hybrid, can-annular	Dry Low NO_x, Can - annular
No. of Combustor	2,(30, 24 Burners)	14	2	1	16	16

Notes:

1. *All the data presented here refers to ISO conditions.*
2. *The rated values given here are for the machines fired with the natural gas fuel.*
3. *A significant amount of data presented here is excerpted from Turbomachinery International [5] and various other sources [6-12].*

2.3 SPECIAL CHARACTERISTICS OF ADVANCED INDUSTRIAL GAS TURBINES

Some of the latest technological advances implemented in developing these machines as compared to their predecessors designs, which were mostly uprated from the then existing designs, are the following:

- Developments in the areas of materials and manufacturing processes which resulted in higher strength alloys, improved high temperature coatings, and higher quality components.
- Better understanding in the areas of aerodynamics, fluid flows and heat transfer in combination with the advances in structural and dynamic analysis and powerful computational analytical tools have contributed to significant improvements in the design phase of these machines.
- Better understanding of the combustion process has significantly improved the emissions associated with the higher firing temperatures.
- Improved cooling techniques for hot gas path components is an important contributing factor in the development of advanced gas turbines with the turbine inlet temperature of 2300°F (1260°C) and higher.

2.4 GENERAL ELECTRIC MS7001F ADVANCED GAS TURBINE

The features and characteristics of key components of the MS7001F gas turbine are briefly discussed in this section. The MS7001F is the first of a new generation of advanced industrial gas turbines incorporating the latest advances in aircraft engine technology [6,7,9]. **Figure 2.1** shows a cross-sectional view of the gas turbine identifying its main components. The firing temperature, measured at the trailing edge of the first stage nozzle, also referred as the rotor (turbine) inlet temperature, has been raised to 2300°F (1260°C) compared to 2020°F (1104.4°C) for its predecessor MS7001EA. Also, hot gases upstream of the nozzle are close to 2580°F (1415.6°C). The initial (introductory) simple cycle ISO rating on natural gas fuel was 135.7 MW with a heat rate of 10,390 Btu/kWh (10960 kJ/kWh) at a firing temperature of 2300°F (1260°C) and an airflow rate of 900 Lb/sec (408.2 kg/sec) [6]. The ISO rating of a more matured gas turbine in simple cycle mode is given in **Table 2.1**. In a departure from GE design practice for heavy-duty industrial gas turbines, the MS7001F output shaft is at the compressor-end (such a unit is called, “cold-end” drive) of the turbine to allow for an axial exhaust thus minimizing exhaust back pressure losses, as well as alignment problems associated with "hot end" drives.

2.4.1 Rotor-Bearing System The MS7001F consists of a single rotor of bolted disk construction supported by two bearings, a design commonly used by GE in low power rating machines (MS5001 and MS6001). By eliminating the midbearing, compared to its predecessor MS7001EA, better accessibility to the combustion system components, simpler construction, and midbearing's maintenance could be achieved for MS7001F.

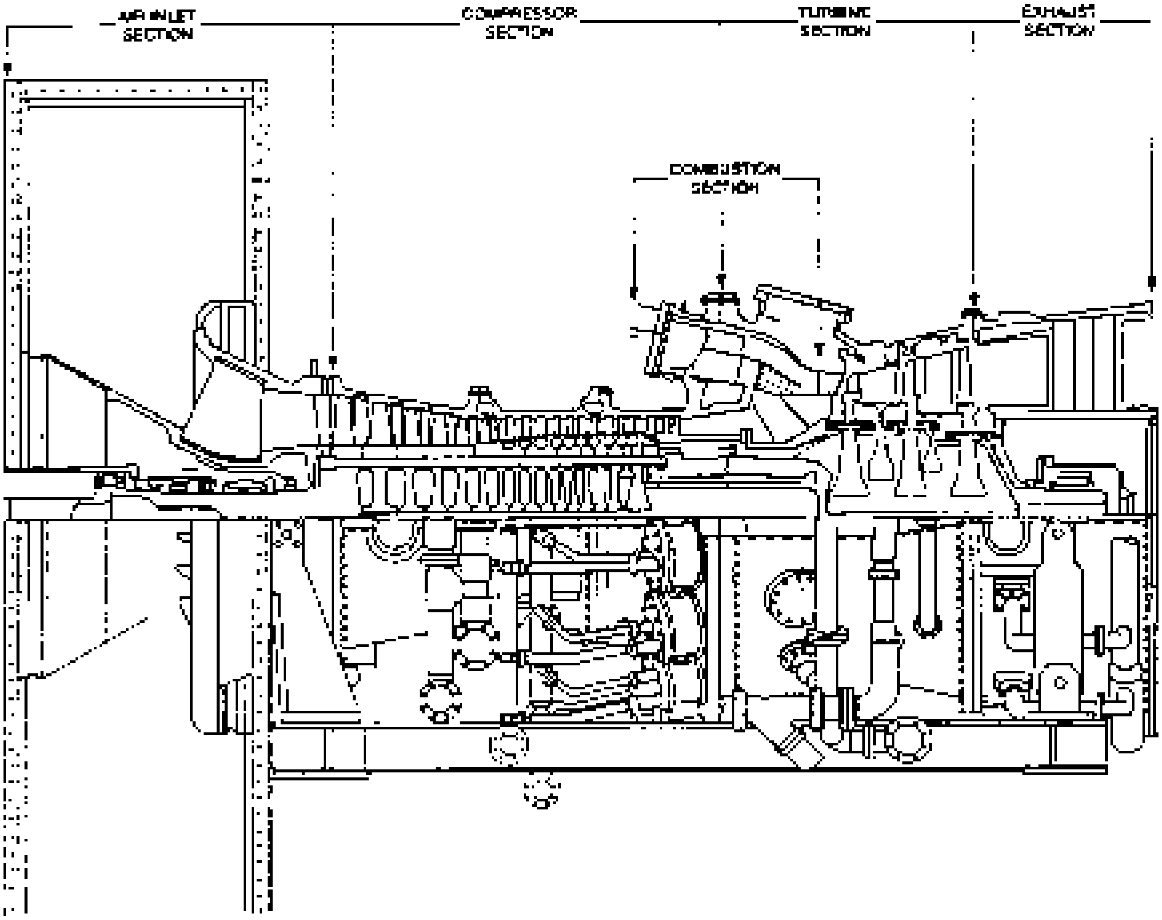


Figure 2.1 Cross-Sectional View GE MS7001F Gas Turbine [13]

Furthermore, this construction is estimated to provide higher critical speed, a critical speed margin in excess of 20% with respect to the synchronous speed, and a better unbalance response for the rotor-bearing system than the other two-bearing gas turbines produced earlier by GE.

2.4.2 Compressor The compressor is an 18 stage axial flow, low stage loading, and bolted disk design with a pressure ratio of 13.5 and provision for extractions at stages 5 and 13. It is a scaled up version of the 17 stage MS7001E, but with an additional zero stage and increased annulus area. The first two stages, stages 0 and 1, have been designed for operation in the transonic flow regime. This redesign of the first two stages resulted in an increase in the surge margin compared to its predecessor. The compressor contains three exit guide vane rows to straighten the flow entering the compressor diffuser to enhance its performance. Surge control of the compressor is accomplished through variable inlet guide vanes (IGVs) and selective bleed at the 13th stage: During start-up of the unit, the IGVs are kept at their minimum setting and then they are controlled along a prescribed schedule as a function of the corrected speed as the unit accelerates. At 100% speed, the IGVs are fully open for simple cycle applications. For combined cycle applications, IGVs are set at an intermediate position during a start-up and then open as a function of the load and the exhaust gas temperature to maintain the maximum thermal efficiency. The 13th stage bleed valve is kept in the closed position during the start-up.

Higher strength alloys have been used because of increased blade stresses caused due to the increase in the compressor's outer diameter. Custom 450 stainless steel is used for IGVs and stages 0 through 8, ANSI with columbium is used in stages 9 through the exit guide vanes.

2.4.3 Combustion System The combustion system has 14 combustors and six fuel nozzles compared to 10 combustors with a single fuel nozzle design in its predecessor MS7001EA. Each combustion chamber contains a fuel assembly, liner, and a transition piece. Also liners in MS7001F are of same diameter (14 inches), but are shorter and of heavier (30% thicker) construction compared to its predecessor. The multi-fuel nozzle design has helped in dramatic reductions in combustion noise (dynamic pressure) and combustion system wear with corresponding increase in the combustion inspection intervals and the combustion system life. Flame is initiated by igniters in two of the combustion chambers, and propagated into the remaining chambers by means of the cross-fire tubes. The walls of the liners are slotted for cooling and lined with a ceramic barrier for additional thermal isolation. Each transition piece consists of two major assemblies. The inner flow ducting assembly is cooled by an outer impingement sleeve of the same general shape. The impingement sleeve is fabricated of AISI-304 stainless steel, the transition piece body of Nimonic 263 and the aft frame of cast FSX-414. The liners are constructed of Hastelloy-x with the addition of HS-188 in the lower portion with the thermal barrier coating to the internal surfaces. These additions provide improved high-temperature strength, reduction of metal temperatures and the thermal gradient.

2.4.4 Turbine The three stage turbine with low degree of reaction has a new aerodynamic design with zero exit swirl at full load and a moderate exit Mach number. The use of advanced cooling methods, in combination with improved materials and effective corrosion protective coatings have allowed higher firing temperature. Each of the three rotor stages consists of 92 investment- cast blades (also, termed buckets) made out of GTD-111, with the first stage blade unshrouded and the second and third stage blades equipped with the integral 'Z' shape tip shrouds. To further enhance the hot corrosion and oxidation resistance properties of GTD-111, blades of all the three stages are coated. The first and the second stage blades are coated with the alloy of Co, Cr, Al and Y using PLASMAGUARD low pressure Plasma spray method and followed by an aluminide overcoat. The third stage blades are coated with a high Cr coating followed by a diffusion heat treatment. The first stage nozzle is made from investment-cast FSX-414 segments and the second and third stage nozzles are made of investment-cast GTD-222 segments.

The first stage nozzles and the first and the second stage blades are air cooled through internal cooling circuits using compressor discharge air and 17th stage bleed air. The second and the third stage nozzles are cooled through external cooling circuits using the 13th stage bleed air. The first stage blades are convectively cooled via serpentine passages with turbulence promoters, a proven technology used in advanced aircraft engines. The cooling air leaves the blade through holes in the tip as well as in its trailing edge. The second stage blade is cooled by convective heat transfer with all the cooling air exiting through the blade's tip.

The first stage nozzle is cooled by a combination of film, impingement, and convective cooling methods. The second stage nozzle is cooled using impingement and convective cooling techniques, whereas, the third stage nozzle is un-cooled. The combination of high blade metal temperature and the high temperature of the cooling air can lead to corrosion of the internal cooling passages. For this reason, the internal cooling passages are also coated with the PLASMAGUARD GT-29 IN-PLUS.

2.5 SUMMARY OF FIRST APPLICATIONS FOR 60 HZ ADVANCED INDUSTRIAL GAS TURBINES

This section provides locations where the first unit of manufacturers' 60 Hz advanced gas turbines have been installed.

Manufacturer	**First US Site Start-Up Date Combustion System**	**Turbine Inlet Temp. °F**	***Installed*** **60 Hertz Model ISO Rating MW**	***Comparable*** **50 Hertz Model ISO Rating MW**
ABB	JCP&L Gilbert Station 4Q 1995 25 ppmvd NOx on Nat. Gas EV / SEV Dry NO_x	2250°F** (1232.2°C)	GT24 165 MW	GT26 240 MW
GE	FP&L Martin Station 4Q 1993 /1Q 1994 25 ppmvd NO_x on Nat. Gas Dry Low NO_x (DLN25)	2350°F (1287.8°C)	Frame 7FA 159 MW	Frame 9FA 226.5 MW
	Sierra Pacific Ship Unknown 25 ppmvd NO_x on Nat. Gas Dry Low NO_x (DLN25)	2350°F (1287.8°C)	Frame 6FA 70 MW	
Siemens	Met. Ed. Portland Station 4Q 1994 25 ppmvd NO_x on Nat. Gas in premix	2350°F** (1287.8°C)	V84.3 152 MW	V94.3* 219 MW
	KCP&L Kansas City, Missouri Ship 1996 25 ppmvd NO_x on Nat. Gas in premix`	2390°F (1310°C)	V84.3A 170 MW	V94.3A 240 MW
West./MHI	FP&L Lauderdale Station 3Q 1993 25 ppmvd NO_x on Nat. Gas with Steam Inj.	2300°F (1260°C)	W501F 185 MW *	
	Seminole, FL 1997 9 ppmvd NOx on Nat. Gas, Dry NO_x	2330°F (1276.7°C)	W501F 145 MW	W701F 227 MW *(9 in operation in Japan)*
	Site Unknown Ship 1996 Emission Guar. less than 25 ppmvd Nat. Gas, Dry	2600°F (1426.7°C)	W501G 230	

* Water or Steam Injection Required.

** ABB and Siemens specify ISO equivalent turbine inlet temperature.

Note: The figures on the following Pages are the respective manufacturer's illustrations.

2.6 ABB GT 24

The GT 24 is a reheat gas turbine with two stages of annular combustors. The sequential combustion is performed in the 1st EV combustor followed by expansion in the turbine first stage and 2nd combustion in the SEV (Sequential Environmental) self igniting combustor and 4 stage turbine. The high pressure ratio ($P_r = 30$) compressor supports the sequential combustion which allows high simple cycle efficiency of 37.5 % and gross heat rate of 9,100 BTU, LHV/kWh. The sequential combustor controls NO_x to 25 ppmvd without water or steam injection on natural gas.

The Figures below show the engine and the combustor concepts.

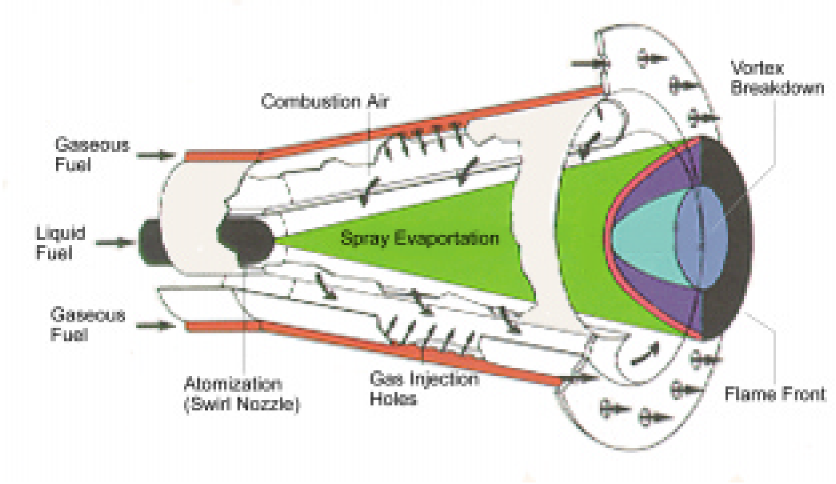
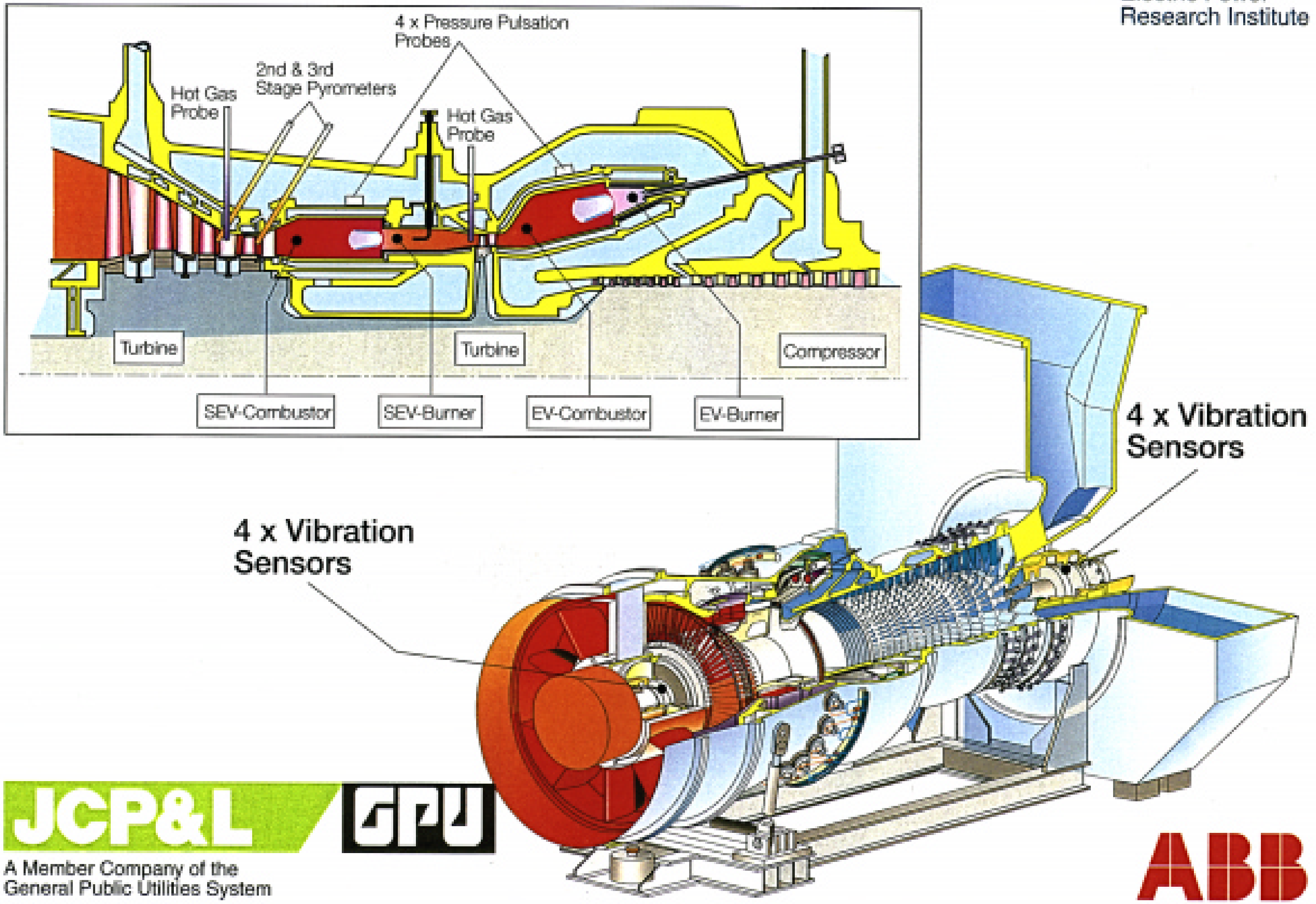


ABB EV Burner Design: Dual Fuel Double Cone Burner

The EV-burner

GT24 Durability Surveillance Instrumentation
JCP&L Gilbert Station CT#9

EPRI
Electric Power
Research Institute

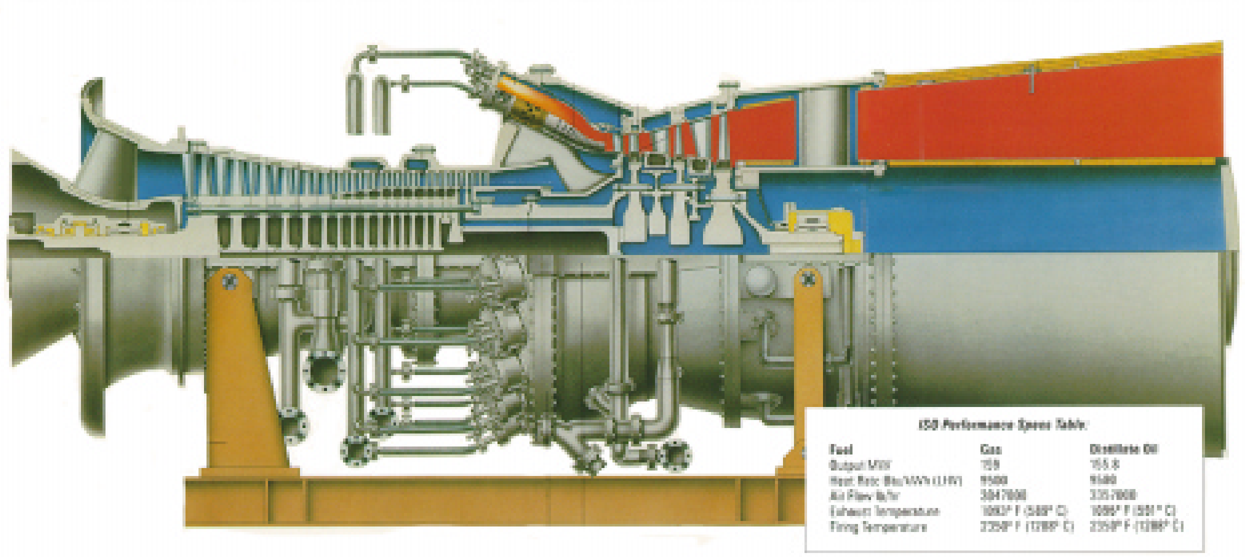


JCP&L GPU
A Member Company of the
General Public Utilities System

ABB

2.7 GENERAL ELECTRIC MS 7221 FA

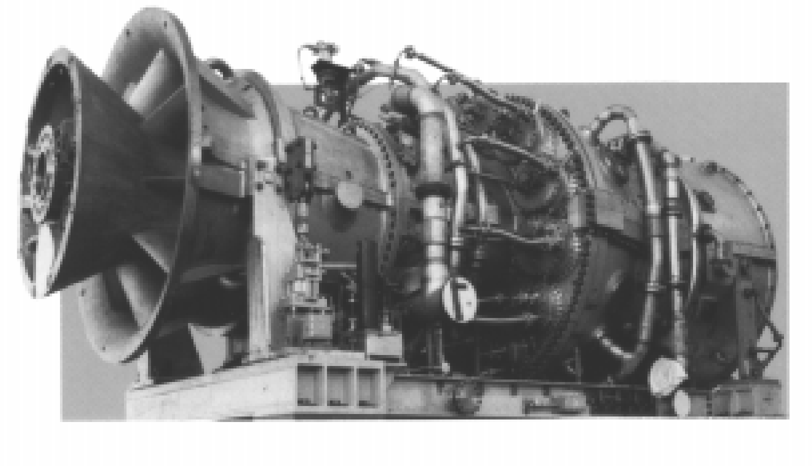
The MS 7221FA is the uprated version of the of the MS 7001 F with a 2350°F (1287.8°C) turbine inlet temperature, which is 50°F (10°C) higher than the 7F. The intense cooling of the 1st and 2nd turbine stages coupled with the Directionally Solidified and coated nickel based superalloy GTD-111 for 1st stage buckets permits operation at high firing temperature and results in increased output and efficiency (heat rate of 9500 BTU/kwh (10021.1 kJ/kWh)). The DLN25 combustion system operates on lean premix basis and allows presently NO_x control to 25 ppmvd, with the goal of 9ppm.



ISO Performance Specs Table:

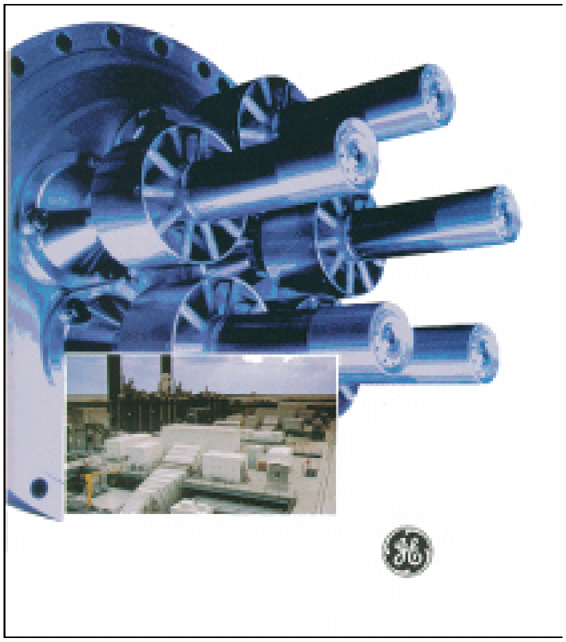
Fuel	Gas	Distillate Oil
Output MW	159	155.8
Heat Rate Btu/kWh (LHV)	9500	9580
Air Flow lb/hr	3847000	3357000
Exhaust Temperature	1093° F (588° C)	1096° F (591° C)
Firing Temperature	2350° F (1288° C)	2350° F (1288° C)

General Electric 7221FA

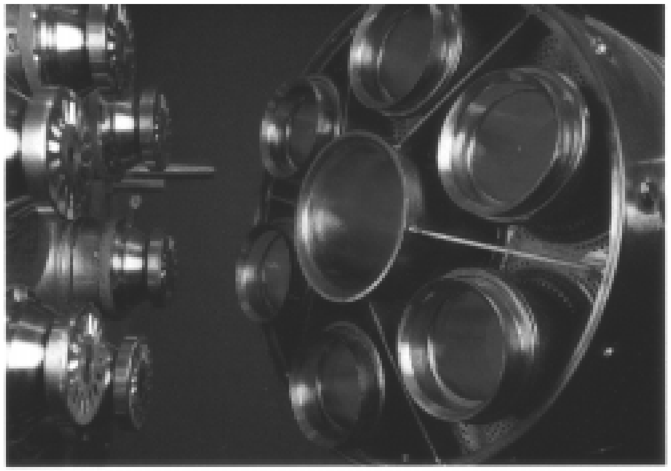


7FA Thermal Block

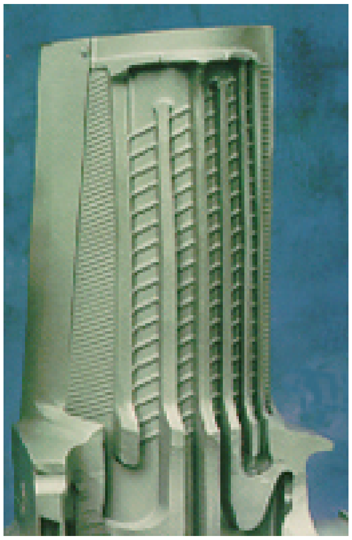
General Electric MS7221FA (cont.)



GE Dry Low NO$_x$ Combustor



7F Combustors

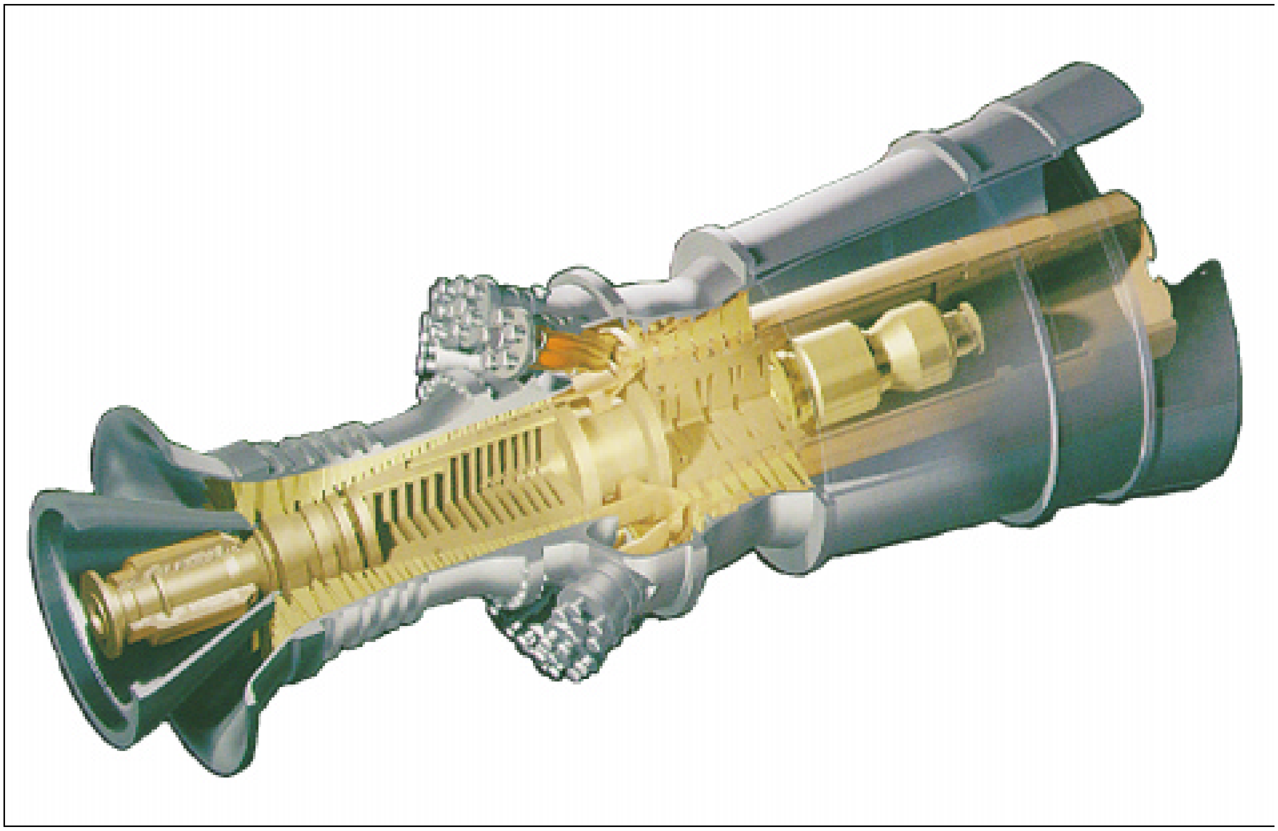


F Technology
1st Stage Bucket

2.8 GENERAL ELECTRIC “G” and “H” TECHNOLOGY

In May 1995 General Electric introduced the G and H platform of the new GE family of advanced gas turbines. The H rating is designed to reach the threshold of 60% net efficiency (LHV) in combined cycle. GE is presenting the synergy of revolutionary new concepts coupled with the designs proven in land based and aero engine service.

A major new concept is the closed loop steam cooling of the turbine section components, which improves the efficiency of the gas turbine section. This steam/heat is transferred to the combined cycle, which improves the overall combined cycle efficiency.



General Electric MS9001H Advanced Gas Turbine

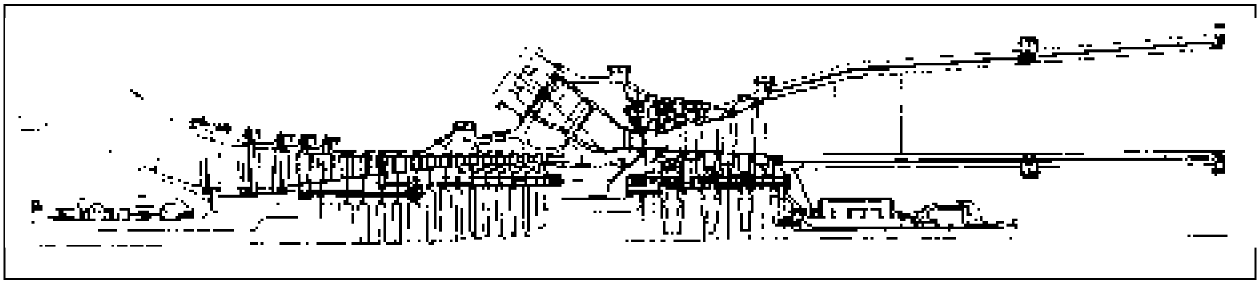
Both G and H gas turbines use an increased firing temperature of 2600°F (1426.7°C). G rating uses open loop, air cooling for the 1st and 2nd stage nozzles and vanes. H rating is an integrated combined cycle which will replace the air cooling of these components with closed loop, steam cooling circuits.

The H class turbines will be tested in 1997, beginning with the MS 9001H and followed by other H and G models.

H Class Gas Turbine Combined Cycle

In order to increase the efficiency and the specific output GE decided to increase the firing temperature from the FA rating at 2,350°F to 2,600°F (1287.8°C to 1426.8°C) for the G and H class. Since this temperature increase has adverse effect on emissions, hot parts life, maintenance costs and nozzle and bucket cooling air requirements, GE used the following means to counter these effects:

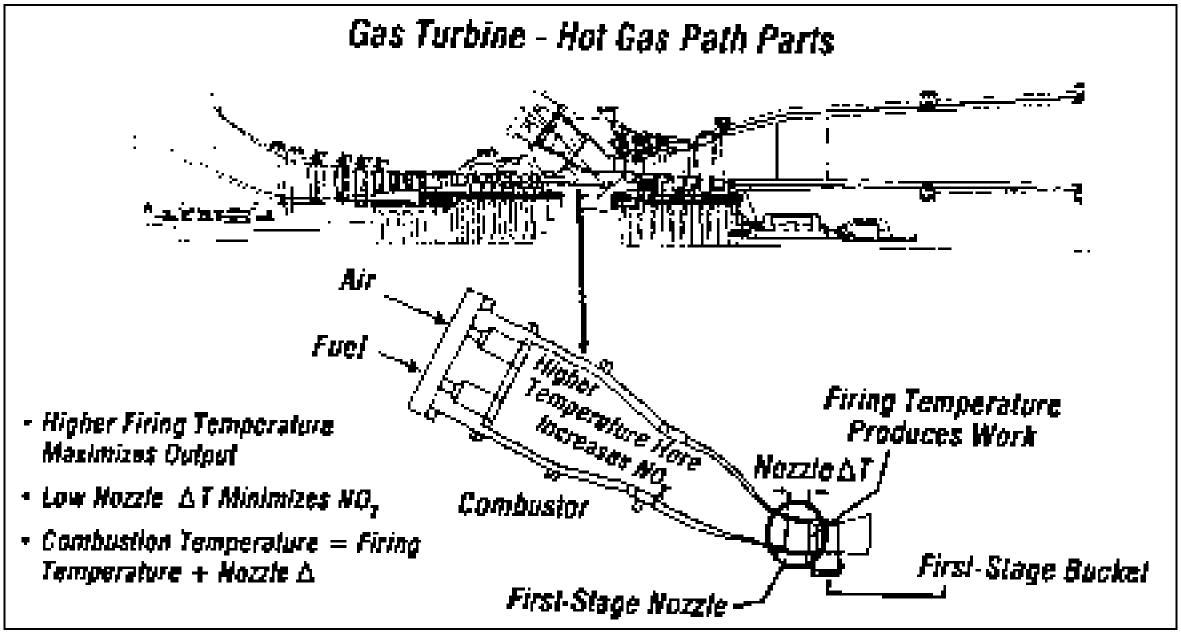
- In the H class, GE changed the conventional open loop nozzle cooling (air) system to closed loop, steam cooling circuit. Steam is used from the combined cycle steam turbine to cool the first and second stage nozzles and buckets and returns this heated steam to the steam cycle. Thus the cooling air does not penalize gas turbine performance, since the cooling steam transfers gas turbine cooling energy to the steam cycle.
- Increased the pressure ratio to 23 (from 16) to allow high power density
- Correspondingly increased the three stage turbine to four stage turbine
- Used the modified DLN-2 premix combustion to reach 9ppm NO_x
- Uses 4 variable stator vanes in the compressor for part load control



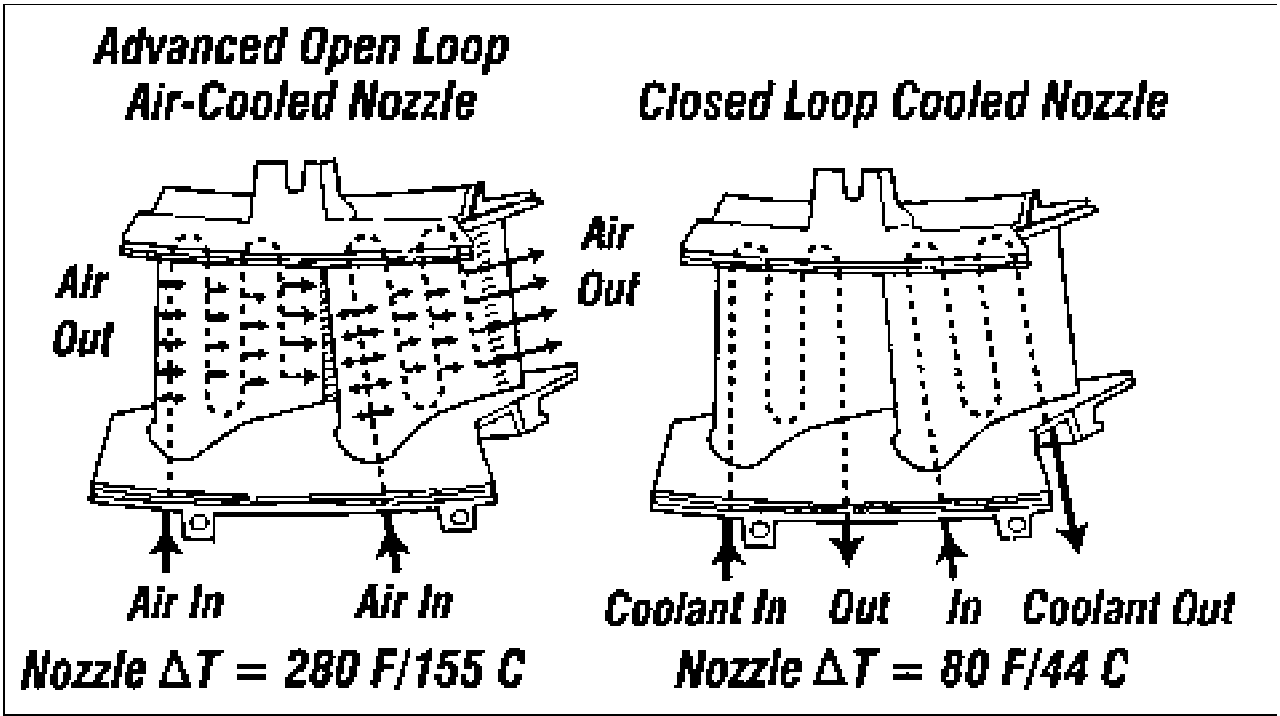
Cross-section of H gas turbine

Turbine Design

The key in reducing the combustor temperatures while increasing the firing temperature (before the 1st bucket) is achieved by using the DLN-2 modified premixed combustors. This combustor design facilitates low combustor temperature, similar to the FA combustor exit temperatures.



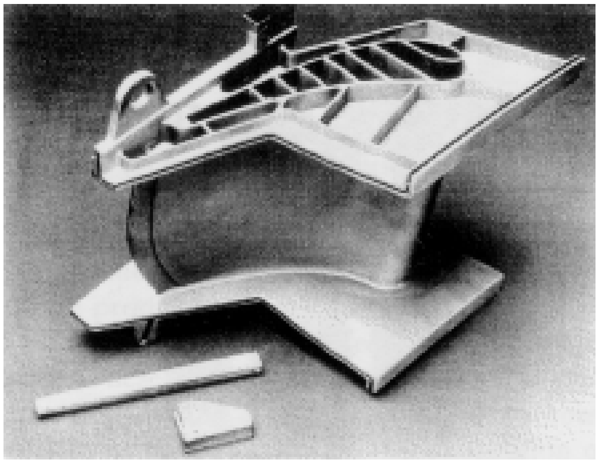
Relationship - combustion temperature to firing temperature



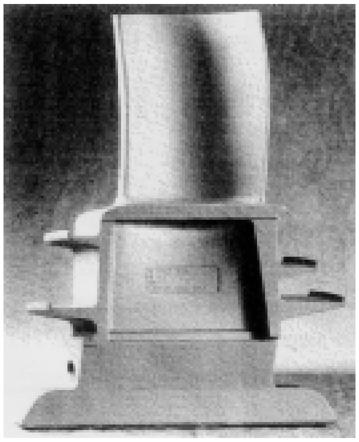
Impact of stage one nozzle cooling method

By improving the cooling of the 1st stage nozzle (using steam) and eliminating the open loop cooling air which presently mixes with the gas stream and results in the nozzle temperature drop of 280°F (137.8°C), the closed loop cooling steam will not mix with combustion gas and the temperature drop across the 1st stage nozzle will be only 80ºF

Consequently the firing temperature (defined by GE as the temperature before the 1st bucket) will increase by 200ºF (280-80=200ºF) (93.3°C), assuming the same combustor exit temperature.



H First Stage Nozzle - Single Crystal



H First Stage Bucket - Single Crystal

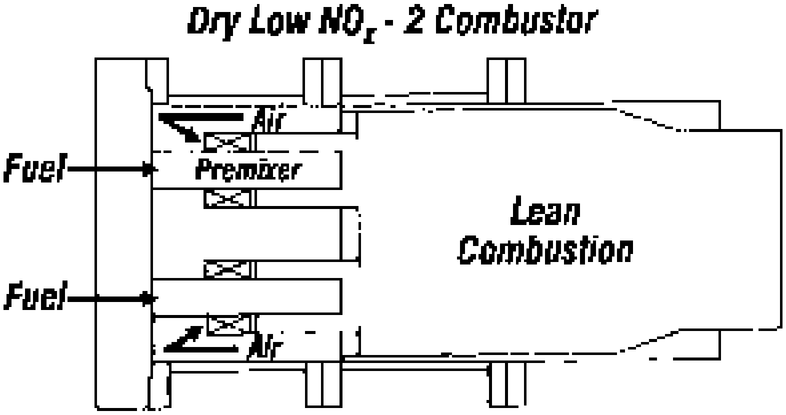
The 4 stage turbine is cooled in 1st and 2nd nozzles and buckets and 1st stage shroud. The 1st nozzles and buckets are made of GE N5 single crystal superalloy materials coated with TBC. This TBC and steam cooling combination will result in lower bulk metal bucket temperatures in the H rating than in the current FA engines.

Compressor Design

The aero compressor from the CF6-80 turboengine was scaled to 9H compressor. The 7H compressor will be scaled from the 9H compressor. Subscale compressor was built and tested to prove the performance. Four variable stator vanes will provide part load efficiency.

Combustor Design

Modified DLN-2 combustors will be used to limit the H class emissions to 9ppm NO_x. By effectively premixing the natural gas fuel and the combustion air, the combustor temperature will be the similar to the current FA rated combustors. The steam cooled nozzle also contributes to lower NO_x since the increased output is achieved without increase in combustor temperature (which would increase the production of thermal No_x).



Dry Low NO_x - 2 combustion - combustor configuration

14 cans will be used for the 9H and 12 identical combustors will be used 7H GTCC. These combustors will be validated by a full scale combustor rig tests.

Operation

One hour hot start, two hour warm start and three hour cold start are designed to meet diverse operating requirements, which include daily starts and stops, load following according to dispatch and base load operation.

Class G Gas Turbines 7G and 9G - 58% CC, 39.5 sc efficiencies

The G class gas turbine will use the air cooling system as used in the FA engines, but with a higher firing temperature of 2600ºF (1430°C). The G engines will operate also in simple cycle and will be upgradable to the H rating by the steam cooling retrofit.

H TECHNOLOGY PERFORMANCE CHARACTERISTICS (60Hz)

	7FA	**7G**	**7H**
Firing Temperature Class, ºF (ºC)	2350 (1300)	2600 (1430)	2600 (1430)
Air Flow, lb/sec (kg/sec)	974 (442)	1230 (558)	1230 (558)
Pressure Ratio	15	23	23
Specific Work, MW/lb/sec (MW/kg/sec)	.26 (.57)	.28 (.63)	.33 (.72)
Simple Cycle Output, MW	168	240	-
Efficiency, %	55	58	-
Combined Cycle Output, MW	253	350	400
Efficiency, %	55	58	60
No_x (ppmvd at 15% O_2)	9	25	9

H TECHNOLOGY PERFORMANCE CHARATERISITICS (50Hz)

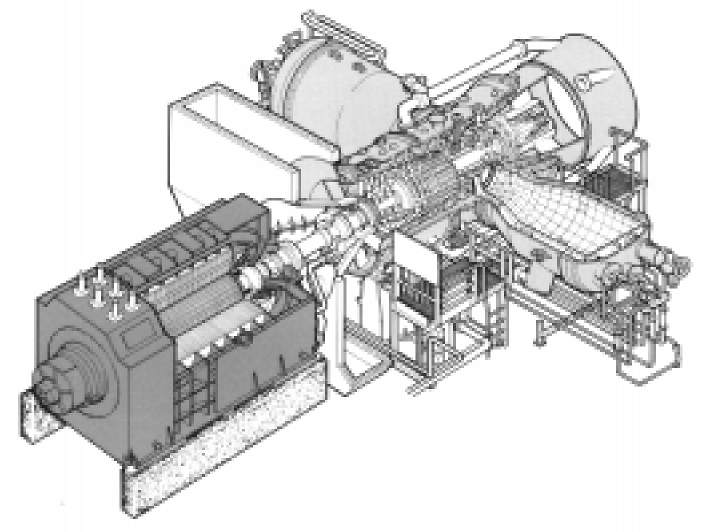
	9FA	**9G**	**9H**
Firing Temperature Class, ºF (ºC)	2350 (1300)	2600 (1430)	2600 (1430)
Air Flow, lb/sec (kg/sec)	1327 (602)	1510 (685)	1510 (685)
Pressure Ratio	15	23	23
Specific Work, MW/lb/sec (MW/kg/sec)	.26 (.57)	.28 (.61)	.32 (.70)
Simple Cycle Output, MW	226	282	-
Efficiency, %	36	39.5	-
Combined Cycle Output, MW	349	420	480
Efficiency, %	55	58	60
No_x (ppmvd at 15% O_2)	25	25	25

Comparison of GE H Technology Family

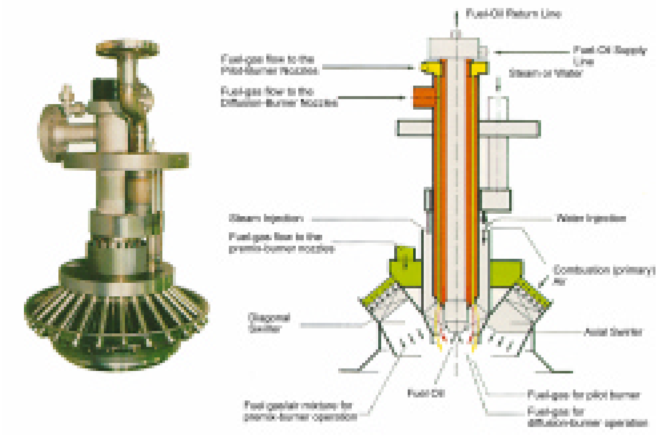
Reference: ***Corman, James C., Paul, Thomas C, Power Systems for the 21st Century "H" Gas Turbine Combined Cycles, General Electric Technical Paper - GER-3935, 1995 GE +Power Systems.***

2.9 SIEMENS ADVANCED GAS TURBINES

2.9.1 Siemens V84.3 The V 84.3 is advanced gas turbine with a firing temperature of 2350°F (1287.8°C). Two horizontal, silo type combustors are equipped each with 8 burners which operate in the lean premix mode for dry control of NO_x emissions expected at 25 ppmvd on natural gas. The access to the hot gas path is via the two combustors, which allows visual inspection of the first stage vanes and blades. The 152 MW machine has 9450 Btu/kWh (9968.4 kJ/kWh) heat rate.



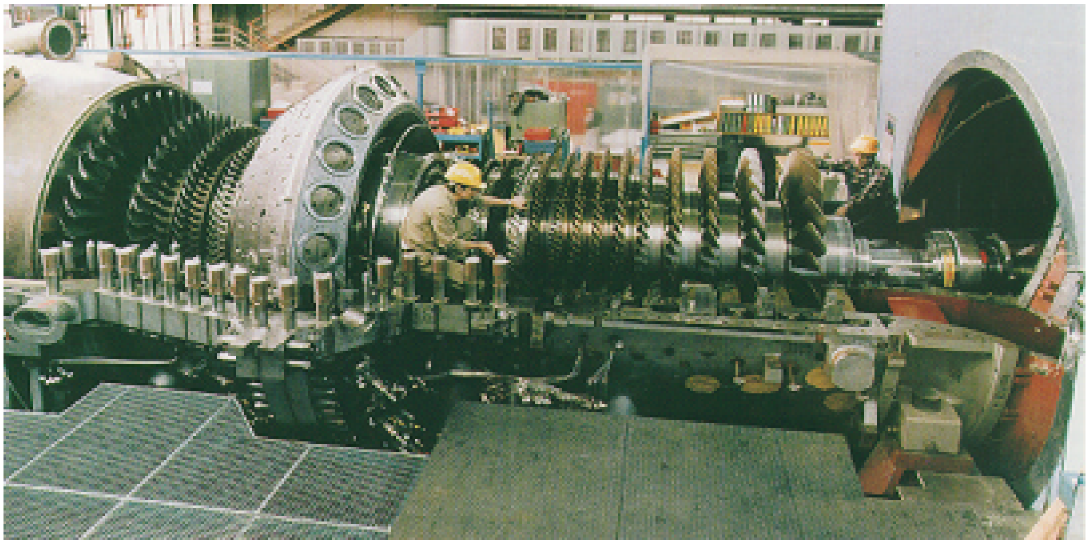
Siemens V84.3 Advanced Gas Turbine



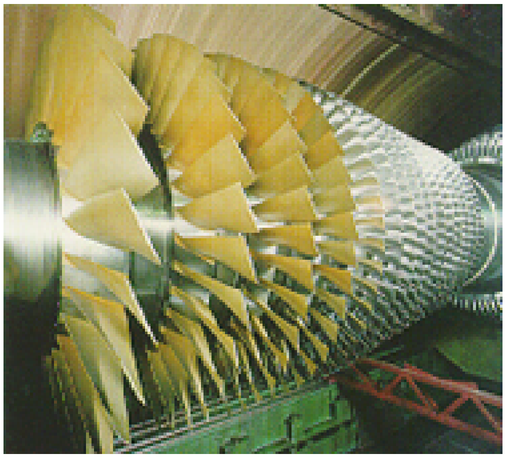
Siemens Hybrid Burner (Model)

2.9.2 Siemens V84.3A The V84.3A utilizes advances in the aero-engine technology in the heavy duty design to increase the efficiency and output. of the engine. Based on designs from Pratt and Whitney, Siemens developed new aerodynamic blading designs, blade cooling and used new blade manufacturing and coating methods, which allowed them to increase the turbine inlet temperature to 2390°F (1310°C).

Such inlet temperature coupled with the advanced compressor design yields simple cycle thermal efficiency of 38%, LHV Heat rate of 8980 Btu/kWh (9472.6 kJ/kWh) and output of 170 MW for the V84.3A. Exhaust flow is 1000 lb/sec (453.6 kg/sec) and emissions are less than 25 ppm NO_x.



Siemens V84.3A Prototype

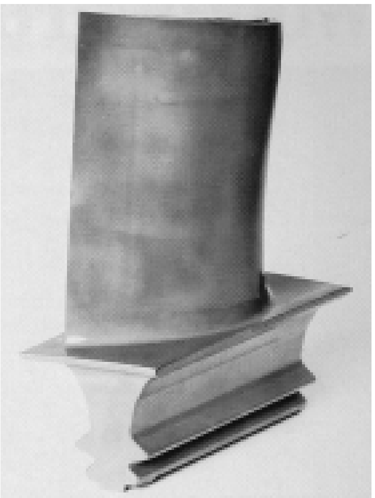


Rotor with Compressor Blading

Rotating Turbine Blades

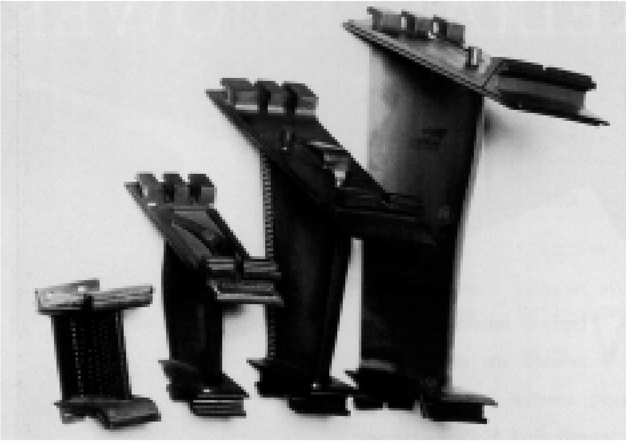
Siemens V84.3A (cont.)

This performance is mainly achieved by advances in new blade materials. The first and second stage rotating blades are made of **single crystal (SC) superalloys**, which allow 85 ºF (29.4°C) higher operating temperature than the Directionally Solidified (DS) blades and 130 ºF (54.4°C) higher than the conventional equiaxed superalloys without additional cooling air. The low cooling air requirement also improves cycle performance.



V84.3A First Stage Blade Casting

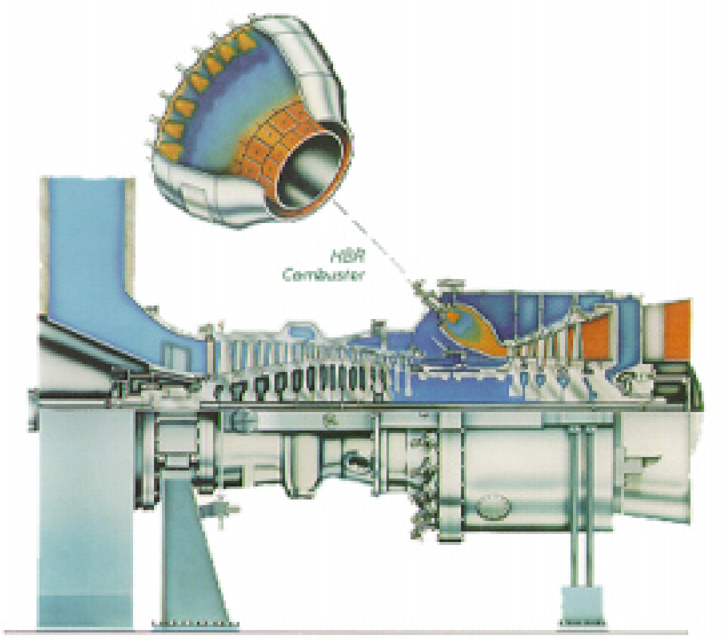
All four (4) vane rows are cooled. The first stage vanes are coated with **thermal barrier coating (TBC)**, which reduce the airfoil metal temperatures (of cooled airfoils) by 230 ºF (110°C). The two layer TBC coat consist of the bond coat of MCrAlY and outer ceramic layer of ZrO_2 (Zirconia).



V84.3A Stationary Vanes Stages One Through Four

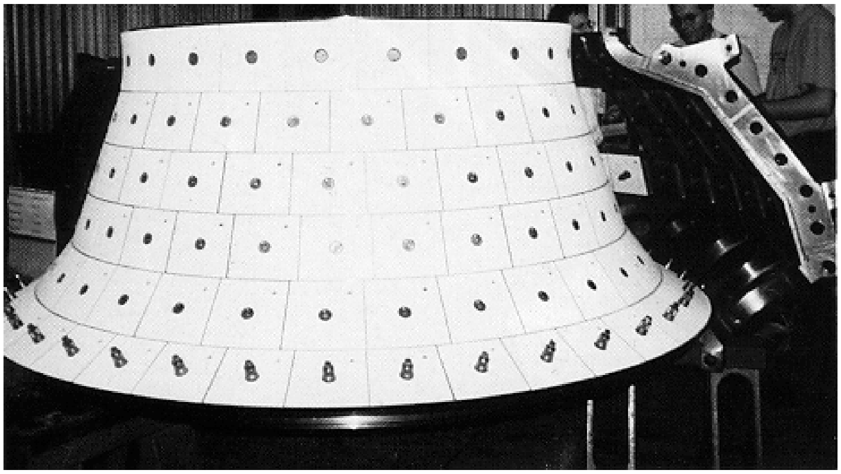
Siemens V84.3A (cont.)

Siemens also developed the annular combustor concept called the Hybrid Burner Ring (HBR) combustor. The HBR uses the premix burners from previous designs and installs 24 of them in the HBR. This design results in low residence time yielding low NOx emissions and low combustor cooling air demand which yields high efficiency.



V84.3 Cross-Section showing Hybrid Burner Ring

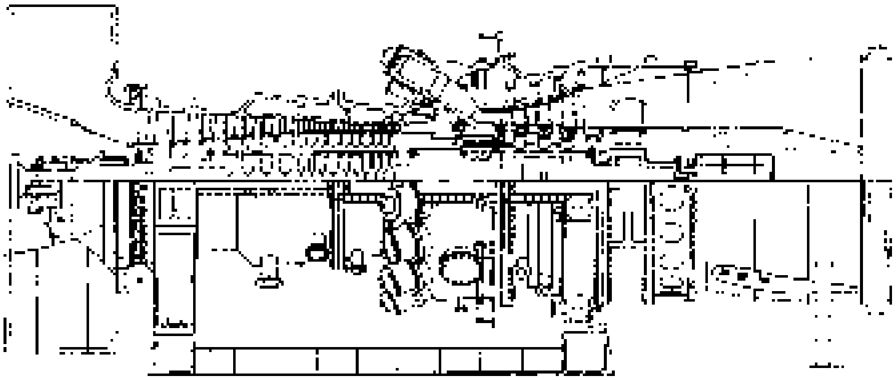
The HBR combustor features 24 hybrid low NO_x burners. Individually replaceable tiles (shown below) are used to reduce the thermal stress in the combustor.



Hybrid Burner Ring (Inside) showing burners

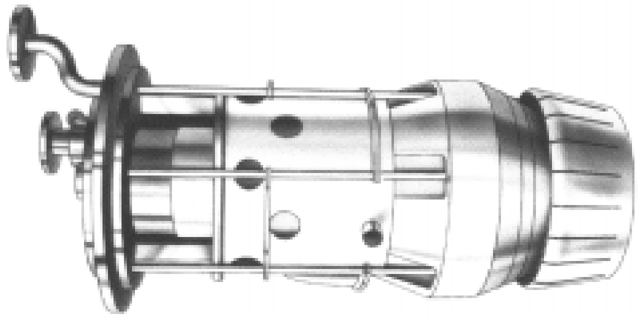
2.10 WESTINGHOUSE ADVANCED GAS TURBINES

2.10.1 Westinghouse 501F The 501F advanced gas turbine is equipped with 16 can-annular combustors each equipped with 8 burners. The 2300°F (1260°C) TIT is supported by intensive cooling and advanced materials. Directionally Solidified nickel based superalloy is used in the first stage rotating blades. The dry (no injection) rating is 157 MW unit with 9590 Btu/kWh (10116 kJ/kWh) heat rate. The latest development in Dry NO_x control reached NO_x below 25 ppm. It is performed in the lean premix burners equipped with the air bypass valve on each combustor, which controls the air flow to the combustion zone during low speed, low flow condition. Similar design is used for the 701F gas turbine design for the 50Hz grid.



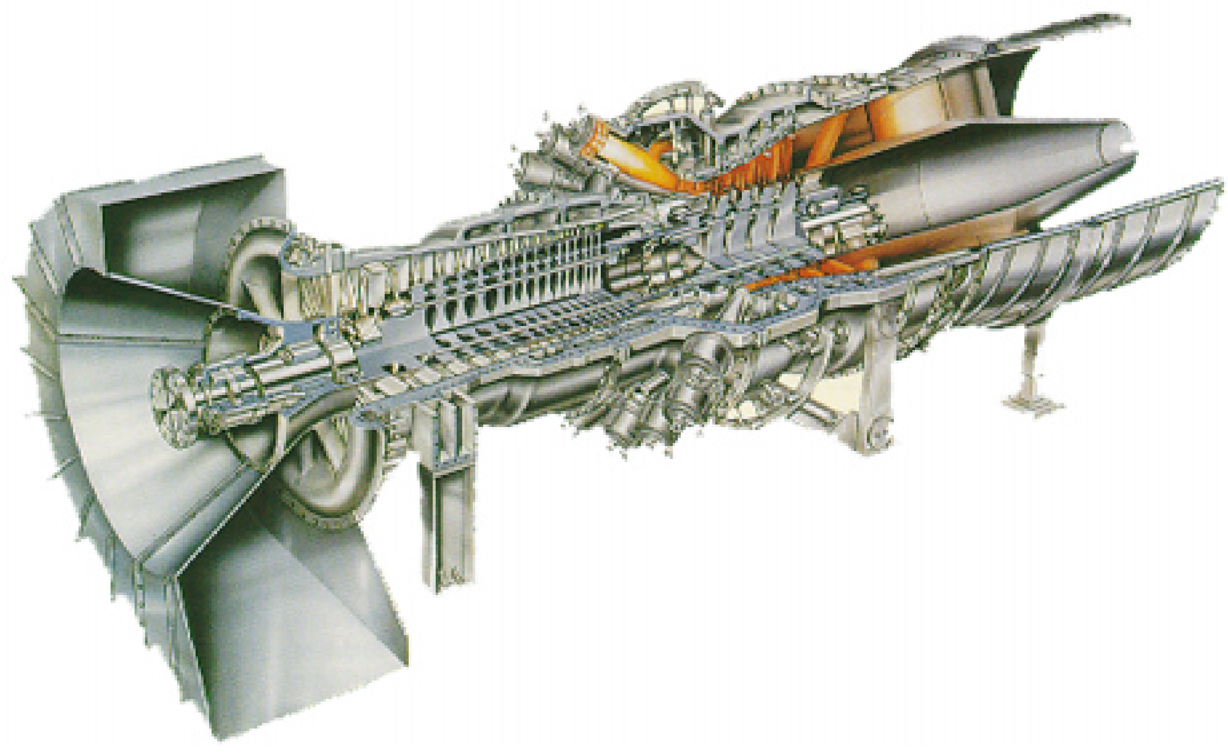
Westinghouse 501F Advanced Gas Turbine

Cooling in the 1st Stage Blade



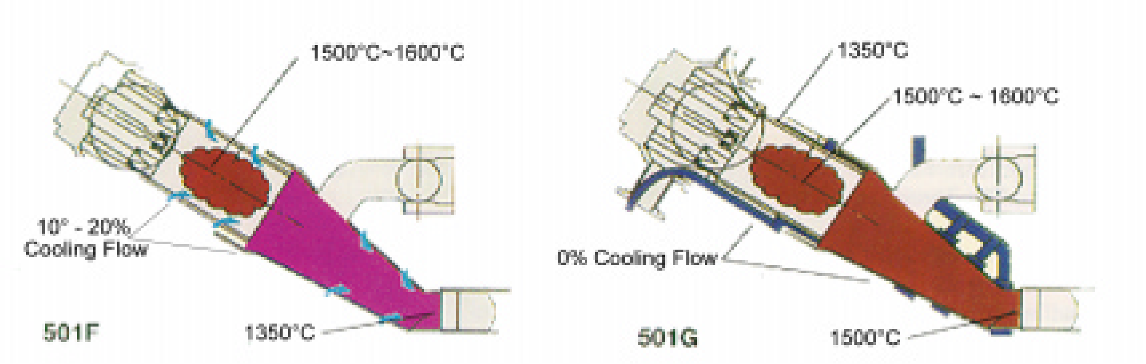
501F Combustor Can

2.10.2 Westinghouse 501G The 501G single shaft rotor is built up of compressor and turbine sections with 17-stage axial-flow compressor at 19.2 to 1 design pressure ratio. Sixteen reverse-flow, can-annular dry low NO_x combustors operate on natural gas or liquid fuels, with the transition steam cooled. Four-stage axial reaction turbine applies 3-D blading design, Directionally Solidified materials; first three stages are air cooled. Machine includes traditional Westinghouse frame gas turbine design elements: two bearing rotor support; cold-end drive with axial exhaust; tangential exhaust bearing strut support; field-removable airfoils with the rotor in position; and horizontally-split casings throughout.



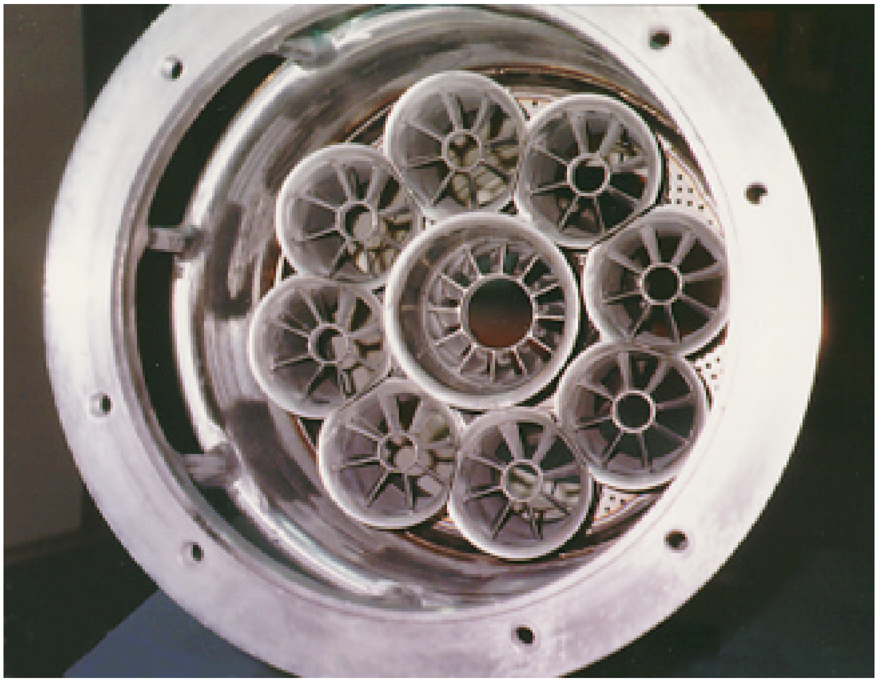
Westinghouse 501G Advanced Gas Turbine

Westinghouse 501G (cont.)



501F Combustor
uses premix for Dry Low NO_x combustion coupled with air cooling of combustors and transitions.

New Technology 501G Combustor
uses steam for cooling of the combustors and transitions, which saves up to 20% of combustor cooling air flow otherwise required. Steam flow of 40,000 pph represents 1% of compressor airflow.
With similar premix combustors as the 501F and associated 1500°F-1600°C flame temperature, the temperature before the first stage vanes are approximately 1500°C because no cooling air dilution is required.



Westinghouse Dry Low NO_x Burner

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3. Brandt, D. E., "MS7001F Gas Turbine Design Evolution and Verification," State of the Art Technology Seminar, GE Publication GER-3622A

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8. Scalzo, A. J., Bannister, R. L., DeCorso, M., and Howard, G. S., "Evolution of Heavy-Duty Power Generation and Industrial Combustion Turbines in the United States," ASME Paper No. 94-GT-488, A Paper Presented at the International Gas Turbine and Aeroengine Congress and Exposition, The Hague, Netherlands, June 13-16, 1994

3

GAS TURBINE MANUFACTURER METHODOLOGY FOR PLANNED MAINTENANCE

3.0 INTRODUCTION

Florida Power and Light's ("FP&L") Martin Station is located in Indiantown, Florida. Martin Station is a CC plant consisting of two power blocks, unit 3 and unit 4.

Each power block consists of two General Electric 7221FA advanced gas turbines, two Vogt, three pressure non-supplementally fired heat recovery steam generators (HRSG) and one GE reheat steam turbine (ST) generator. **The two power blocks operate at total net plant output of 898 MW** (ISO design rating).

These units operate at, or near, full load (140-165 MW depending on the ambient temperature) for 80% of the time. Power reductions are most typically in the early morning hours, and are commonly to 100-130 MW but occasionally have gone as low as 40 MW. The first 40 MW of power reduction is handled entirely by closing the inlet guide vanes -which reduces airflow, increases exhaust temperature slightly, and keeps firing temperature and bucket temperatures relatively constant. Power reductions beyond 40 MW are handled by reducing the firing temperatures, which lowers both bucket and exhaust temperatures

3.1 HOT GAS PATH COMPONENTS

The major hot gas path parts as shown in the **Figure 3-1**, "MS 7221FA Cross Section", are:

- Combustor System
- Turbine Rotating Blades (buckets in GE terminology)
- Turbine Stationary Vanes (nozzles in GE terminology)
- Shrouds
- Seals

3.2 LIFE EXPECTANCY OF HOT GAS COMPONENTS

The life expectancy of hot gas components is estimated by gas turbine manufacturers for each part. These estimates consider service hours before the first repair and additional service hours after refurbishment. The life expectancy of hot gas components is generally determined by:

- contaminants present in the fuel, water and air
- operating duty cycles (continuous service versus cycling)
- maintenance practices

The most favorable operating conditions for hot gas path parts include clean fuel (such as pipeline quality natural gas), continuous service with minimum starts / stop cycles and adherence to the OEM maintenance practices. Such a regime would theoretically yield component life similar to that estimated by the manufacturer. The turbines at Martin CC are operating at these favorable conditions.

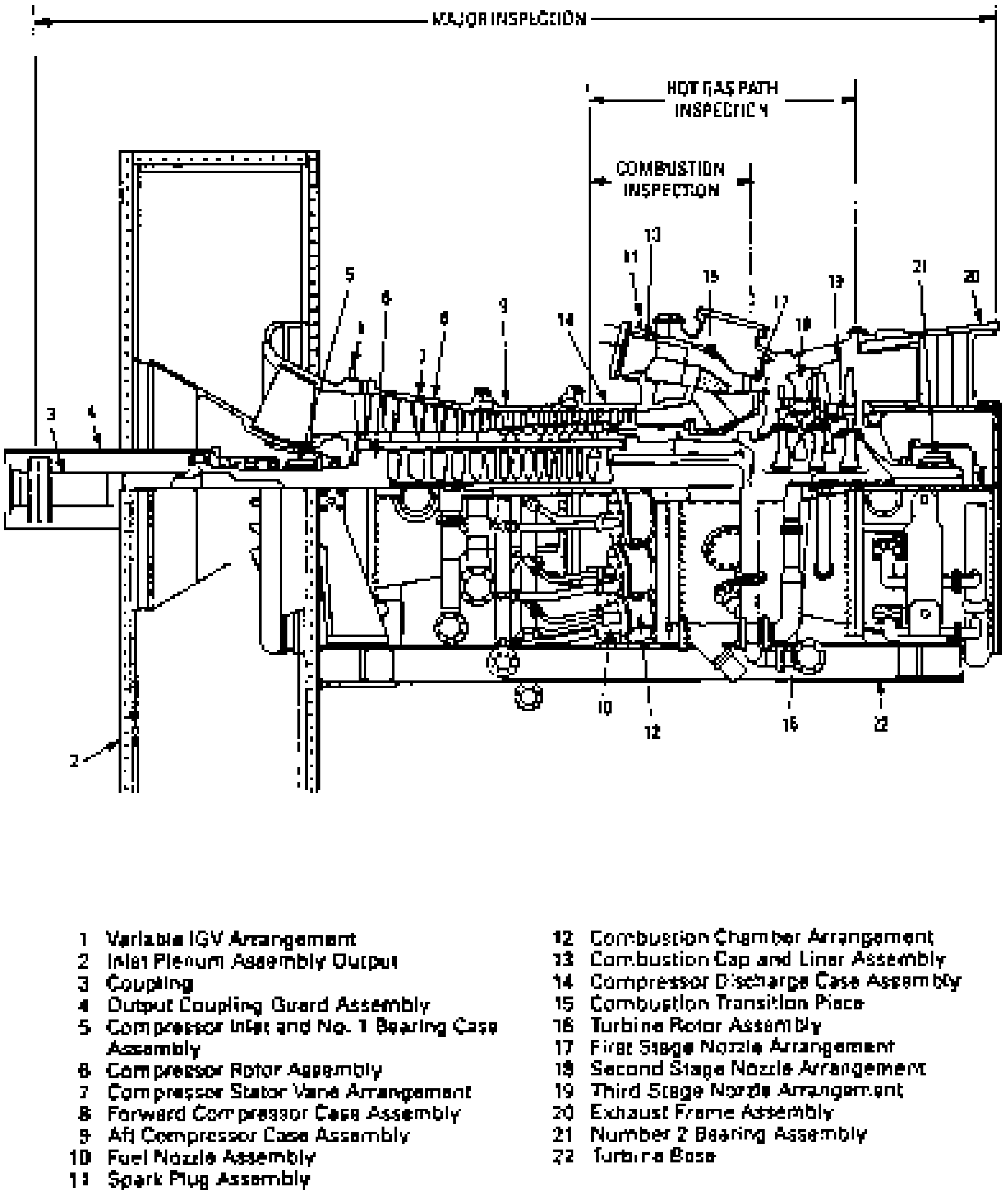


Figure 3-1
Advanced Gas Turbine General Electric MS 7221FA
(From Station H Service Manual)

3.3 INSPECTION INTERVALS

GE has traditionally recommended three types of inspections. These are Combustion Inspections, Hot Gas Path Inspections, and Major Inspections in increasing order of machine disassembly and inspection coverage. Combustion hardware only is removed at Combustion Inspections, while turbine upper casings are removed at Hot Gas Path Inspections and all upper casings and the rotor are removed at Major Inspections.

The reference Maintenance Interval is the one for the most favorable case - that of a base load machine, fired on natural gas with no water/steam injections. The FP&L-Martin Station is therefore an example of a reference case. The GE recommended inspection intervals for the MS 7221FA reference case are as follows:

Type of Inspection	Designation	Interval Hours
Combustion Inspection	CI	8000
Hot Gas Path inspection	HGPI	24000
Major Inspection	Maj	48000

The reference Maintenance Interval is calculated according to the following formula:

$$\text{Maintenance Interval (in hours)} = \frac{24000}{\text{Maintenance Factor}}$$

where —

$$\text{Maintenance Factor} = \frac{\text{Factored Hours}}{\text{Actual Hours}}$$

and —

Factored Hours = G + 1.5D
Actual Hours = G + D

and —

G = annual base load operating hours on gas fuel
D = annual base load operating hours on distillate fuel

Nothing in these inspections suggested that the inspection intervals should be lowered for the reference case of a base loaded FP&L-Martin machine fired at 2350°F (1288°C). There might, in fact, be some optimism for increasing the Combustion Inspection interval sometime in the future (Unit 4B just completed a 9624 hour interval). Inspection intervals for the current hardware might, however, be lowered because these machines were actually fired at 2384°F (1307°C) for a significant part of their life.

A shorter Combustion Inspection interval was occasionally used to get a preliminary assessment of a new hardware design. This practice was good, and should be considered for any significant innovations in the future.

3.4 LIFE OF HOT GAS PARTS

GE references life of individual parts as multiples of the recommended standard Maintenance Intervals mentioned above. The philosophy for any new machine is to use appropriate design tools as tempered by past field experience, and then follow the fleet leaders to verify that design - as is currently being done for the MS 7221FA. GE has presented the following lives for the MS 7001E model which, at 70000 hours, is a more mature design than the MS 7221FA:

	Repair Interval	Replace Interval
1st Stage Buckets and Shrouds	HGPI	2 HGPI/3 HGPI (a)
2nd, 3rd Stage Buckets and Shrouds	HGPI	3 HGPI
1st , 2nd, 3rd Stage Nozzles	HGPI	3 HGPI
Combustion Liners	CI	5 CI
Fuel Nozzles, Cross Fire Tubes	CI	3 CI
Transition Pieces	CI	6 CI

(a) Bucket Only: 3 HGPI with refurb/recoat

It is anticipated that the lives of some current FP&L parts, particularly the 1st stage bucket, will be shorter than these because of the higher firing temperature used initially.

It is impossible to project the results of the current 4000-14000 hour visual inspections out to the 48000-72000 hour level, certainly without the benefit of destructive analyses. Most observations were encouraging, however, and didn't *disprove* the use of the above MS 7E table for an FP&L MS 7221FA fired at 2350°F (1288°C). The 1st stage bucket, however, may be the item that is most in question (see Condition of Parts).

4

OPERATION OF FP&LS MARTIN CC STATION FOUR GENERAL ELECTRIC MS 7221FA ADVANCED GAS TURBINES (BASE LOAD APPLICATION)

4.0 FP&L MARTIN CC STATION COMBINED CYCLE

Florida Power and Light's ("FP&L") Martin CC Station is located in Indiantown, Florida. Martin CC Station is a combined cycle plant consisting of two power blocks, unit 3 and unit 4. **Figure 4.1** shows the plot plan of Units 3 & 4.

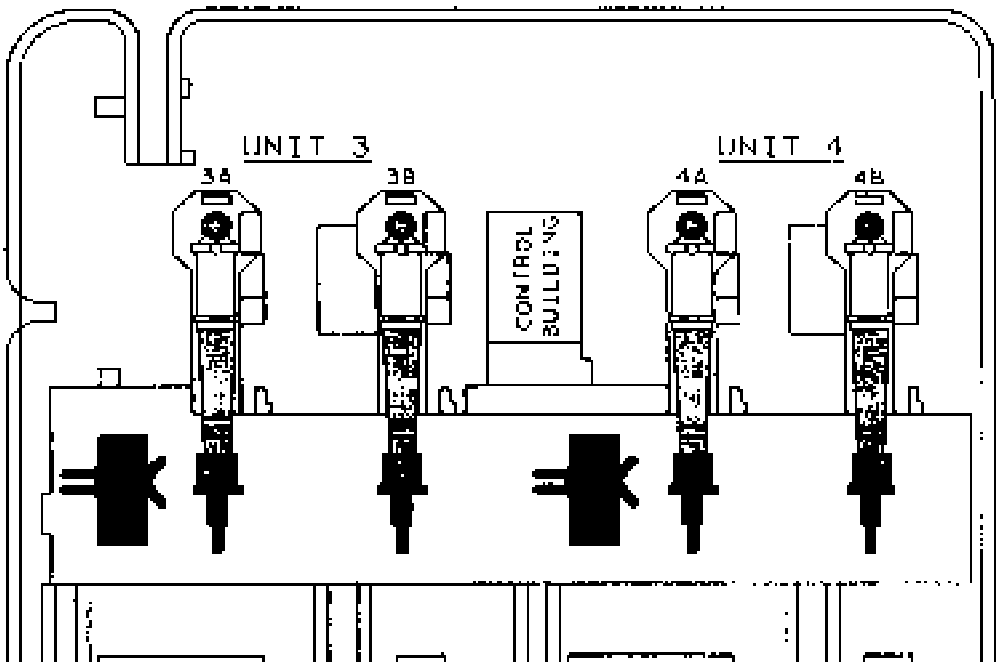


Figure 4.1
Martin Station CC Plot Plan

Each power block consists of two General Electric 7221FA advanced gas turbines, two Vogt, three pressure non-supplementally fired heat recovery steam generators (HRSG) and one GE reheat steam turbine (ST) generator. **The two power blocks operate at total net plant output of 898 MW** (ISO design rating).

The Turbines were first synchronized in latter 1993, and went commercial in early 1994. The units have natural gas/distillate dual fuel capability and provision for steam power augmentation, but neither distillate fuel or power augmentation has been used as of November, 1995.

These units operate at, or near, full load (140-165 MW depending on the ambient temperature) for 80% of the time. Power reductions are most typically in the early morning hours, and are commonly to 100-130 MW but occasionally have gone as low as 40 MW. The first 40 MW of power reduction is handled entirely by closing the inlet guide vanes which reduces airflow, increases exhaust temperature slightly, and keeps firing temperature and bucket temperatures relatively constant. Power reductions beyond 40 MW are handled by reducing the firing temperatures, which lowers both bucket and exhaust temperatures.

The compressors are cleaned by on-line and off-line techniques. On-line cleaning is done twice a week with demineralized water. Off-line cleaning is done with detergent demineralized water at the annual inspection, and occasionally during other machine shutdown. On-line cleaning restores about 3 MW of power when it is done shortly after an off-line cleaning - but this restoration becomes less as the months go by.

Infrared Pyrometers are installed on each Martin gas turbine as a means of monitoring bucket temperatures. Together with an extensive Data Acquisition System (DAS), they were installed by EPRI as part of the Durability Surveillance Program.

4.1 DESCRIPTION OF MS 7221FA

The MS 7221FA's installed at Martin CC Station were introduced by General Electric in 1990. It is an uprated version of the MS7221F which was introduced in 1986. The MS 7221FA (**Figure 4.2**) consists of an 18 stage axial compressor, 14 cross-connected combustion chambers and a 3 stage reaction turbine directly coupled to a 2 pole 3600 RPM generator and is rated 159 MW (ISO) at base load operation.

The MS 7221FA is an advanced design machine utilizing a rotor inlet temperature of approximately 2350°F (1288°C). The temperatures of hot gas path components (including turbine blades) is proportionate to the firing temperature. As a result, the high firing temperature of the MS 7221FA requires application of new technologies for the turbine blades. To survive at these harsh conditions the first and second stage buckets are air-cooled. The first stage buckets are convectivley cooled via serpentine passages and second stage buckets are cooled via convective heat transfer through drilled radial holes. The MS 7221FA, achieve improved efficiency through higher inlet gas temperature which was made possible by the introduction of blade cooling **(Figure 4.3)**. If not properly cooled, these blades are exposed to temperatures well above their operating limit. Turbine blade cooling is critical for effective operation of advanced (turbine inlet temperature above 2300°F or 1260°C) combustion turbines. Since most superalloys begin to melt at about 2200°F or 1204°C, hot gas components (including turbine blades) must be cooled to maintain temperatures well below this temperature.

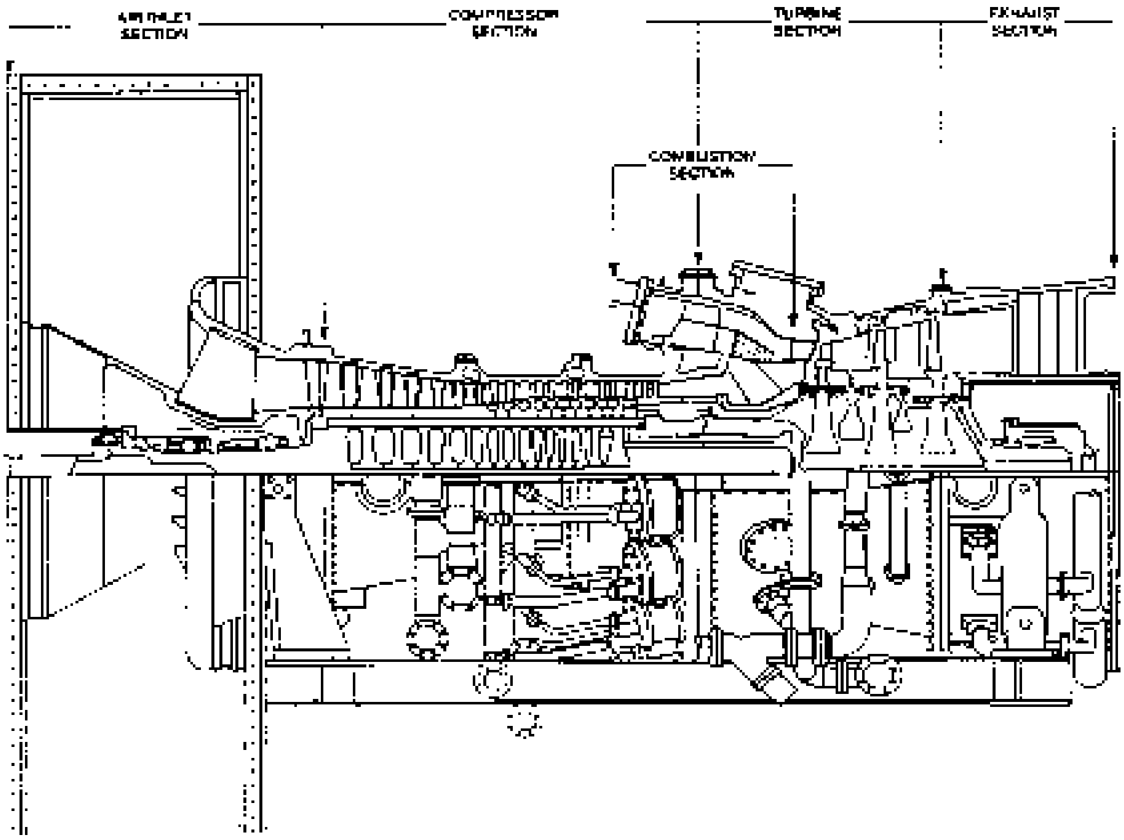


Figure 4.2
General Electric MS 7221FA Advanced Gas Turbine

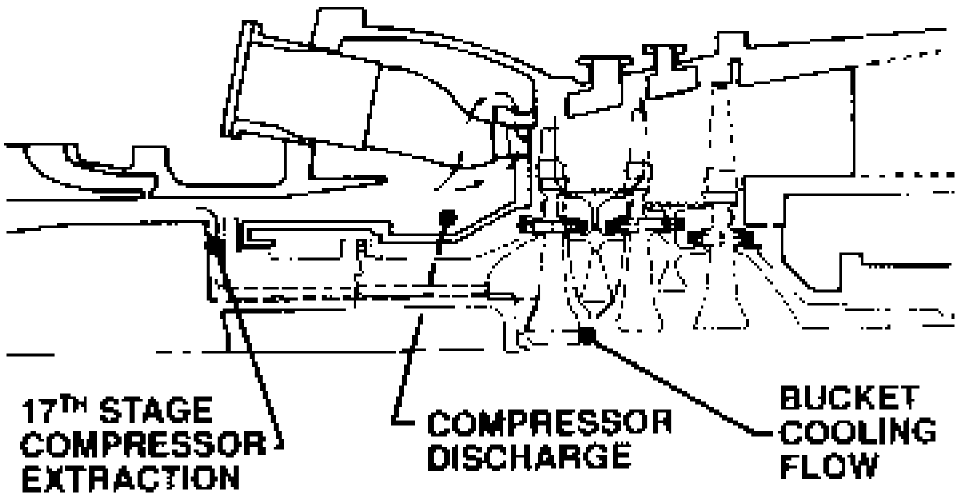


Figure 4.3
Blade Cooling Air of First Stage Bucket via
Extraction Air from 17th Compressor Stage

Gas turbine buckets (particularly 1st and 2nd stage) are the most burdened components of the gas turbine due to high heat, intense stress and the harsh environment. The first stage turbine bucket must withstand the most severe combination of temperature, stress and environment. and is generally the limiting item on the machine. Blades must be designed to successfully address the following areas:

- Thermal Fatigue (cracking)
- Alloy Hot Corrosion
- High Temperature Oxidation
- Blocked Cooling Passages/Loss of Cooling
- Loss of Material

4.2 OPERATION OF GAS TURBINES

FP&L - Martin CC Station is the high time MS 7221FA site. It is a base loaded site with a DLN-2 combustion system that has used natural gas exclusively to date. The site has four gas turbines operating in a base load combined cycle mode.

The current operating statistics for the four Martin CC Station machines are shown in **Table 1**. The high time machine (Unit 3A) has accumulated 16352 hours of service, with 88 fired starts and 38 trips as of November 1995. The four machines have accumulated a collective total of 56906 hours of service with 278 fired starts and 108 trips as of November 1995. Operation prior to May 1994 was characterized by numerous shutdowns, largely due to the new DLN-2 technology (typically running at 10 to 18 ppm NO_x levels) that was being introduced. Since that time, however, it has been the more typical base load operation. Overall, operation has averaged 198 fired hours per start since installation, and about 480 hours/start from latter 1994 to the end of 1995.

All four machines were inspected on a scheduled basis, or as a result of the installation of new technology hardware or other events. There have been 5 Combustion, 1 Hot Gas Path, and 2 Major Inspections on the Martin machines since their installation in late 1993, and all are shown in **Table 2**.

Table 1
Operating Statistics As Of 11/14/95

	Unit 3A	**Unit 3B**	**Unit 4A**	**Unit 4B**
Turbine Number	295810	295851	295854	295855
Installation				
First Synchronized	Late 1993	Late 1993	Late 1993	Late 1993
Commercial	Early 1994	Early 1994	Early 1994	Early 1994
Last Inspected	Nov. 1994	June 1995	Feb. 1995	Nov. 1995
Inspection Type	Comb'n	Comb'n	Major	Comb'n
Fired Hours	16352	16062	10228	14264
Fired Starts	88	66	64	60
Trips	38	22	27	21
Total Starts	93	73	74	71
Normal Starts	116	101	79	85
Manual Starts	90	64	56	62
Compressor Surge Indications	9	9		0
Primary Mode Fired Hrs.-Gas	17	6	19	8
Primary Mode Fired Hrs. - Oil	0	0	0	0
Lean-Lean Mode Fired Hours	796	452	114	361
Secondary Mode Fired Hours		0		
Premix Mode Fired Hours	6768	11643	10082	4295
Premix Transfers	54	64	0	0

Table 2
Significant History

Unit	Date	Fired Hours	Fired Starts	Trips	Comments
3A	6/93	0	0	0	First synchronized
	12/93	~450			Combustion and 1st shroud modifications
	2/94	~1200			Commercial operation
	4/13/94	3549	64	27	Combustion Inspection
	5/15/94	~4300			Load swings, (a)
	11/14/94	8079	74	32	Combustion Inspection
	7/18/95	~13600			Firing temp. readjusted from 2384 to 2365°F (1307 to 1296°C)
	11/14/95	16352	88	38	Latest Status
3B	6/93	0	0	0	First synchronized
	12/93	~450			Combustion and 1st shroud modifications
	2/94	~1200			Commercial operation
	3/4/94	2295	40	16	Borescope Inspection
	5/15/94	~3500			Load swings, (a)
	5/21/94	~4000			Peak load test demonstration of about an hour
	5/23/94	4082	47	17	Hot Gas Path Inspect.- nozzle tip loss, (a)
	6/11/95	12586	60	21	Combustion Inspection
	7/28/95	~13500			Firing temp. readjusted from 2384 to 2365°F (1307 to 1296°C)
	11/14/95	16062	66	22	Latest Status
4A	12/93	0	0	0	First synchronized
	2/94	~100			Combustion modifications
	4/94	~300			Commercial operation
	5/15/94	~1000			Load swings, (a)
	11/7/94	4867	42	21	Major inspection - rotor vibration - (a)
	2/16/95	6120			Major Inspection - compr. blade failure - (a)
	6/21/95	~6700			Firing temp. readjusted from 2384 to 2365°F (1307 to 1296°C)
	11/14/95	10228	64	27	Latest Status
4B	12/93	0	0	0	First synchronized
	2/94	~100			Combustion modifications
	4/94	~300			Commercial operation
	5/15/94	~1000			Load swings, (a)
	9/14/94	4402	41	21	Combustion Inspection
	7/15/95	~11500			Firing temp. readjusted from 2384 to 2365°F (1307 to 1296°C)
	11/14/95	14264	60	21	Combustion Inspection. Latest Status

(a) Described in Section 9.

Table 3
Parts Hours History

	UNIT 3A		UNIT 3B		UNIT 4A		UNIT 4B	
Part	Current 11/14/95	Last Inspection 11/14/94	Current 11/14/95	Last Inspection 6/11/95	Current 11/14/95	Last Inspection 2/15/95	Current 11/14/95	Last Inspection 11/14/95
1st Buckets	16352	8079	11980	8504	4108/8190 (b)	6120	14264	14264
2nd Buckets	16352	8079	16062	12586	4108	6120	14264	14264
3rd Buckets	16352	8079	16062	12586	4108/10228	6120	14264	14264
1st Nozzle	16352	8079	11980	8504	4108	6120	14264	14264
2nd Nozzle	16352	8079	16062	12586	4108	6120	14264	14264
3rd Nozzle	16352	8079	16062	12586	10228	6120	14264	14264
1st Shrouds	16352	7600	11980/16062	8504/12586	4108/10228	6000	14264	14264
2nd Shroud	16352	8079	16062	12586	10228	6120	14264	14264
3rd Shroud	16352	8079	16062	12586	10228	6120	14264	14264
Comb. Cap	8273	4530	3476	8504	5361	1253	9862	9862
Fuel Nozzles	8273	4530	3476	8504	5361	1253	9862	9862
Comb. Liner	8273	4530	3476	8504	4108	1253	9862	9862
Trans. Piece	8273	4530	3476	8504	5361	1253	9862	9862

(a) Hours are since installation. Most were new as installed. Some parts (mostly combustion) may have been refurbished after seeing prior service in another machine.

(b) One set of half new/half serviced buckets were installed in February 1995. 42 were new; 50 were not refurbished, but had seen 4082 hours of prior service in Unit 3B. All had GT-29IN-PLUS coating.

4.3 TURBINES MAJOR OPERATING EVENTS

Units 3A, 3B, 4A, 4B (5/15/94):

All units experienced unique load swings which were caused by a fuel gas delivery malfunction. The machines went from a fully loaded 150 MW to about 25 MW in a few seconds, reestablished at full load, possibly repeated, and then tripped. Control modifications were made as protection against a repeat occurrence, and nothing like this has occurred since.

Unit 3B (5/94, 4082 hours):

Lost a fuel nozzle tip which was discovered at the scheduled inspection of 5/23/94 (there have been no subsequent tip losses). This is a 2”x2” (50.8 x 50.8 mm) cylinder of 60-120 mil (1.524-3.048 mm) wall thickness and 4 ounce (113.4 gms) weight. No defects were found in metallurgical examination and the observations were consistent with a fuel flashback. Exhaust temperature spreads were normal two months before, but were skewed within two weeks of the inspection (no interim data was available). It is believed that the tip loss triggered the exhaust temperature shift, and both occurred from combustion flashbacks. The downstream damage was surprisingly little. The 1st stage nozzle partitions and buckets were both removed for repair; while 2nd and 3rd stage nozzles and buckets were left in the machine. Leading edges on three 2nd stage buckets and two 3rd stage buckets were carefully blended in the machine.

Unit 4A (2/95, 6120 hours). Compressor Blade Failure

The compressor rotor developed significant vibration and was replaced with a compressor rotor section from another site. The rebuilt rotor then experienced a compressor blading failure in early February 1995. There had been a loss of output (8 MW) and the compressor discharge pressure dropped about 6% approximately sixteen (16) hours prior to the high vibration trip. Portions of three compressor blades went downstream (stator 4, rotor 4, stator 14), and most blades downstream of stage 3 were dented and bent. Combustion parts were essentially intact; 1st and 2nd stage nozzles and buckets and some 3rd stage buckets were removed for refurbishment, and the 3rd stage nozzle was quickly refurbished and reinstalled in the same machine. The rotor is under investigation by the OEM. Interestingly, station instrumentation indicated that the machine had been producing about 7 MW more power than the other three for at least part of it operation.

5

HOT GAS PATH PARTS DESIGN & MATERIALS

Design and Materials/Coatings

This section contains a brief outline of the design and materials aspects of the MS 7221FA machines at FP&L, so that the inspection results will be more meaningful.

1st Stage Buckets:

92 buckets which are convectively cooled by serpentine passages with turbulence promoters. They are directionally solidified (DS) buckets cast from the GTD-111, a nickel base superalloy. All are of the "FA", as opposed to, the earlier "F" design. Two types of squealer tip designs have seen service at FP&L - the earlier solid wall and the slotted wall respectively (the intent was to get cooling air from the tip cavity to bleed over the trailing edge tip). Sheet metal plates are welded to the tip cavity floor to control the cooling air in both the serpentine bucket and in the squealer tip cavity.

The buckets are coated with GT-29IN-PLUS (*GT-29IN-PLUS is a registered trademark of the GE Company)*.. It is a bi-layered coating, with a CoCrAlY/VPS basecoat onto which an aluminide topcoat has been diffused; internal surfaces are also aluminide coated.

2nd Stage Buckets:

92 radial cooled buckets, cast from equiaxed GTD-111 and GT-29IN-PLUS coated.

3rd Stage Buckets:

92 uncooled buckets, cast from equiaxed GTD-111 and diffusion chrome coated.

1st Stage Nozzle Segments:

24 two-vane segments cast of FSX-414, a cobalt base superalloy with core plugs inside the chambers. The nozzle is cooled by a combination of film, impingement and convection techniques, and each segment has over 500 cooling holes including racetrack

cooling slots on the trailing edge. They are uncoated except for a TBC patch on the aft part of the convex vane.

2nd Stage Nozzle Segments:

24 two-vane segments cast from equiaxed GTD-222, a nickel base superalloy. All segments are convectively cooled and have been coated with an aluminide coating on external and internal surfaces.

3rd Stage Nozzle Segments:

20 uncoated and uncooled three-vane segments cast in equiaxed GTD-222.

Combustion Hardware:

14 individual combustion systems, each with an end cap/fuel nozzle assembly with five fuel nozzles, a combustion liner, and a transition piece. The systems have the capability of dual fuel operation and some for power augmentation, but neither has been used to date. The liners and transition pieces are primarily made from Hastelloy X and Nimonic 263 respectively, but a number of other alloys are also represented in the overall combustion system. Both the liners and the transition pieces are TBC coated.

1st Stage Stationary Shrouds:

96 inner shroud blocks facing the gas path and the bucket tips, each made from an equiaxed IN 738 casting. Rubbing surfaces are coated with about 50 mils of an MCrAlY plasma coating. Newer design shrouds (as are virtually all of FP&L's) have cooling holes on the leading face, the center face and the side edges. Three of these inner shrouds are assembled into an outer shroud block segment.

2nd and 3rd Stage Stationary Shrouds:

These are individual, uncoated, heavy stainless segment blocks which are slid into a groove in the casing.

Discourager Seals/Bucket Angel Wing Seals:

The discourager seals are sheet metal strips that run in close proximity to the bucket angel wings seals, and are attached to the nozzle diaphragms or to other stationary parts as a means of controlling wheelspace temperatures.

Labyrinth Seals:

These are the tooth-like seals between the outside diameter of the wheel spacers and the inside diameter of the nozzle diaphragms. They maintain correct pressures between turbine stages.

Identification:

Most hot gas parts are identified by position in the machine. The convention, which periodically occurs in this report, is as follows. In each case, the orientation is looking downstream with the remaining parts numbered consecutively in a counterclockwise direction from the #1 part.

Nozzles: #1 segment is located at 3 o’clock.
Buckets: #1 bucket is the locking bucket.
Combustion: #1 chamber is located at 11:30 o’clock

Post-Service Inspection Coverage:

Inspection coverage is really a measure of accessibility to all surfaces of the various parts. This, in turn, varies with the type of inspection. Three inspection types were used at FP&L as shown in **Table 1**. The inspections were done visually and, occasionally, borescopically although the latter was limited because of difficulty in ratchetting the rotor and removal of some inspection plugs.

Table 1

	Combustion Inspection (Borescope With Rotor Ratchetting)	Hot Gas Path Inspection	Major Inspection
	All liners and transition pieces removed	Plus upper turbine casing	All upper casings and rotor
Combustion Parts	100% coverage	100% coverage	100% coverage
1st Stage Turbine	70-90% coverage with borescope, 50-70% coverage without. Convex vanes, bucket tip cavities limited.	100% coverage	100% coverage
2nd Stage Turbine	60-90% coverage with borescope, 0-20% coverage without. Vanes limited	100% coverage	100% coverage
3rd Stage Turbine	80-100% coverage with borescope, 50-70% coverage without. Forward convex vanes limited	100% coverage	100% coverage
Shrouds/Seals	30% coverage 1st and 3rd stage stationary shrouds only	90% coverage	100% coverage

There were differences in operating times and inspection times between parts in the four machines, because of different installation times and replacement needs. From late 1993 to the end of 1995, there were a total of 5 Combustion Inspections, 1 Hot Gas Path Inspection, and 2 Major Inspections performed on these four FP&L machines. Operating time on hot gas parts in each of the FP&L machines, as of 11/14/95, is shown in **Table 2**. The high time service and inspection times - not necessarily in the same machine - are:

Table 2

Part	High Time Hours	Inspection Range Hours	No. of Inspections
1st Stage Buckets	16352	3549 to 14264	8
2nd Stage Buckets	16352	4082 to 14264	4
3rd Stage Buckets	16352	3549 to 14264	7
1st Stage Nozzles	16352	3549 to 14264	8
2nd Stage Nozzles	16352	4082 to 14264	4
3rd Stage Nozzles	16352	3549 to 14264	8
Combustion Hardware	9862	1253 to 9862	8
Stationary Shrouds - 1st & 3rd Stage	16352	3100 to 14264	7
Stationary Shrouds - 2nd Stage	16352	4082 to 14264	3

6

SUMMARY OF INSPECTION RESULTS AT 4 ADVANCED GAS TURBINES AT MARTIN COMBINED CYCLE FROM FIRST 16,000 HOURS OF BASE LOAD OPERATION

6.0 POST SERVICE CONDITION OF PARTS

These descriptions contain a number of details which may be relatively minor from a gas turbine operational standpoint, but are included strictly for record purposes and as a guide for future inspections and comparisons with the other units.

Foreign Object Damage (FOD) occurred on a number of parts, and are summarized in Section 6.9.

Because of their number, representative pictures of these inspections are all part of Section 8.

6.1 1ST STAGE BUCKETS

	Unit 3A	Unit 3B	Unit 4A	Unit 4B
Current Hours (11/14/95)	16352	11980	4108/8190 (a)	14264
Last Inspection, Hours	8079	8504	6120	14264

a) GT29IN-PLUS coated buckets installed in Feb. 1995. 42 were new; 50 were not refurbished, but had seen 4082 prior hours service in Unit 3B.

Overall Assessment (8 individual inspections):

The 1st stage buckets are the most sensitive part in the machine to firing temperature, and most of their life to date has been at a firing temperature of 2384°F (1307°C). This translates to about a 20°F (11.1°C) higher bucket temperature than normal - which is a small, but significant, increase. Overall, the buckets appeared to be in quite good condition after some 14000 hours of service. The coatings have been universally protective through the 8000 hour inspections, but some localized breach was seen on the first 14000 hour set. This was possibly attributable, in part, to elevated firing temperatures and/or some fine material that was ingested into that machine. It would imply that the coating breach life for a 2350°F (1288°C) fired machine might be somewhere between 14000 and 24000 hours, but this can only be verified by future inspections.

Potential items of concern are:

Vanes:	FOD. Oxidation on the leading edges
Squealer Tips:	Squealer tip oxidation, which is quite probably self limiting. Cavity plate oxidation, when squealer tips have been lost by FOD.

Vanes (See Figures 8.2 - 8.10):

Mechanically, all buckets examined to date have appeared to be in good condition, with no thinning, or cracking or mechanical deterioration other than impacts/FOD - see Section 6.8. They were similar to each other within a set, and between sets of equivalent service. Trailing edges were not distorted or cracked, and cooling holes were fully open and functioning and uncracked.

The GT-29IN-PLUS coating has been fully protective to 8000 hours, but was breached in small local areas on the first set inspected at 14000 hours. The breach was associated with 2-10 mils (.0508 -.254 mm) base metal attack and was confined to leading edges on two buckets, and convex vanes just behind the leading edge on all buckets. All other areas continued to look good and be protective. Contributors to the breach might be the higher firing temperature and/or some very fine sand-like material that was ingested into that specific machine early in it’s life (although the pattern didn’t seem to be associated with oxidation). This will be assessed in future inspections.

Oxide colors were typically an even tan/rose on the concave face and a mixture of white/gray/black on the convex. The buckets in Unit 3B had a slightly lighter and whiter hue at the May 1994 inspection - presumably from the 1 hour peak load test or the loss of a fuel nozzle tip on that machine.

Pyrometer readings have varied from 1600-1750°F (871-954°C) and occasionally to 1780°F (971°C) for the upper part of the 1st stage bucket leading edge.

Squealer Tips/Tip Cavities (See Figures 8.7 - 8.10):

a) All tips were oxidized in two places - the mid-third chord and the immediate trailing edge. The mid-chord oxidation was generally on the concave squealer wall and extended 1″ (25.4 mm) axially and 0.3″ (7.62 mm) from the tip. It was rarely more than coating loss plus 10 mils (0.254 mm) of base metal. The trailing edge location was heavier, and coating loss extended 1″ (25.4 mm) axially and 0.3″ (7.62 mm) from the tip. Tip metal loss was 40-60 mils (1.016-1.52 mm) deep at 4000 hours, 80-120 mils (2.032-3.048 mm) at 8000 hours, and 120-150 mils (3.048-3.71 mm) at 14000 hours. Although proceeding linear with time to date, it will possibly be self limiting in depth as it approaches the trailing edge cooling holes that are nearby - although that point has not yet be reached. This oxidation results from limited cooling flow over the tip region. A modified tip design put a slit in the cavity wall to increase that cooling flow, but did not minimize the oxidation at the trailing edge tip.

b) Two sets of tip cavity plates have been examined to date (Unit 3B, 5/94, 4082 hours and Unit 4A, 2/95, 6120 hours). Both were in good condition with no distortion, bending or oxidation except where the squealer tip was removed by impact (Unit 4A). This caused heavy oxidization of the plates from the hot combustion gases that were then ingested into those cavities.

c) Light tip rubs (5-20 mils or 0.127-0.508 mm) were commonly seen, and occasionally were heavier at 30-60 mils (0.762-1.524 mm) depth. They generally occurred on only one portion of the tip - such as either the leading or trailing edge, and resulted from rubs with the shroud blocks at the horizontal joints. Rub lips were frequently seen on the forward running wall of the convex and/or concave squealer wall. They were friable mixtures of bucket and shroud coating oxides whose size (20 to 220 mils or 0.508-5.588 mm) was independent of the amount of tip rub. A better indication of rub depth was the loss of coating on the adjacent wall.

d) Squealer tip cracking was seen on only one of the five FP&L bucket sets examined to date (Unit 3B, 5/94, 4082 hours). Twenty eight (28) of those buckets had radial tip cracks on the concave vane between 60 and 200 mils (1.524-5.08 mm) in length - most commonly 2 to 4 cracks per bucket. None of the cracks had gone below the base of the tip cavity platform. There was no correlation between tip cracks and the degree of tip rubbing, however, the buckets with cracked tips were all within clusters around the wheel.

Angel Wing Seals

Only one set of buckets has been inspected for angel wing seal rubs to date. There were no rubs on that particular set.

6.2 2ND STAGE BUCKETS

	Unit 3A	Unit 3B	Unit 4A	Unit 4B
Current Hours (11/14/95)	16352	16062 (a)	4108/8190 (b)	14264
Last Inspection, Hours	--	12586 (a)	6120	14264

(a) Three buckets were blended in the machine due to FOD

(b) GT29IN-PLUS coated buckets installed in Feb. 1995. 42 were new; 50 were not refurbished, but had seen 4082 prior hours service in Unit 3B.

Overall Assessment (4 inspections)

The buckets appear to be in good condition after some 14000 hours of service other than for any impactions/FOD. The vane coating appears to have at least 24000 hours capability at this site.

Vane (See Figures 8.11 - 8.14):

Those examined appeared to be in good condition, with no thinning, cracking or mechanical deterioration other than impacts/FOD. They were similar to each other within a set, and between sets of equivalent service. Leading and trailing edges were in good condition, and not distorted. The coatings were still in good condition to the 14000 hour point, and there was no evidence that the topcoat was thin or that there was any damage to the basecoat. Oxide colors were typically mixtures of gray-white-tan on both the concave and convex surfaces.

Shrouds (See Figure 8.12):

There was no mechanical damage such as cracking or distortion, and no significant creep lifting of the tip shrouds in that shroud engagements were uniformly over 90%. There was no significant wear or galling on the shroud Z-forms, and the outer racetrack shroud seals were not rubbed or deteriorated.

Angel Wings:

Only two sets of buckets has been inspected for angel wing seal rubs to date. There were no rubs on those particular sets.

6.3 3RD STAGE BUCKETS

	Unit 3A	Unit 3B	Unit 4A	Unit 4B
Current Hours (11/14/95)	16352	16062 (a)	4108/10228	14264
Last Inspection, hours	8079	12586 (a)	6120	14264

(a) Two of the buckets were blended in the machine due to FOD.

Overall Assessment (7 individual inspections):

The buckets appeared to be in good condition after some 14000 hours of service other than for any impactions/FOD. Portions (20-30%) of the coating have gone - but this is of no significance at FP&L in that the coating was only applied for hot corrosion protection which doesn't appear to be a factor at this site.

Vanes (See Figures 8.11, 8.15, - 8.17):

There was no cracking, thinning or mechanical deterioration other than impacts/FOD. They were similar to each other within a set, and between sets of equivalent service. Leading and trailing edges were in good condition and not distorted, and there has been no base metal attack to date.

10-30% of the coating was gone or deteriorated on half of the buckets. The loss was in a seemingly random pattern, but was mostly in the central concave pocket and leading/trailing edge locations. The coating was probably variable and thin as first installed as a result of a gentle cleaning operation used by the coating vendor and subsequently discontinued. The coating loss is of little importance to this particular FP&L site - it had been applied to protect against the Type 2 hot corrosion caused by contaminated atmospheres. Neither corrosion nor salt deposits have been seen at this particular FP&L site even in the areas of lost coating.

Shrouds (Figure 8.17):

There was no mechanical damage such as cracking or distortion, and no significant creep lifting of the tip shrouds in that shroud engagements were uniformly over 90%. There was no significant wear or galling on the shroud Z-forms; the shroud coating still was in place and in apparently good condition, and the outer racetrack shroud seals were not rubbed or deteriorated.

Angel Wings:

Only two sets of buckets has been inspected for angel wing seal rubs to date. There were no rubs on those particular sets.

6.4 1ST STAGE NOZZLES

	Unit 3A	Unit 3B	Unit 4A	Unit 4B
Current Hours (11/14/95)	16352	11980	4108	14264
Last Inspection, Hours	8079	8504	6120	14264

Overall Assessment (8 sets examined)

The nozzles were in good condition after some 14000 hours of service other than for any impactions/FOD. Limited vane cracking has been seen, as well as small amounts of sidewall oxidation and sidewall cracking.

Vanes (See Figures 8.2, 8.5, 8.6, 8.18, - 8.27):

Other than the effects of impacts/FOD, the vanes were similar to each other within a set, and between sets of equivalent service. None of the vane cooling holes or slots or trailing edge slots were plugged and cooling circuits appeared to be effective and had the anticipated oxide patterns around and downstream of the holes. There was no deformation or bowing of the vanes. Oxidation was insignificant (generally less than 5 mils depth), including the area that had previously been of concern (the convex vane, double cooling slot area). Leading and trailing edges were in good condition and the TBC coating on the aft convex surface was at least 95% intact.

The only cracks that were seen were on two high-time vanes (Unit 4B, 11/95, 14264 hours). Both vanes had a single 2.5″ (63.5 mm) crack extending from the first to the last row of film cooling holes on the concave vane which was parallel to, and 0.7″ (17.8 mm) from, the inner sidewall. Both cracks had started at the center and then progressed forward and aft, and were similar to those seen on the MS 7E machine model.

Sidewalls (See Figures 8.22, 8.25, 8.27):

All cooling holes were open and functioning well. The sidewalls were in good mechanical condition, but did have some very fine cracks (0.5″ or 12.7 mm) at 8000 hours and 1″ or 25.4 mm by 14000 hours). These were at the Z-notch (mostly inner sidewall) or the trailing edge junction (both inner and outer sidewalls) to the adjacent vane, **Figure 8.20**. These cracks are similar to those seen on the MS 7E machine models.

Oxidation was very minor over the majority of the vane surface, and was generally less than 2 mils (0.0508 mm) in depth. There were four local areas with somewhat more oxidation in sporadic cases, none of which were felt to be life limiting, and which were as follows at 14000 hours:

- Most 4x4 mm (0.158 x 0.158 in.) and 2x2 mm (0.079 x 0.079 in.) cooling holes, on the inner sidewall throat (10 mils or 0.254 mm oxidation), **Figure 8.20**
- Some sidewalls, at the Z-form joints between the segments (up to 60 mils or 1.524 mm oxidation), **Figure 8.21**
- Some convex side vane/inner sidewall fillets, near the leading edge (10 mils or 0.254 mm oxidation), **Figure 8.21**
- Two sidewalls in Unit 4B had oxidation troughs somewhat like the outer sidewall oxidation on the MS 6B/7E machines. These were the first seen on an MS 7FA machine The oxidation cut was 80 mils (2.032 mm) on one segment, **Figure 8.22**.

The Z-form oxidation pattern indicates that the F-Tech sidewall seals are more effective in restricting air leakage than are those on earlier models like the MS 6B/7E.

6.5 2ND STAGE NOZZLES

	Unit 3A	Unit 3B	Unit 4A	Unit 4B
Current Hours (11/14/95)	16352	16062	4108	14264
Last Inspection, Hours	--	4082	6120	14264

Overall Assessment (4 inspections)

The nozzles appear to be in very good condition after some 14000 hours of service other than for any impactions/FOD. The coating appears to have at least 24000 hours capability at this site.

Vanes and Sidewalls (See Figures 8.28, 8.29):

Leading and trailing edges were not damaged mechanically and there was no deformation, thinning or hot spot bowing. There were no cracks at any location on the vane or sidewall, including the fillet between the vane-sidewall fillet or the root of the sidewall Z-notches, and the cooling circuits remained open and fully functioning. The coating was white-gray, was not breached or thinned, and had the capability of significantly longer service. There was no oxidation/corrosion of the base metal.

6.6 3RD STAGE NOZZLES

	Unit 3A	Unit 3B	Unit 4A	Unit 4B
Current Hours (11/14/95)	16352	16062	10228	14264
Last Inspection, Hours	8079	12586	6120	14264

Overall Assessment (8 inspections)

These uncoated nozzles were in very good condition after some 14000 hours of service other than for any impactions/FOD.

Vanes and Sidewalls (See Figures 8.30, 8.31):

Leading and trailing edges were not damaged mechanically and there was no deformation, thinning or hot spot bowing. There were no cracks at any location on the vane or sidewall, including the fillet between the vane and sidewall or the root of the sidewall Z-notches. The surfaces of both the vane and the sidewall were in good condition with no significant oxidation or corrosion. The oxide color was dark gray, which is typical of uncoated super alloys operating in this temperature range. There was no oxidation/corrosion of the base metal.

Stationary Shrouds and Seals

	Unit 3A	Unit 3B	Unit 4A	Unit 4B
Current Hours (11/14/95)	16352	16062	10228	14264
Last Inspection, Hours	8079	12586	6120	14264

Shrouds and seals play an integral part in the performance of the hot gas parts, and are of three types: Stationary Shrouds, Discourager/Angel Wing Seals, and Labyrinth Seals. Most can only be seen when the upper casings, and sometimes, the rotor are removed. Overall service is shown in the table above.

Overall Assessment

Most shrouds/seals were in very good condition with considerably more life potential. There were essentially no rubs on 2nd and 3rd stage shrouds. The 1st stage shrouds that were close to the horizontal joints were frequently rubbed, but the others were not. Rubs on the discourager, angel wing, and labyrinth seals were minor and less common, and were more on 2nd stage than on the 3rd.

6.7 1ST STAGE STATIONARY SHROUDS (SEE FIGURES 8.32, 8.33):

Many shrouds have now been inspected after 10000 to 14000 hours of service, and their condition varied from fair to very good. Rubs have been the main concern to date - 39 of the 384 inner shrouds at the site were refurbished or replaced. The shrouds were otherwise in good condition and there was no indication of cracking, oxidation, coating deterioration or cooling hole restriction.

Rubs, when they occur, were at both horizontal joint locations and, to a much lesser degree, at the 12 o’clock position. They varied from a very light “kiss” to a more substantial 60 mil cut which converted the normal dark-gray oxide color to a smeared, glassy layer that was white-gray. There was no preference as to whether it was a leading, center or trailing shroud (three of these “inner” shrouds are mounted into a single outer block). The coating withstood the rub until it was only 10 mils thick, at which point the coating remnants peeled away. Rubs of 30 mils depth also partially closed the center face cooling holes - the holes that were typically reworked or replaced at inspection.

2nd and 3rd Stage Stationary Shrouds (See Figures 8.34, 8.35):

These shrouds were in very good condition after 14000 hours of service. There were no cracks, oxidation, or deterioration. Minor rubs were occasionally found at some horizontal joint locations on the 2nd stage, but were virtually non existent on the 3rd stage.

Discourager Seals/Bucket Angel Wing Seals

Very few inspections have been conducted to date, but the indication is some minor rubbing on the 2nd stage and virtually none on the 3rd.

Labyrinth Seals

Only two sets of seals have been inspected to date. Unit 3B (5/94, 4082 hours) had some rubs on the 2nd stage but not the 3rd, and Unit 4A (2/95, 6120 hours) had no rubs on either.

6.8 COMBUSTION SYSTEM

	Unit 3A	Unit 3B	Unit 4A	Unit 4B
Current Hours (11/14/95) (a)	8273	3476 (b)	5361	9862
Last Inspection, Hours (a)	4530 (b)	8504 (b)	1252	9862 (b)

(a) These hours may represent time since any refurbishment. Total life might be longer than showndepending on the number of times the part was refurbished

(b) Removed for refurbishment.

Combustion operation before March 1994 was characterized by many shutdowns and some hardware modifications. The operation since that time has basically been baseloaded. Two machines have recently demonstrated 8000^{+} hour runs on 7FA - DLN2 hardware, at 8504 and 9862 hours. Most combustion hardware has now been refurbished at least once.

Overall Assessment

Combustion hardware, particularly with the more recent modifications, was in generally good condition and successfully refurbished a number of times. The coatings were still intact, the cooling holes were effective and, with the exception of the liner distortion, there generally wasn't much deterioration.

The areas of potential concern are:

A pattern of inward bulging on the liner walls

Occasional small hot spots/distortion on the face plate

Liner cracks - isolated, unrelated, and rare

Transition piece end frame wear - but reduced by design and material modifications.

End Cap Assemblies (See Figures 8.36, 8.37):

End cap assemblies have been in very good condition. All cooling holes were open and functioning, hula seal wear was minimal, and tube guards were in good condition and not worn. There were local hot spot areas frequently near the OD of the face plate, but they were not limiting to date. These zones were typically 2″ (50.8 mm) in diameter, close to the tertiary nozzle, oxidized 5-10 mils (0.127-0.254 in.) deep, and occasionally were slightly bulged to 0.1″ (2.54 mm).

Fuel Nozzles (See Figures 8.36, - 8.39):

Most fuel nozzles were in very good condition and there was no distress on the upstream vanes and their holes. Typically, the five fuel nozzles in each chamber were similar in appearance and had run cool with no oxidation or erosion on the tip ends. The tertiary nozzle, however, was sometimes a little hotter. The holes and annuli on the nozzle tip itself were generally open and unchanged, but some earlier atomizing air annuli had doubled in size due to oxidation.

Unit 3B (5/94, 4082 hours) lost a nozzle tip downstream (**Figure 8.39**), as was described in Section 4.3.

Unit 4B (11/95, 14264 hours) had some long-time dual fuel nozzles with internal deposits that occasionally blocked 25% of the atomizing air annulus. They were always on the lowest fuel nozzle in a chamber and were also worst in the “top-high” and “bottom-low” chambers. The source was probably the purge air.

Liners and Cross Fire Tubes (See Figures 8.40, - 8.50):

The combustion liners have been in generally good condition, but have universally had some distortion (inward bulging). The cooling holes were open and apparently unchanged, and there was no base metal thinning or oxidation. Hula seals and cross fire tube collars were not worn significantly.

The performance of the TBC coatings was very good - they have been fully intact other than on three liners with heavier distortion as shown in **Figures 8.41, 8.43, 8.45, and 8.47**. In these cases, the topcoat had spilled over a 2″ diameter area in the area of maximum distortion, although the basecoat still had not been damaged. The TBC coatings commonly have a wide variation in color, but did not correlate to the amount of distortion.

The distortion, or “inward bulging”, was seen near the head end of most liners, and is shown in **Figures 8.42, 8.43, 8.46, and 8.47**. It was centered consistently about 8" downstream of the liner head end and faced the central axis of the machine. The bulging was generally spread over a 10″ axial and 5″ circumferential area and was most highly distorted at the center of these areas. It’s maximum depth varied between liners in a given machine - being only 0.1″ on some liners but up to 0.8″ on others. Distortion at the two recent 8000$^+$ inspections (Unit 3B, 6/95, 8504 hours-- Unit 4B, 11/95, 9868 hours) was similar to that in previous 4000 hour inspections, so there is a possibility it stabilizes over time.

Three liners (of the 112 liners examined) also had a crack, but all were in completely different locations. Although of concern, it was felt these suggested isolated manufacturing problems (two were associated with welds) rather than a generic technical problem. One (Unit 4B, 11/95, 9868 hours, **Figure 8.48**) was a 5″ circumferential crack near the exit end immediately ahead of the last two series of cooling holes and was associated with a seam weld. Early on, another machine (Unit 4A, 11/94, 4867 hours) had two liners with cracks—one a 2″ cross fire tube collar weld, and the other a 7″ semi-circumferential center body crack, **Figure 8.49**.

The cross fire tubes themselves were also in good condition, with minimal (< 60 mils or 1.524 mm) wear on mating surfaces on the ends and the barrels, **Figure 8.50**. Two of the 91 tubes, however, were heavily worn and distorted on the end, as was caused by rubbing with the clips.

Transition Pieces (See Figures 8.51, - 8.57):

Early transition pieces were in good condition after service, while the more recent designs (with wear modifications) have been in very good condition. There was no thinning due to oxidation, and the TBC coatings remained consistently in very good condition, and was over 95% intact as shown in **Figures 8.53 - 8.56**.

The only service related degradation was wear on the end frames. Early designs consistently had wear in these slots/faces after 4000 hours which varied from 10 to 60% of the ligament thickness. The general severity was:

Side slot wear > ID slot/face wear > OD slot/face wear.

Wear was always heavier on the end of a slot rather than the center, **Figure 8.51**.

Various methods were evaluated over a period of time to minimize this wear. The first to be adopted into production was a slight repositioning of the end face together with a weld overlay on parts of the end frame. This was beneficial in that it allowed the end face wear to be distributed over a larger area, and on a more wear resistant material. The next to be evaluated was two methods for reducing wear in the side seal slots -- one with wear strips and the other with a change in end frame material. Both have now been examined after extended runs:

Two machines with wear strips had virtually no wear (**Figure 8.55**) but two of the many strips had cracks in the attachment weld. Neither caused the strip to be lost or damaged, and the cracks didn't look like they were propagating. They should be monitored because of their potential for downstream bucket damage.

One machine with FSX-414 end frames (the same alloy used for the 1st stage nozzle) had even less wear. Two of the 14 end frames, however, developed 1-2" (25.4-50.8 mm) cracks which were in completely different locations. Both cracks were very tight and looked as if propagation was very slow, and one initiated at a cooling hole, **Figure 8.57**.

6.9 FOD/IMPACTIONS

Overall Assessment

The most significant cause of hot gas path blading damage to date has been from impacts/FOD. This has been the only reason for removal/refurbishment of the FP&L hot gas path blading so far. The MS 7221FA appears to be as tolerant to these impacts as are the MS 7221E models. Parts with larger impacts, however, will probably have to be removed from service sooner, however, because of increased oxidation from the higher firing temperatures.

Small, Random Impactions (< 60 mils diameter)

Many older gas turbine models have some buckets or nozzle partitions with a few small impactions. The source of the impactions is generally not known, but these isolated "nicks" have not shortened the lives of those parts. The MS 7221FA seems to follow that same pattern in that two of three sets had similar sized impacts, possibly associated with initial installation of the gas turbines. Typically, the impacts were small (30-60 mils or 0.76-1.52 mm diam. x 5-20 mils or 0.127-0.508 mm deep), and on the 1st stage bucket just aft of the convex leading edge but not on any other stage. In one case, there was no additional growth of the impacts after 10000 hour more service. This will be monitored as service time increases, but it appears that the MS 7221FA will be equally tolerant to these very small impactions.

Larger Impactions (> 120 mils diameter)

There have been three instances where larger pieces have gone through the FP&L machines, two of which were from upstream parts. In each case, the parts were quite robust in view of the size of the ingested pieces, and fairly similar to the MS 7221E in this respect. In general, the first stage components were damaged more than were the latter stages - although the reverse has occasionally been seen on the MS 6B/7E.

FP&L MS 7221FA experience to date with larger impacts is as follows:

a. Unit 3A

(11/94, 8079 hours) had a single, large leading edge impact (0.3″ diam. x 20 mil deep) at 80% radial height which had disturbed both the coating and base metal (**Figure 8.6**), and was left in service.

b. Unit 3B

(5/94, 4082 hours) lost a fuel nozzle tip downstream, as is described in Section 4.3. Pictures are shown in **Figures 8.7, 8.11-8.13, 8.23-8.25, 8.28, 8.30, 8.32-8.35, and 8.39**. The downstream damage was surprisingly little. The 1st stage nozzle partitions and buckets were both removed for repair, while 2nd and 3rd stage nozzles and buckets were left in the machine. Leading edges on three 2nd stage buckets and two 3rd stage buckets were carefully blended in the machine.

Nozzles:

The only damage was to 1st stage nozzle segments and two 2nd stage nozzle segments. All 1st stage nozzle segments had impacts within 4″ (101.6 mm) of the convex trailing edge (up to 1″ or 25.4 mm diam. x 100 mils or 2.54 mm deep, and with 20% of the associated TBC coating removed). The tip had apparently lodged momentarily in the throat of one particular segment and disrupted it's cooling flow pattern. The result was matching gouges (2″ or 50.8 mm diam. x 50 mils or 1.27 mm deep) of oxidized/melted metal cut into the adjacent surfaces of that throat. A 0.5″ (12.7 mm) triangle was also removed from one of those trailing edges. The two 2nd stage segments had a breached coating (1″ or 25.4 mm diam. x 10 mils or 0.254 mm deep) at the leading edge pitch line.

Buckets:

All 1st stage buckets had impacts (up to 120 mils or 3.048 mm diam. x 30 mils or 0.762 mm deep), while five buckets also had larger impacts (up to 250 mils or 6.35 mm diam. 60 mils or 1.516 mm deep). All impacts were within 2″ or 50.8 mm of the convex leading edge. The leading edge tip was also lost on 2 buckets in 0.7″ or 17.8 mm triangles which exposed the #1 cooling channel.

All 2nd stage buckets had small leading edge impacts (10-80 mils or 0.254-2.16 mm diam. x 30 mils or 0.762 mm deep), while 15 buckets also had larger leading edge impacts (up to 300 mils or 7.62 mm diam. x 125 mils or 3.175 mm deep). All 3rd stage buckets had small leading edge impacts (10-60 mils or 0.254-1.516 mm diam. x20 mils or 0.508 mm deep), while 15 buckets also had larger leading edge impacts (up to 200 mils or 5.08 mm diam. x 200 mils or 5.08 mm deep). None of these 2nd or 3rd stage impacts had changed much in appearance when they were examined some 8000 hours later.

c. Unit 4A

(2/95, 6120 hours) experienced a compressor blade failure as described in Section 4.3. Pictures are shown **in Figures 8.9, 8.10, 8.14, 8.26, 8.27, 8.29, 8.31**. Combustion parts were essentially intact; 1st and 2nd stage nozzles and buckets and some 3rd stage buckets were removed for refurbishment, while the 3rd stage nozzles were quickly refurbished and reinstalled in the same machine.

Nozzles:

All 1st stage segments had impacts/scrapes on the convex vane within 4″ of the trailing edge (up to 1″ diam. x 100 mils deep, and with 20% of the associated TBC coating removed). The 2nd stage segments had impacts/scrapes (up to 500 mils diam. x 10 mils deep) within 4″ of the trailing edge, and on the leading edge (a few scuffs, up to 400 mils diam. x 20 mils deep). 3rd stage nozzle impacts were confined to an area within 4″ of the convex trailing edge (numerous scuffs, up to 500 mils diam. x 10 mils deep). All nozzles had been in good condition when inspected some 1300 hours previously.

Buckets:

There were impacts/scrapes within 2″ (50.8 mm)of the convex face leading and trailing edge of all 1st stage buckets, and sufficient to breach the coating (up to 500 mils or 12.7 mm diam. x 10 mils or 0.127 mm deep). About 20 buckets also had leading edge impacts (up to 500 mils or 12.7 mm diam. x 100 mils or 2.54 mm deep). The leading edge tip was also lost on 5 buckets in the form of 0.5″ (12.7 mm) triangles, and there was a 0.5″ or 12.7 mm diameter pierced wall on one bucket that exposed the #1 cooling channel at 70% radial height.

All 2nd stage buckets had small leading edge impacts/scrapes (30-500 mils or 0.762-12.7mm diam. x 10 mils or 0.127 mm deep), while 20 buckets also had larger leading edge impacts (up to 200 mils or 5.08 mm in diam. x 100 mils or 2.54 mm deep), and one bucket had lost part of it’s tip shroud. All 3rd stage buckets had small leading edge impacts (up to 100 mils or 2.54 mm diam. x 10 mils or 0.254 mm deep), while one bucket also had 0.5″ or 12.7 mm convergent cracks on the leading edge near the tip.

7

INDIVIDUAL INSPECTIONS - HIGHLIGHTS CHARTS

General Notes

These charts are condensed versions of the individual Inspection Reports that were issued for each inspection.

They contain a number of details, some of which are relatively minor from the gas turbine operational standpoint. They are included strictly for record purposes and as a guide for future inspections.

The Inspection Charts are in the following order:

7.1	Unit 3A	Combustion Inspection	4/13/94
7.2	Unit 3A	Combustion Inspection	11/14/94
7.3	Unit 3B	Hot Gas Path Inspection	5/23/94
7.4	Unit 3B	Combustion Inspection	6/11/95
7.5	Unit 4A	Major Inspection	11/7/94*
7.6	Unit 4A	Major Inspection	2/16/95
7.7	Unit 4B	Combustion Inspection	9/14/94
7.8	Unit 4B	Combustion Inspection	11/14/95

The Inspection highlight chart put together from notes taken at the site during the various inspections.

The following notes pertain to all of the Inspection Charts in this Section 7.

Pictures that represent these inspections are all included in Section 8 which has it's own Index.

All parts in a given stage looked similar, unless indicated otherwise.

Service life, in hours, is the life of the parts after they were last installed. Some parts (particularly combustion parts) might have longer total life because of refurbishment before installation.

All blading remained in service unless indicated. Combustion parts, however, were mostly taken out for scheduled refurbishment.

Combustion Parts have been identified by arbitrary designations.

DLN2 - 1G - original fuel nozzle design, gas only assembly.

DLN2 - 2G - newer fuel nozzle design, gas only.

DLN2 - 2DF newer fuel nozzle design, dual fuel.

The newer fuel nozzle design had more center protrusion and a tack weld on the face.

Transition pieces did not have the wear modifications (strips or cast FSX-414 end frames) unless noted.

Hula seal and transition piece wear is shown as percentage loss in thickness of the part or of its mating ligament.

Conversion Table

(Dimensions of Length only)

English Unit	Metric Unit
1 mil (or $1x10^{-3}$ inch)	00.0254 mm
10 mils (or $1x10^{-2}$ inch)	00.254 mm
100 mils (or 0.1 inch)	02.54 mm
1000 mils (or 1.01 inch)	25.4 mm

SECTION 7.1

UNIT 3A Combustion Inspection Highlights: 4/13/94 -- 3549 Operating Hours

Description (See General Notes at Beginning of Section 7)	
Part: 1st Stage Nozzles	
Vanes	(3549 hours. 12 vanes inspected. No crakcs, mechanical damarge or impacts/FOD; no significant oxidation (<5 mils or 0.127 mm) at any point; all cooling holes and slots were open with normal oxide patterns around the holes; leading and trailing edges were not burned or distorted. The TBC coating on the aft convex face could not be inspected.
Sidewalls	No cracks, mechanical damage or distortion; oxidation was less than 5 mils.
Part: 1st Stage Buckets	
Vanes and Coatings	(3549 hours) 12 buckets inspected. No mechanical damage such as FOD, cracks, dents, thinning or distortion of the trailing edge; coatings were in very good condition with no evidence of local breaching; concave oxide colors were an even tan/rose, while convex were gray/white/tan.
Squealer Tips	(original non-slotted tip design). Intact with no cracks on convex or concave walls; but oxidized on the concave side at the midchord (1″ or 25.4 mm axial and within 0.3″ or 7.62 mm of tip, with coating breach and 10 mils metal oxidation) and also at immediate trailing edge tip (1″ or 25.4 mm axial and within 0.3″ or 7.62 mm of tip, with coating breach and 20-60 mils metal oxidation); no rub lips could be seen. Tip caps were not accessible for inspection.
Part: 2nd Stage Nozzles	
(3549 hours)	Not accessible for inspection.
Part: 2nd Stage Buckets	
(3549 hours)	Not accessible for inspection
Part: 3rd Stage Nozzles	
Vanes	(3549 hours). No cracks, impact/FOD or mechanical damage; leading and trailing edges were in good condition and not distorted or burned; surface oxides were a typical even dull gray; no base metal oxidation (<2 mils or 0.0508 mm) at any location.
Sidewalls	No mechanical damage or cracks on either the sidewall or the Z-form; surface oxides were anticipated even dull gray; no oxidation of the base metal (<2 mils or 0.0508 mm).
Part: 3rd Stage Buckets	
Vanes	(3549 hours) No cracks, impact/FOD, mechanical damage or base metal oxidation. The coating was anticipated black, but uneven with local thinning and had been lost over about 10% of the vane surface.
Shrouds	No cracks, oxidation or mechanical damage; minimal wear on the Z-notches; wear coating was still intact; Z-form engagement was 90%. The outer shroud seal was not accessible for inspection.

Shanks Neither forward or aft angel wing seals were accessible for inspection.

Part: Shrouds/Seals

1st Stage Stationary Shrouds (3100 hours). Not accessible for inspection.

2nd Stage Stationary Shrouds (3549 hours). Not accessible for inspection.

Discourager/Angel Wing Seals (3549 hours). Not accessible for inspection.

2nd and 3rd Stage Labyrinth Seals (3549 hours). Not accessible for inspection.

Part: Combustion System

End Caps (DLN2-1G) (1000 hours). No cracks, oxidation, distortion, overheating or significant hula wear.

Fuel Nozzles (1000 hours). Not inspected.

Liners (3549 hours). No cracks or oxidation; TBC and hulas were both 95% intact. Liner bulging was minor if at all.

Cross Fire Tubes (3549 hours). In good condition with minimal wear.

Transition Pieces (3549 hours). No cracks, distortion or oxidation, and TBC was still 95% intact.

End frame wear was 50-80% both on side seal slots and ID/OD slots/face.

SECTION 7.2

UNIT 3A Combustion Inspection Highlights: 11/14/94 -- 8079 Operating Hours

	Description (See General Notes at Beginning of Section 7)
Part: 1st Stage Nozzles	
Vanes	(8079 hours). No cracks, mechanical damage or impacts/FOD; no significant oxidation (< 5 mils) at any point; all cooling holes and slots were open with normal oxide patterns around the holes; leading and trailing edges were not burned or distorted; TBC coating on the aft convex face was still 95% intact. Three vanes (11 PM looking downstream) had impacts (1″ diameter x 0.1″ deep - note single 1st stage bucket impact) where TBC was pierced but no damage or oxidation was seen.
Sidewalls	No mechanical damage or distortion; oxidation generally less than 5 mils deep but was 10 mils in three locations (Z-form joint between segments, convex fillet near the leading edge/outer sidewall junction, and downstream of the 4x4 and 2x2 cooling holes on the inner sidewall). There were six 0.5″ cracks - three at Z-form notches and 3 at trailing edge/inner sidewall junctions; no other cracks or deterioration could be seen.
Part: 1st Stage Buckets	
Vanes and Coatings	(8079 hours, 12 buckets inspected). No mechanical damage such as cracks, thinning or distortion anywhere on the vane; coatings were in very good condition, with no evidence of local breaching. Concave oxide colors were an even tan/rose, while convex were gray/white/tan. One bucket had a large leading edge impact (300 mils diam. x 20 mils depth at 80% radial height) at which oxidation had started, while most buckets had small (<60 mil diam.) impacts/FOD on the leading edge with no coating breach.
Squealer Tips	(original non-slotted tip design). The squealer tip was intact with no cracks on convex or concave walls; but oxidized on the concave side at the midchord (1″ axial and within 0.3″ of tip, with coating breach and 10 mils metal oxidation) and also at immediate trailing edge tip (1″ axial and within 0.3″ of tip, with coating breach and 60 - 100 mils metal oxidation); rub lips projected forward from the tip for 20-100 mils, but the minor adjacent coating damage suggested that the bucket tips had not rubbed severely. Tip caps were not accessible for inspection. Other than increased squealer tip oxidation, the buckets had not changed significantly since the 4/13/94 inspection.
Part: 2nd Stage Nozzles	
	(8079 hours). Not accessible for inspection.
Part: 2nd Stage Buckets	
	(8079 hours). Not accessible for inspection.

Part: 3rd Stage Nozzles

Vanes (8079 hours) No cracks, impact/FOD or mechanical damage; leading and trailing edges were in good condition and not distorted or burned; surface oxides were a typical even dull gray; no base metal oxidation (<2 mils) at any location.

Sidewalls No mechanical damage or cracks in either sidewall or Z-form; surface oxides were anticipated even dull gray; no base metal oxidation (<2 mils). Overall there was no significant change in appearance since the 4/13/94 inspection.

Part: 3rd Stage Buckets

Vanes (8079 hours). No cracks, impact/FOD, mechanical damage, or base metal oxidation. The coating was the anticipated black color but was uneven with local thinning, and had been lost over about 20% of the vane surface.

Shrouds No cracks or mechanical damage; insignificant wear on the Z-notches; Z-form engagement was 90%. The outer shroud seal was not accessible for inspection.

Shanks Neither forward or aft angel wing seals were accessible for inspection.Overall there was no significant visual change since the 4/13/94 inspection other than the increased loss of coating.

Part: Shrouds/Seals

1st Stage Stationary Shrouds (7600 hours). 12 of 92 had rubbed moderately (10-40 mils) at 9 PM. The rest were in excellent shape with no cracking, oxidation, coating deterioration or hole plugging.

2nd and 3rd Stage Stationary Shrouds (8079 hours). Not accessible for inspection.

Discourager/Angel Wing Seals (8079 hours). 3rd stage was in excellent shape with no cracks or oxidation, and minor rubs (< 10 mils) just at 9 PM.

2nd and 3rd Stage Labyrinth Seals (8079 hours). Not accessible for inspection.

Part: Combustion System

End Caps (DLN2-1G) (4530 hours). No cracks or distortion and insignificant hula wear; local face plate oxidation 2″ diam. x 10 mils deep.

Fuel Nozzles (4530 hours). No cracks or distortion, and all nozzles looked similar; atomizing air annuli opened 0.12″ on six nozzles.

Liners (4530 hours). No cracks or oxidation; TBC and hulas were both 95% intact. Liner bulging: 1 at 0.5″, 4 at 0.3″ and 9 below 0.2″.

Cross Fire Tubes (8079 hours). 13 in good condition with only minor wear; 1 had heavy wear on one end, possibly from clip wear.

Transition Pieces (4530 hours). No cracks , distortion or oxidation, and TBC was 95% intact. End frame wear was 10 to 60% on side seal slots, and 10-40% on ID/OD seal slots/face.

SECTION 7.3

UNIT 3B Hot Gas Inspection Highlights: 5/23/94 -- 4082 Operating Hours

(Fuel Nozzle Tip Loss, see Figures 8.7, 8.11-8.13, 8.23-8.25, 8.28, 8.30, 8.32-8.35, 8.39)

	Description (See General Notes at Beginning of Section 7)
Part: 1st Stage Nozzles	
Vanes	(4082 hours). 23 segments - no cracks, mechanical damage or impacts/FOD; no significant oxidation (< 5 mils) at any point; all cooling holes and slots were open with normal oxide patterns around the holes; leading and trailing edges were not burned or distorted; TBC coating on the aft convex face was still 95% intact. The remaining segment (#3): Similar to others except for damage in enclosed throat where fuel nozzle tip had lodged momentarily and disrupted cooling flow. Damage was two 2″ diameter zones at 40-80% radial height - one at concave trailing edge and the other at adjacent convex mid span location. Affected metal was heavily oxidized/melted/wasted up to 0.12″ in depth, three nearby cooling slots had oxidized closed, and one trailing edge had also lost a 0.5″ x 0.7″ triangle. Although graphic, this segment is repairable (the entire nozzle was removed for refurbishment).
Sidewalls	No cracks, mechanical damage or distortion; oxidation generally less than 5 mils deep but was 10 mils in three locations (Z-form joint between segments, convex fillet near the leading edge/outer sidewall junction, and downstream of the 4x4 and 2x2 cooling holes on the inner sidewall).
Part: 1st Stage Buckets	
Vanes and Coatings	(4082 hours). All buckets had impacts/FOD up to 120 mils diam. and 5 buckets had impacts up to 250 mils diam. and 60 mils deep - all just aft of leading edge on the concave side; two buckets had lost leading edge tips (0.7″ triangles). The rest of bucket vanes did not have mechanical damage such as cracks, thinning or distortion and the coatings there were in good condition with no evidence of breaching. Concave oxide colors were an even white/rose while convex were white/black.
Squealer Tips	(newer slotted tip design). Radial tip cracks of 60-200 mils length on the concave squealer wall (28 buckets) and the aft squealer tip cavity cutout (6 buckets); squealer tip was oxidized on the concave side at the midchord (1″ axial and within 0.3″ of tip, with coating breach and 10 mils metal oxidation) and also at immediate trailing edge tip (1″ axial and within 0.3″ of tip, with coating breach and 80-120 mils metal oxidation); rub lips projected forward from the tip up to 200 mils and there were also modest tip rubs (20 mils). Tip caps had not deteriorated, cracked or bent. Overall, the buckets looked a little “hotter” than others at this site (possibly from the peak load test) and the damage less than might have been anticipated from the ingested part. The bucket set was removed, and the substantial majority appear capable of reuse/refurbishment.

Part: 2nd Stage Nozzles	
Vanes	(4082 hours). No cracks or mechanical damage; trailing edges in good condition and not distorted or burned. 22 segments had no coating breach or base metal oxidation at any point and an even gray-white coating oxide; cooling holes were open and clear. The remaining 2 segment were similar but had coating breach and base metal oxidation (1” diam. x 10 mils deep) on leading edge of only one vane (in line with, and caused by, the lost fuel nozzle tip).
Sidewalls	No cracks, mechanical damage on sidewalls or Z-form. Coating was even gray-white and unbreached.
Part: 2nd Stage Buckets	
Vanes	(4082 hours) No cracks, mechanical damage, base metal oxidation or coating breach except for impacts/FOD on leading edge (generally to 60 mils diam.) but heavier on 15 buckets (50-300 mils diam. x 10-120 mils deep - 3 of which were blended in machine); coating was anticipated mixture of tan-gray.
Shrouds	No cracks or mechanical damage; insignificant wear on the Z-notches, Z-form engagement was 90%; no rubs on outer shroud seal.
Shanks	No rubs on either the forward or aft angel wing seals.
Part: 3rd Stage Nozzles	
Vanes	(4082 hours). No cracks, impact/FOD, or mechanical damage; leading and trailing edges were in good condition and not distorted or burned; surface oxides were a typical even dull gray; no base metal oxidation (<2 mils) at any location.
Sidewalls	No mechanical damage or cracks on either sidewall or Z-form; surface oxides were anticipated even dull gray; no base metal oxidation (<2 mils).
Part: 3rd Stage Buckets	
Vanes	(4082 hours). No cracks, mechanical damage, base metal oxidation or coating breach except for impacts/FOD on leading edge (generally to 60 mils diam.) but heavier on 2 buckets (200 mils diam. x 200 mils deep which were blended in machine); coating was the anticipated black color but was locally thinned, and had been lost over about 10% of the vane surface.
Shrouds	No cracks or mechanical damage; insignificant wear on Z-notches, Z-form engagement 90%; no outer shroud seal rubs.
Shanks	The forward angel wing seal was not rubbed; the aft seal was not accessible for inspection.
Part: Shrouds/Seals	
1st Stage Stationary Shrouds (4082 hours). Substantial rubs (10-60 mils at 3 PM, 9 PM and 12 PM looking downstream), some probably occurred pre-3/94 and 30 of the 96 shrouds were replaced. The others were in excellent shape with no cracking, oxidation, coating deterioration or hole plugging.	
2nd Stage Stationary Shrouds (4082 hours). Minor rubs (10-20 mils) at 3 PM and 9 PM and sporadically in upper half, but otherwise in excellent condition.	

3rd **Stage Stationary Shrouds** (4082 hours). In excellent shape, with no cracking, oxidation, or rubs.
2nd **Stage Discourager Seals** (4082 hours). Forward - slightly rubbed. Aft - not rubbed 3rd **Stage Discourager Seals** (4082 hours). Forward - not rubbed. Aft - not rubbed **Angel Wings** (4082 hours). No bucket angel wings were rubbed on any stage.
2nd **Stage Rotor Labyrinth Seals** (4082 hours). Rubs (10-20 mils) on wheelspace teeth, rubs on the nozzle diaphragm seal (10-90 mils) at 3 PM, 9 PM and 12 PM. 3rd **Stage Rotor Labyrinth Seals** (4082 hours). No rubs on the wheelspace seal, and minor rubs on the nozzle diaphragm seal (10-20 mils) at 12 PM.
Part: Combustion System **End Caps** (DLN2-1G) (2500 hours). Small cracking (0.5") and insignificant hula wear; local face plate oxidation 2" diam. x 5 mils deep with minor distortion.
Fuel Nozzles (2500 hours) 13 Chambers - no cracks or distortion, tertiary nozzles were a little hotter; atomiz. annuli opened to 0.12" **1 Chamber (#12)** - similar to others except tertiary nozzle tip had been lost at circumferential EB weld on barrel.
Liners (4082 hours). No cracks, or oxidation; TBC and hulas were both 95% intact. Liner bulging: 5 at 0.4", 5 at 0.2" and 4 below 0.2" **Cross Fire Tubes** (4082 hours). 13 in good condition with only minor wear; 1 had heavy wear on one end, possibly from clip wear.
Transition Pieces(4082 hours). No cracking , distortion or oxidation, and TBC was 95% intact. End frame wear was 20-80% on side seal slots, and 10-60% on ID/OD seal slots/face.

SECTION 7.4

UNIT 3B Combustion Inspection Highlights: 6/11/95 -- 12586 Operating Hours(See Figures 8.2, 8.40-8.43, 8.52-8.55)

Description (See General Notes at Beginning of Section 7)
Part: 1st Stage Nozzles **Vanes** (8504 hours). No cracks, mechanical damage or impacts/FOD; no significant oxidation (< 5 mils) at any point; all cooling holes and slots were open with normal oxide patterns around the holes; leading and trailing edges were not burned or distorted; TBC coating on the aft convex face was still 95% intact. **Sidewalls** No cracks, mechanical damage or distortion; oxidation generally less than 5 mils deep but was 10 mils in three locations (Z-form joint between segments, convex fillet near the leading edge/outer sidewall junction, and downstream of the 4x4 and 2x2 cooling holes on the inner sidewall).
Part: 1st Stage Buckets **Vanes and Coatings** (8504 hours). No mechanical damage such as cracks, impacts/FOD, thinning or distortion anywhere on the vane; cooling holes were clean and there were no indications of trailing edge cracks; coatings were in very good condition, with no evidence of local breaching; concave oxide colors were an even tan/rose, while convex were gray/white/tan. **Squealer Tips** (newer slotted tip design). Tip was intact with no cracks on convex or concave walls; tip oxidized on the concave side at the midchord (1″ axial and within 0.3″ of tip, with coating breach and 10 mils metal oxidation) and also at immediate trailing edge tip (1″ axial and within 0.3″ of tip, with coating breach and 60-120 mils metal oxidation); rub lips projected from the tip 20-100 mils, but the minor adjacent coating damage suggested only minor bucket rubs. Tip caps were not accessible for inspection. **Angel Wings** Not accessible for inspection.
Part: 2nd Stage Nozzles 12586 hours).Not accessible for inspection.
Part 2nd Stage Buckets **Vanes** (12586 hours). No cracks, mechanical damage, base metal oxidization or coating breach except for FOD on leading edge (which have not changed significantly in size or oxidation since the 5/23/94 inspection); coatings were typical tan-gray. **Shrouds** No cracks or mechanical damage; insignificant wear on the Z-notches; Z-form engagement was 90%. The outer shroud seal was not accessible for inspection. **Shanks** Forward and aft angel wing seals were not accessible for inspection.

Part: 3rd Stage Nozzles

Vanes (12586 hours). No cracks or mechanical damage or impacts/FOD; leading and trailing edges were in good condition and not distorted or burned; surface oxides were a typical even dull gray; no base metal oxidation (<2 mils) at any point.

Sidewalls No mechanical damage or cracks on either sidewall or Z-form: surface oxides were anticipated even dull gray color; no oxidation of the base metal (<2 mils). Overall: No significant change in appearance since the 5/23/94 inspection.

Part: 3rd Stage Buckets

Vanes and Shrouds (12586 hours). No significant change since 5/23/94 inspection including the size/oxidation of the impactions and Z-shroud engagement; outer shroud seal was not rubbed; coating was the anticipated black color but was locally thinned, and had been lost over about 20% of the vane surface.

Shanks Neither the forward or aft angel wing seals were accessible for inspection.

Part: Shrouds/Seals

1st Stage Stationary Shrouds (8504/12586 hours, 30 of 96 shrouds replaced at 4082 hrs). Minor rubs of 10-20 mils at 3 PM and 9 PM

2nd Stage Stationary Shrouds (12586 hours). Not accessible for inspection.

3rd Stage Stationary Shrouds (12586 hours). Good condition with no cracking, oxidation, or rubs.

Discourager/Angel Wing Seals(12586 hours). Not accessible for inspection.

2nd and 3rd Stage Labyrinths (12586 hours). Not accessible for inspection.

Part: Combustion System

End Caps (DLN2-1G) (8504 hours). Insignificant hula wear. Five face plates had local oxidation zones mostly near OD and tertiary nozzle (2″ diam. x 5 mils deep, some distorted to 0.1″ height); cap #14 had a 1″ face plate crack assemblies good condition otherwise.

Fuel Nozzles (8504 hours). No cracks or distortion; all nozzles looked similar; atomizing air annulus not oxidized open.

Liners (8504 hours). No cracks or oxidation and hulas were 95% intact. Liner bulging: 1 at 0.7″, 2 at 0.4″ and 2 at 0.3″ and 10 below 0.2″. TBC 95% intact on all liners, except locally spalled and cracked on the single 0.7″ bulge.

Cross Fire Tubes (8504 hours). Good condition with minor wear.

Transition Pieces (8504 hours). (Wear strip mods.) No cracking , distortion or oxidation, and TBC was 95% intact. End frame wear was 0-10% on side seal slots, and 10-30% on ID/OD seal slots/face; a 1″ crack on one wear strip weld attachment joint.

SECTION 7.5

UNIT 4A Major Inspection Highlights: 11/7/94 -- 4868 Operating Hours

Description (See General Notes at Beginning of Section 7)
Part: 1st Stage Nozzles **Vanes** (4868 hours). 12 segments examined. No cracks, mechanical damage or impacts/FOD; no significant oxidation (< 5 mils) at any point; all cooling holes and slots were open with normal oxide patterns around the holes; leading and trailing edges were not burned or distorted; TBC coating on the aft convex face was still 95% intact. **Sidewalls** No cracks, mechanical damage or distortion; oxidation generally less than 5 mils deep but was 10 mils downstream of the 4x4 and 2x2 cooling holes on the inner sidewall.
Part: 1st Stage Buckets (4868 hours). Not available for inspection.
Part: 2nd Stage Nozzles **Vanes** (4868 hours). No cracks or mechanical damage; leading and trailing edges in good condition and not distorted or burned; no coating breach or base metal oxidation at any point and an even gray-white coating oxide; cooling holes open and clear. **Sidewalls** No cracks, mechanical damage on sidewalls or Z-form. Coating was even gray-white and unbreached.
Part: 2nd Stage Buckets (4868 hours). Not available for inspection.
Part 3rd Stage Nozzles **Vanes** (4868 hours). No cracks, impact/FOD, or mechanical damage; leading and trailing edges were in good condition and not distorted or burned; surface oxides were a typical even dull gray; no base metal oxidation (<2 mils) at any location. **Sidewalls** No mechanical damage or cracks on either sidewall or Z-form; surface oxides were anticipated even dull gray; no base metal oxidation (<2 mils).
Part 3rd Stage Buckets (4868 hours). Not available for inspection.
Part: Shrouds/Seals **1st Stage Stationary Shrouds** (4868 hours). Moderate rubs at 9 PM, and 12 of 92 shrouds were replaced. In all other respects, the shrouds were in good condition, with no cracks, oxidation or coating loss.
2nd and 3rd Stage Stationary Shrouds (4868 hours). In good condition with no cracking, oxidation, or rubs.
Discourager/Angel Wing Seals (4868 hours). Not accessible for inspection.
2nd and 3rd Stage Labyrinths (4868 hours). Not accessible for inspection.

Part: Combustion System **End Caps** (DLN2-1G) (4700 hours). No cracks, distortion or oxidation (5 mils) or hula wear.
Fuel Nozzles (4700 hours). No cracks or distortion; all nozzles looked similar and cool; atomizing air annulus had oxidized about 60 mils on one fuel nozzle, but not on others.
Liners (4868 hours). No oxidation, and TBC and hulas were 95% intact. Liner bulging: 2 at 0.7″, 3 at 0.5″ and 10 below 0.3″. TBC 95% intact except for topcoat spall (1″x2″) on liners #8 & #13 at maximum bulge; one liner had 2 cracks (7″ body crack and a 2″ crack at the cross fire tube collar weld). **Cross Fire Tubes** (4868 hours). Good condition with only minor wear.
Transition Pieces (4868 hours). No cracks , distortion or oxidation, and TBC was 95% intact. End frame wear was 10-60% on side seal slots, and 10-40% on ID/OD seal slots/face.

SECTION 7.6

UNIT 4A Major Inspection Highlights: 2/16/95 -- 6120 Operating Hours (Compressor Blade Failure, see Figures 8.9, 8.10, 8.14, 8.26, 8.27, 8.29, 8.31)

Description (See General Notes at Beginning of Section 7)
Part: 1st Stage Nozzles **Vanes** (6120 hours). No cracks, mechanical damage or significant oxidation (< 5 mils) at any point; all cooling holes and slots were open with normal oxide patterns around the holes; leading and trailing edges were not burned or distorted. A total of 20 impactions (0.2-1.0″ diam. x 0.1″ deep) were on the aft convex vanes within 4″ of the trailing edges - some caused small cracks. Most impactions were oxidized, but 20% were straw colored which suggested short time at temperature. The TBC coating in this area was chipped off and was now only about 80% effective **Sidewalls** No cracks, mechanical damage or distortion; oxidation generally less than 5 mils deep but was 10 mils downstream of the 4x4 and 2x2 cooling holes on the inner sidewall. The nozzle was removed for refurbishment.
Part: 1st Stage Buckets **Vanes and Coatings** (6120 hours). Pierced leading edge on 1 bucket (70% height); scuffs/impactions (to 0.5″ diam. x 10 mils deep) on all buckets on convex vane within 1.5″ of both leading and trailing edges, where coating was breached but there was no base metal oxidation; 20 buckets had larger impactions (0.5″ diam. x 0.1″ deep) with base metal deformation but not yet oxidized. All other areas were in good condition with no cracks, thinning, distortion or local topcoat thinning or breaching; concave oxide colors were an even tan/rose, while convex were gray/white/tan **Squealer Tips** (original non-slotted tip design). Leading edge tips (0.5″ triangle) were lost on 5 buckets to expose the #1 channel while another 5 buckets had lost part of their squealer tip wall (to 0.5″) in various other locations; tip caps in these buckets were significantly oxidized (which otherwise were not cracked or bent or oxidized); no radial tip cracks were seen. The tips were oxidized on the concave side at the midchord (1″ axial and within 0.3″ of tip, with coating breach and 10 mils metal oxidation) and also at immediate trailing edge tip (1″ axial and within 0.3″ of tip, with coating breach and 60-100 mils metal oxidation). Rub lips projected forward from the tip up to 200 mils and there were modest rubs (20 mils) on the leading edge tip. **Angel Wing Seals**. There were no rubs on either the forward or aft angel wing seal. The buckets were removed for refurbishment. Replaced with GT29IN-PLUS buckets (42 new, 50 reused from Unit 3B).

Part:2nd Stage Nozzles

Vanes	(6120 hours). No cracks, mechanical damage, distortion or coating breach/base metal oxidation except for 6 nozzles that had impactions on the leading edge and all nozzles had them on the convex trailing edge (0.2″-0.5″ diam. x 10 mils deep). Coating, which generally was gray-white, was breached in impacted areas but there was no base metal oxidation.
Sidewalls	No cracks or mechanical damage on sidewalls or Z-form; coating was an even gray-white color and unbreached Other than the FOD impactions, the nozzle had not changed significantly since 11/7/94. The nozzle was removed for refurbishment.

Part: 2nd Stage Buckets

Vanes	(6120 hours). No cracks, mechanical damage, base metal oxidation or coating breach except for impacts/FOD on convex leading edge (generally to 60 mils diam.) and convex trailing edge (0.5″ diam. x 10 mils deep). 20 buckets also had leading edge impactions (0.2″ diam. x 0.1″ deep) with some associated dents. Coating color was tan-gray.
Shrouds	No cracks or mechanical damage; insignificant wear on the Z-notches, Z-form engagement was 90%; no rubs on outer shroud seal.
Shanks	No rubs on either the forward or aft angel wing seals. The bucket set was removed for refurbishment.

Part: 3rd Stage Nozzles

Vanes	(6120 hours). No cracks, mechanical damage or impacts/FOD other than convex trailing impactions (0.2″-0.5″ diam. x 10 mils deep); leading and trailing edges were otherwise in good condition and not distorted or burned; surface oxides were a typical even dull gray; no base metal oxidation (<2 mils) at any point.
Sidewalls	No mechanical damage or cracks on either sidewall or Z-form; surface oxides were anticipated even dull gray color; no oxidation of the base metal (<2 mils). Other than the impactions, the nozzle had not changed significantly since 11/7/94. It was refurbished and reinstalled.

Part: 3rd Stage Buckets

Vanes	(6120 hours). No cracks, mechanical damage, base metal oxidation or coating breach except for impacts/FOD on leading edge (generally to 60 mils diam. x 10 mils deep) and a single bucket with converging 0.5″ leading edge cracks from impact near the tip; coating was the anticipated black color but was locally thinned, and had been lost over 10% of the vane surface - in addition to the impacted areas.

Shrouds No cracks or mechanical damage; insignificant wear on the Z-notches, Z-form engagement was 90%; no rubs on outer shroud seal.

Shanks Forward and aft angel wing seals were not rubbed. Twenty three (23) buckets were replaced.

Part: Combustor System

End Caps (DLN2-2DF) (1253 hours). No cracks, oxidation, distortion overheating or significant hula wear.

Fuel Nozzles (1253 hours). No cracks or distortion, all nozzles looked similar; atomizing air annulus not oxidized open.

Liners (1253 hours). No cracks or oxidation. TBC and hulas were both 95% intact. Liner bulging: 5 at 0.2″, 5 at none.

Cross Fire Tubes (1253 hours). Good condition with only minor wear.

Transition Pieces (1253 hours, Wear strip mods.). No cracking ,distortion or oxidation, and TBC was 95% intact. End frame wear was 0-10% on side seal slots, and 0-10% on ID/OD seal slots/frame; one wear strip weld joint had a 4″ crack.

Part: Shrouds/Seals

1st Stage Stationary Shrouds (6120 hours). Moderate rubs (10-60 mils, but location not known as shrouds were removed); 9 of the 96 shrouds were replaced. The others were in good condition with no cracks, oxidation or coating deterioration or hole plugging.

2nd Stage Stationary Shrouds (6120 hours). A few, inconsequential rubs (0-10 mils) on the upper half.

3rd Stage Stationary Shrouds (6120 hours). Good condition, with no cracking, oxidation, or rubs.

Discourager Seals (6120 hours). Not inspected.

Bucket Angel Wing Seals (6120 hours). Not rubbed on any stage

Rotor Labyrinths - 2nd/3rd 2nd and 3rd Stage (6120 hours). Good condition with no rubs.

Part: Compressor

(6120 hours). From Stage 3, most of the blading was damaged by impact or deformation. Parts of three blades (stator #3, rotor #4 and stator #11) had also broken and gone downstream. GTD-450 blades resisted impact more than those of AISI 403Cb.

SECTION 7.7

UNIT 4B Combustion Inspection Highlights: 9/14/94 -- 4402 Operating Hours

Description
(See General Notes at Beginning of Section 7)

Part:1st Stage Nozzles

Vanes (4402 hours). No cracks, mechanical damage or impacts/FOD; no significant oxidation (< 5 mils) at any point; all cooling holes and slots were open with normal oxide patterns around the holes; leading and trailing edges were not burned or distorted; TBC coating on the aft convex face was still 95% intact. Many small "positives" (<30 mils) on leading edges from material going through the machine, but had not caused harm to date.

Sidewalls No cracks, mechanical damage or distortion; oxidation generally less than 5 mils deep but was 10 mils in two locations (Z-form joint between segments, and downstream of the 4x4 and 2x2 cooling holes on the inner sidewall).

Part:1st Stage Buckets

Vanes and Coatings (4402 Hours). No mechanical damage such as cracks, thinning or distortion anywhere on the vane; coatings were in very good condition; no evidence of local breaching. Concave oxide colors were an even tan/rose, while convex were gray/white/tan. Most buckets had small (<60 mil diam.) impacts/FOD on the leading edge with no coating breach.

Squealer Tips (original non-slotted tip design). The squealer tip was intact with no cracks on convex or concave walls; but oxidized on the concave side at the midchord (1" axial and within 0.3" of tip, with coating breach and 10 mils metal oxidation) and also at immediate trailing edge tip (1" axial and within 0.3" of tip, with coating breach and 60-100 mils metal oxidation); rub lips projected forward from the tip for 20-100 mils, but the minor adjacent coating damage suggested that the bucket tips had not rubbed severely. Tip caps were not accessible for inspection.

Part:2nd Stage Nozzles

(4402 hours). Not accessible for inspection.

Part:2nd Stage Buckets

(4402 hours). Not accessible for inspection.

Part:3rd Stage Nozzles

Vanes (4402 hours). No cracks or mechanical damage or impacts/FOD; leading and trailing edges were in good condition and not distorted or burned; surface oxides were a typical even dull gray; no base metal oxidation (<2 mils) at any point.

Sidewalls No mechanical damage or cracks on either sidewall or Z-form: surface oxides were anticipated even dull gray color; no oxidation of the base metal (<2 mils).

Part: 3rd Stage Buckets

Vanes	(4402 hours). No cracks, impact/FOD, mechanical damage or base metal oxidation. The coating was anticipated black, but uneven with local thinning and had been lost over 20% of the vane surface.
Shrouds	No cracks, oxidation or mechanical damage; insignificant wear on the Z-notches; Z-form engagement was 90%. The outer shroud seal was not accessible for inspection.
Shanks	Neither forward or aft angel wing seals were accessible for inspection.

Part: Shrouds/Seals

1st Stage Stationary (4402 hours). Moderate rubs (10-50 mils) on 20 of the 96 shrouds at 3 PM and 9 PM; rest were in good condition with no cracks, oxidation, coating deterioration or hole plugging.. Rainbow coated shrouds were in good condition; not in rubbed zone.

2nd Stage Stationary Seals (4402 hours). Not accessible for inspection.

3rd Stage Stationary Seals (4402 hours). Good condition with no rubs.

Discourager/Angel Wing Seals (4402 hours). Not accessible for inspection.

2nd/3rd Stage Labyrinths (4402 hours). Not accessible for inspection.

Part: Combustion System

End Caps (DLN2-1G) (4300 hours). No cracks, distortion, overheating, significant oxidation (< 5 mils) or hula wear.

Fuel Nozzles (4300 hours). No cracks or distortion; nozzles looked similar and cool; atomizing air annuli not oxidized.

Liners (4402 hours). No cracks or oxidation and hulas were 95% intact. Liner bulging: 1 at 0.8″, 5 at 0.4″ and 9 below 0.2″. TBC 95% intact on all liners, except locally at the single 0.8″ bulge (# 12 liner, 1″x2″ topcoat loss but no bondcoat distress).

Cross Fire Tubes (4402 hours). Good condition with only minor wear.

Transition Pieces (4402 hours). No cracks , distortion or oxidation, and TBC was 95% intact. End frame wear was 10 to 50% on side seal slots, and 10 to 50% on ID/OD seal slots/frame.

SECTION 7.8

UNIT 4B Combustion Inspection Highlights: 11/14/95 -- 14264 Operating Hours

Description
(See General Notes at Beginning of Section 7)

Part:1st Stage Nozzles

Vanes (14264 hours). Good condition. No impacts/FOD or significant oxidation (< 5 mils) at any point; 2 vanes had 2.5″ cracks on concave side (0.7″ from inner sidewall, between 1st and 3rd row of film cooling holes); all cooling holes and slots were open with normal oxide patterns around the holes; leading and trailing edges were not burned or distorted; TBC coating on the aft convex face was still 95% intact. Many small "positives" (<30 mils) on leading edges from material going through the machine, but had not caused harm to date.

Sidewalls No mechanical damage or distortion; number of fine 1″ cracks (Z- notch or trailing edge to adjacent vane fillet); oxidation generally less than 5 mils deep but was more in four locations [Z-form joint (60 mils), convex fillet at leading edge (10 mils), downstream of the 4x4 and 2x2 cooling holes on the inner sidewall (20 mils), cooling holes ahead of leading edge on one segment only (20 mils)] In addition, two segments had quite heavy outer sidewall oxidation troughs to 80 mils.

Part:1st Stage Buckets

Vanes and Coatings (14264 hours): Quite good condition. No mechanical damage, cracks, thinning or distortion anywhere on the vane; coating was good over most of vane but locally breached with 10 mils base metal attack in two locations (two buckets - on leading edge at 30-80% and 50-80% radial height; all buckets - 1.5″ behind leading edge on convex side also with some coating craze cracks); oxidation possibly accentuated by 2384F firing (about 20F hotter bucket) plus (less lightly) small impacts seen at 4402 hour inspection; colors were tan/rose (concave), and gray/white/tan (convex).

Squealer Tips (original non-slotted tip design): The squealer tip was intact with no cracks on convex or concave walls. Tips had oxidized on the concave side at the midchord (1″ axial within 0.3″ of tip, with coating breach and 10 mils metal oxidation) and also at immediate trailing edge tip (1″ axial within 0.3″ of tip, with coating breach and 120-150 mils metal oxidation loss) - both more than seen at previous 4402 hour inspection. Rub lips projected forward from the tip for 20-100 mils, but the minor coating damage indicated tip rubs not too severe and similar to 4402 hour inspection.

Part:2nd Stage Nozzles

Vanes (14264 hours). Very good condition. No cracks or mechanical damage; leading and trailing edges in good condition and not distorted or burned; no coating breach or base metal oxidation at any point and an even gray-white coating oxide; cooling holes open and clear.

Sidewalls No cracks, mechanical damage on sidewalls or Z-form. Coating was even gray-white and unbreached.

Part:2nd Stage Buckets

Vanes (14264 hours). Good condition. No cracks, mechanical damage, base metal oxidization or coating breach; coatings were typical tan-gray. ShroudsNo cracks or mechanical damage; insignificant wear on the Z-notches; Z-form engagement was 90%.

Part:3rd Stage Nozzles

Vanes (14264 hours). Very good condition. No cracks or mechanical damage or impacts/FOD; leading and trailing edges were in good condition and not distorted or burned; surface oxides were a typical even dull gray; no base metal oxidation (<2 mils) at any point.

Sidewalls No mechanical damage or cracks on either sidewall or Z-form: surface oxides were anticipated even dull gray color; no oxidation of the base metal.

Part:3rd Stage Buckets

Vanes (14264 hours). Quite good condition. No cracks, impact/FOD, mechanical damage or base metal oxidation. The coating was anticipated black, but uneven with local thinning and had been lost over 20-30% of the vane surface.

Shrouds No cracks, oxidation or mechanical damage; Z-notches had insignificant wear and engagement was 70-90% (a little less than at 4402 hrs).

Part:Shrouds/Seals

1st Stage Stationary (14264 hours). Moderate to good condition. Moderate rubs (10-50 mils) on 20 of the 96 shrouds at 3, 9, and 12 PM; rest were in good condition with no cracks, oxidation, coating deterioration or hole plugging. Rainbow coated shrouds were in good condition and not in rubbed. zone

2nd Stage Stationary (14264 hours). Not accessible for inspection.

3rd stage Stationary (14264 hours). Very good condition with no rubs.

Discourager/Angel Wings (14264 hours). Not accessible for inspection.

2nd/3rd Stage Labyrinths (14264 hours). Not accessible for inspection.

Part: Combustion System

End Caps (DLN2-2DF) (9682 hours). Good condition with no hula wear. Most had 1-2" hot spots near OD and tertiary nozzle with 5 mils oxidation and some distortion. Liner #14 had 2" crack near OD that was not associated with hot spot, and appeared to be innocuous.

Fuel Nozzles (DLN2-2DF) (9682 hours). These were dual fuel nozzles and were in good condition. No cracks or distortion; all nozzles looked similar and cool; atomizing air annuli not oxidized. One fuel nozzle in each chamber had center post deposits - some blocking 25% of atomizing air annulus - deposits were on "lowest" fuel nozzle and were worst at "top-high" and "bottom -low" chambers - they came with purge air. FP&L given sample for analysis.

Liners (9682 hours). In quite good to very good condition. No oxidation and hulas were 95% intact. TBC 95% intact on all liners. Liner bulging: 2 at 0.6-0.7″, 7 at 0.3-0.4″ and 5 below 0.2″. Liner #4 had a 5″ circumferential crack near the exit end, and immediately ahead of the last two series of cooling holes. It initiated and followed the edge of a seam weld in both directions - finally turning away from the weld at the very end. **Cross Fire Tubes** (9682 hours). Good condition with only minor wear. Coating on clips were in very good condition.
Transition Pieces (9682 hours). In good condition. No distortion or oxidation, and TBC was 95% intact. This machine had end frames of FSX-414, and had no significant side seal slot or end face wear. Two TP had cracks in different locations; TP #2 at 2″ near outer corner and #10 at 1″ and outer midspan. In all other respects, the FSX-414 end frames were in very good condition.

8

PHOTO DOCUMENTATION OF HOT GAS PATH COMPONENTS DURING GT INSPECTIONS

These photographs have been selected from the individual inspection reports as the most representative of the status of the Hot Gas Path Components.

For each component, the "high-timer" is generally shown to represent the capability of that part. The majority of the pictures are from the most recent inspection (Unit 4B, 11/95, 14264 hours). Other pictures have also been included as backup or to show any unusual characteristics or operation - irrespective of the machine on which it occurred.

Machine hours are shown and, unless noted differently, are the same as for the part being described. The Index to the pictures is as follows:

FIG.	UNIT	DATE	MACHINE TIME	TITLE
8.1				Martin CC Station General View
8.2	3B	6/95	12586 hrs.	1st Stage Buckets Showing Good Coating Condition After 8504 Hours.
8.3	4B	11/95	14264 hrs.	1st Stage Buckets Showing Good Coating Condition.
8.4	4B	11/95	14264 hrs.	1st Stage Buckets - Leading Edge Oxidation (Seen On Two Buckets Only).
8.5	4B	11/95	14264 hrs.	1st Stage Buckets - Oxidation Seen On Forward Part Of Concave Vane (Seen On All Buckets, As Viewed Through A Mirror).
8.6	3A	11/94	8079 hrs.	1st Stage Bucket Showing Good Coating Condition, But With A Leading Edge impact On One Single Bucket.
8.7	3B	5/94	4082 hrs.	1st Stage Bucket Showing Oxidation At Tip Of Trailing Edge.
8.8	4B	11/95	14264 hrs.	1st Stage Bucket Showing Oxidation At Tip Of Trailing Edge (As Viewed Through A Mirror).
8.9	4A	2/95	6120 hrs.	1st Stage Buckets After Compressor Blade Impactions.
8.10	4A	2/95	6120 hrs.	1st Stage Buckets Showing Convex Side Damage From Compressor Blade Impactions.
8.11	3B	5/94	4082 hrs.	2nd And 3rd Stage Buckets - Overall View.

FIG.	UNIT	DATE	MACHINE TIME	TITLE
8.12	3B	5/94	4082 hrs.	2nd Stage Bucket From Leading Edge Side Showing Good Coating And Shroud Condition.
8.13	3B	5/94	4082 hrs.	2nd Stage Bucket From Trailing Edge Side.
8.14	4A	2/95	6120 hrs.	2nd Stage Buckets Showing Convex Side Scuffing From Compressor Blade Impactions.
8.15	4B	11/95	14264 hrs.	3rd Stage Buckets and Nozzles Showing Generally Good Condition.
8.16	4B	11/95	14264 hrs.	Same As In Fig. 15. Note Loss Of Coating Locally On Some Vanes.
8.17	4B	11/95	14264 hrs.	Same As In Fig. 15. Note Good Condition Of Shroud (Flashlight Lit).
8.18	4B	11/95	14264 hrs.	1st Stage Nozzle Showing Typical Good Condition.
8.19	4B	11/95	14264 hrs.	1st Stage Nozzle Showing Typical Good Condition.
8.20	4B	11/95	14264 hrs.	1st Stage Nozzle Sidewall, Showing Fine Crack At Z-Notch And Slight Oxidation Of 2x2 and 4x4 Cooling Holes (Flashlight Lit).
8.21	4B	11/95	14264 hrs.	1st Stage Nozzle Showing Slight Oxidation On Forward Convex Fillet and Z-Form.
8.23	3B	5/94	4082 hrs.	1st Stage Nozzle Showing Heavy Oxidation In Single Throat Where Fuel Nozzle Tip Lodged Temporarily. Other Nozzle Throats Were Unaffected.
8.24	3B	5/94	4082 hrs.	Adjacent Side Of Nozzle Throat Shown in Fig 23.
8.25	3B	5/94	4082 hrs.	Aft Side Of Nozzle Throat Shown In Fig 23, Showing Good Coating Condition Except For Local Deterioration Where Nozzle Tip Lodged Temporarily.
8.26	4A	2/95	6120 hrs.	1st Stage Nozzle Showing Minor Concave Side Damage From Compressor Blade Impactions.
8.27	4A	2/95	6120 hrs.	1st Stage Nozzle Showing Convex Side And Coating Damage From Compressor Blade Impactions.
8.28	3B	5/94	4082 hrs.	2nd Stage Nozzle Showing Good Condition. Most Spots Are Oil Marks.
8.29	4A	2/95	6120 hrs.	2nd Stage Nozzle Showing Minor Damage From Compressor Blade Impactions. Most Large Spots Are Oil Marks From Disassembly.
8.30	3B	5/94	4082 hrs.	3rd Stage Nozzle Showing Good Condition.
8.31	4A	2/95	6120 hrs.	3rd Stage Nozzle Showing Minor Damage From Compressor Blade Impactions.
8.32	3B	5/94	4082 hrs.	1st Stage Stationary Shroud. Good Condition With No Rubs.
8.33	3B	5/94	4082 hrs.	Same As in Fig. 32, But At Horizontal Flange And With Considerable Rub.
8.34	3B	5/94	4082 hrs.	2nd Stage Stationary Shroud. Good Condition, And Typical Of Others Examined At Site.
8.35	3B	5/94	4082 hrs.	3rd Stage Stationary Shroud. Good Condition, And Typical Of Others Examined At Site.

FIG.	UNIT	DATE	MACHINE TIME	TITLE
8.36	4B	11/95	14264 hrs.	Typical Condition Of End Cap And Fuel Nozzles, After 9682 Hours.
8.37	4B	11/95	14264 hrs.	End Cap, Showing Minor Local Oxidation And Distortion That Is Occasionally Seen. 9682 Hours Service.
8.38	4B	11/95	14264 hrs.	Typical Condition Of Fuel Nozzles, After 9682 Hours.
8.39	3B	5/94	4082 hrs.	Lost Fuel Nozzle Tip, After 2500 Hours. Attributed To A Fuel Flashback.
8.40	3B	6/95	12586 hrs	Combustion Liner In Good Condition, After 8504 Hours.
8.41	3B	6/95	12586 hrs.	Same As In Fig. 40, But Showing Good Condition Of Coating.
8.42	3B	6/95	12586 hrs.	Combustion Liner With Distortion (Inward Bulging), After 8504 Hours.
8.43	3B	6/95	12586 hrs.	Same As In Fig. 42, But Showing Small Coating Deterioration In Immediate Area Of Distortion.
8.44	4B	11/95	14264 hrs.	Combustion Liner In Good Condition, After 9682 Hours.
8.45	4B	11/95	14264 hrs.	Same As In Fig. 44, But Interior View Showing Good Condition Of Coating.
8.46	4B	11/95	14264 hrs.	Combustion Liner With Distortion (Inward Bulging), After 9682 Hours.
8.47	4B	11/95	14264 hrs.	Same As In Fig. 46, But Interior View Showing Coating and Area Of Distortion.
8.48	4B	11/95	14264 hrs.	Combustion Liner Showing Aft End Crack, After 9682 Hrs. (Seen In One Liner Only).
8.49	4A	11/94	4868 hrs.	Combustion Liner Showing Body Crack, After 4868 Hrs. (Seen In One Liner Only).
8.50	4B	11/95	14264 hrs.	Cross Fire Tubes. Typical Condition After 4000-10000 Hours. These Had 9682 Hours.
8.51	4B	9/94	4402 hrs.	Transition Piece In Generally Good Condition After 4402 Hours, But With Some Wear On The End Frame (Without Design Modification).
8.52	3B	6/95	12586 hrs.	Transition Piece In Good Condition, After 8504 Hours.
8.53	3B	6/95	12586 hrs.	Same As In Fig. 52, But Showing Good Condition Of Coating.
8.54	3B	6/95	12586 hrs.	Same As In Fig. 52.
8.55	3B	6/95	12586 hrs.	Same As In Fig. 52, But Showing Design Modification Resulting In Minimal Wear.
8.56	4B	11/95	14264 hrs.	Transition Piece In Good Condition, After 9682 Hours.
8.57	4B	11/95	14264 hrs.	Same As In Fig. 56, Showing Material Modification To End Frame (FSX-414), With No Wear But A Crack On Two (of 14) Transition Pieces.

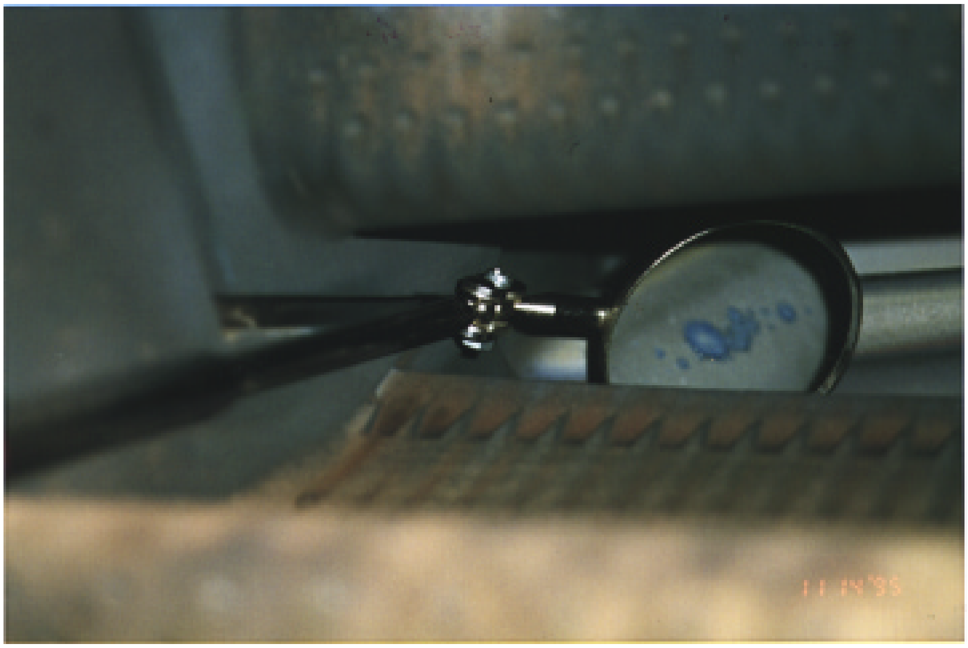
Figure 8.1 Martin CC Station, general view.

The coating of the 1st stage buckets appears to be in good condition after 8,504 hours of GT operation.

Figure 8.2 Unit 3B 6/95, 12,586 hrs.

1st stage bucket shows good coating condition.
Figure 8.3 Unit 4B 11/95, 14,264 hrs. 1st Stage Buckets.

1st stage bucket shows localized oxidation has breached the coating on the leading edge.
Figure 8.4 Unit 4B 11/95 14,264 hrs. 1st Stage Buckets.

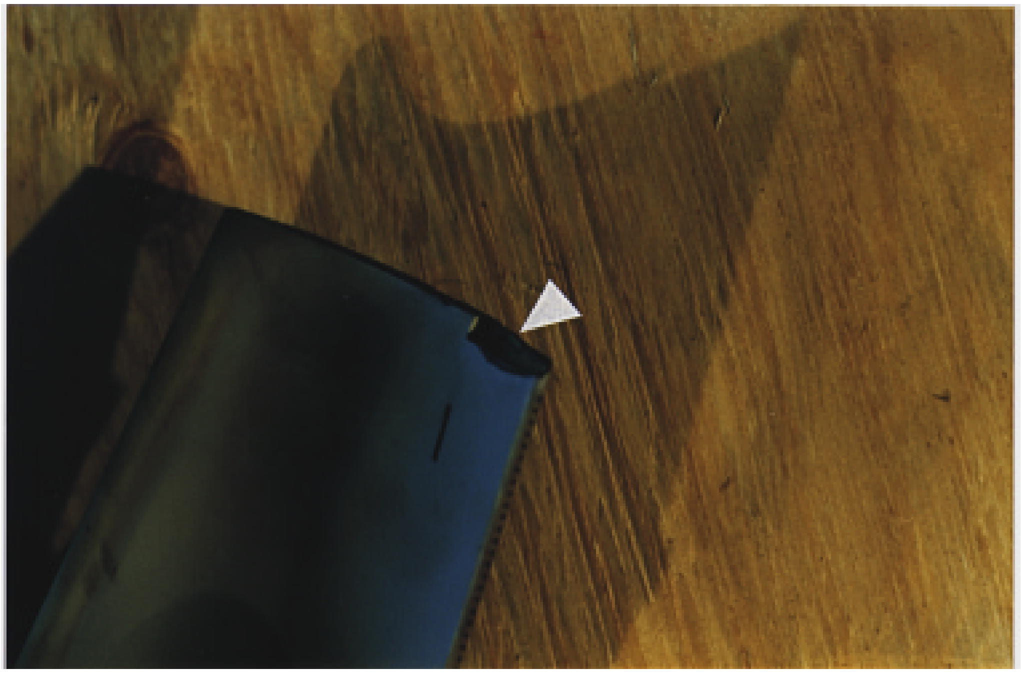


1st stage bucket shows oxidation on the forward part of the concave vane.
The mirror, which is part of this photograph, shows oxidation present elsewhere on the bucket.

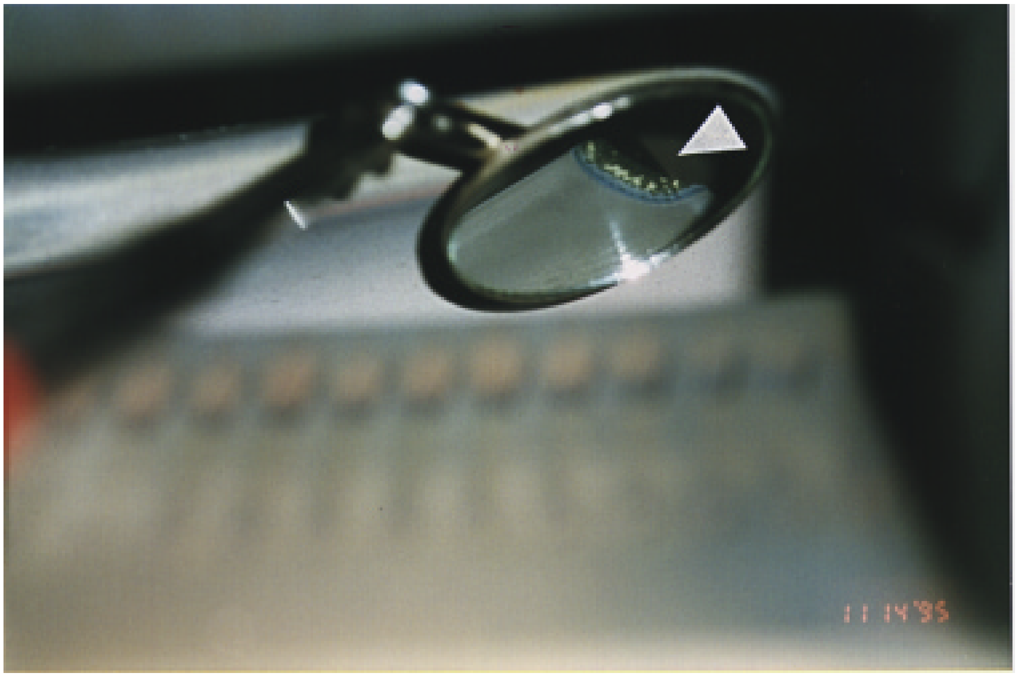
Figure 8.5 Unit 4B 11/95 14,264 hrs. 1st Stage Buckets.

This photograph shows a leading edge impact on one single bucket.

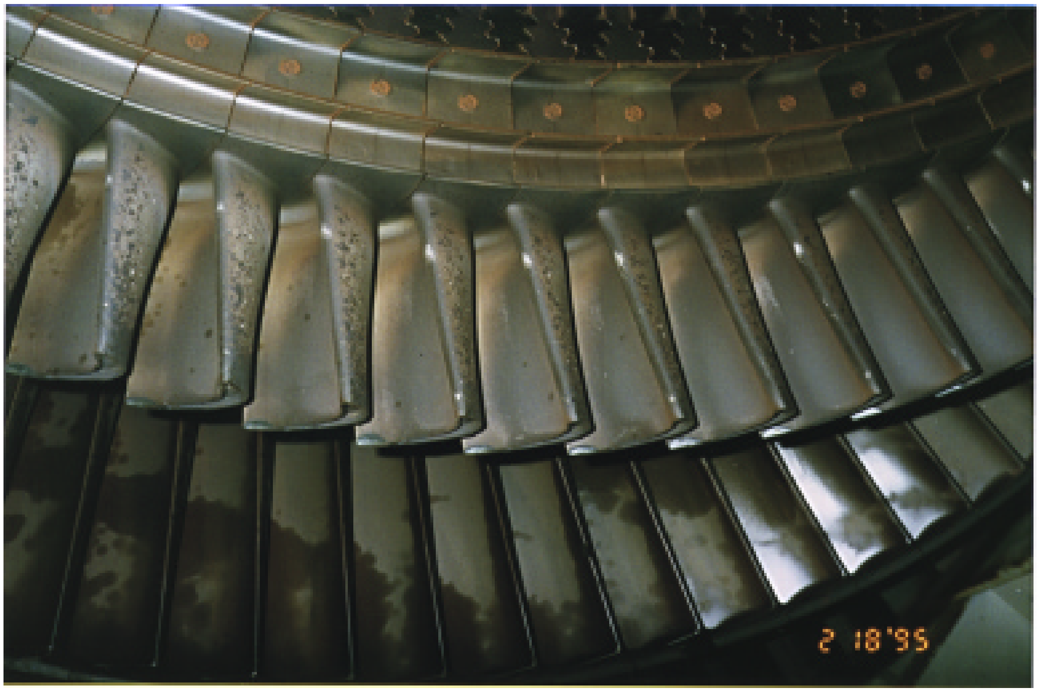
Figure 8.6 Unit 3A 11/94, 8,079 hrs. 1st Stage Buckets.



1st stage bucket is showing oxidation at the tip of the trailing edge.
Figure 8.7 Unit 3B 5/94, 4,082 hrs. 1st Stage Buckets.



One 1st stage bucket shows oxidation at the tip of the trailing edge. (as viewed through a mirror).
Figure 8.8 Unit 4B 11/95, 14,264 hrs. 1st Stage Buckets.

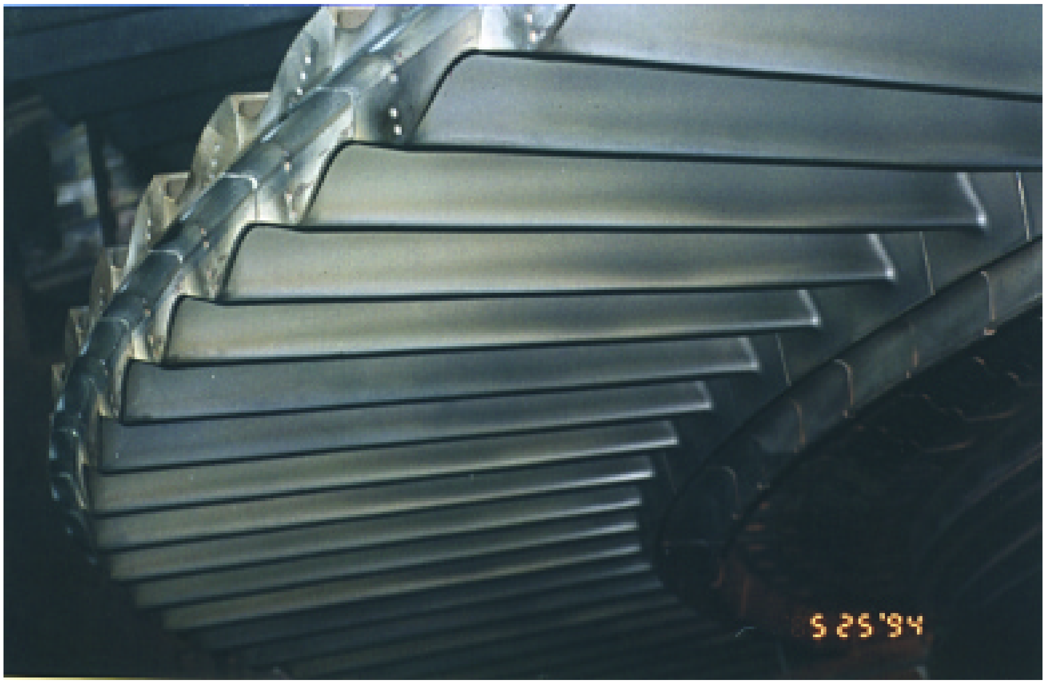


The 1st stage buckets are shown after the impactions from the compressor blades.
Figure 8.9 Unit 4A 2/95, 6,120 hrs. 1st Stage Buckets.

1st stage buckets showing convex side damage from compressor blade impactions.
Figure 8.10 Unit 4A 2/95, 6,120 hrs. 1st Stage Buckets.

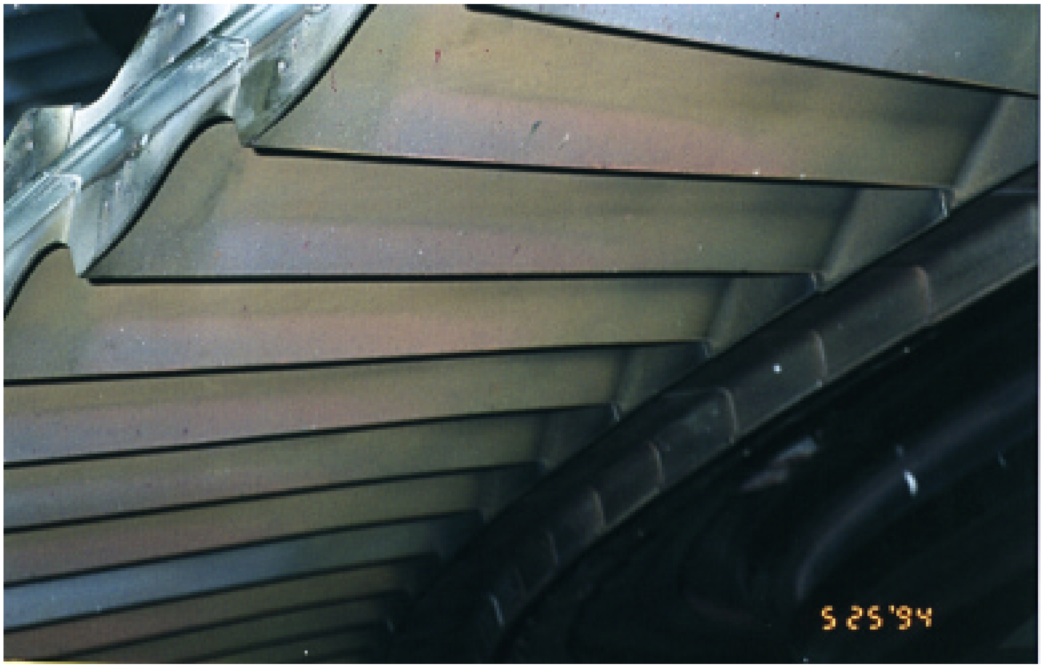
Overall view of 2nd and 3rd stage buckets.

Figure 8.11 Unit 3B 5/94, 4,082 hrs. 2nd And 3rd Stage Buckets.

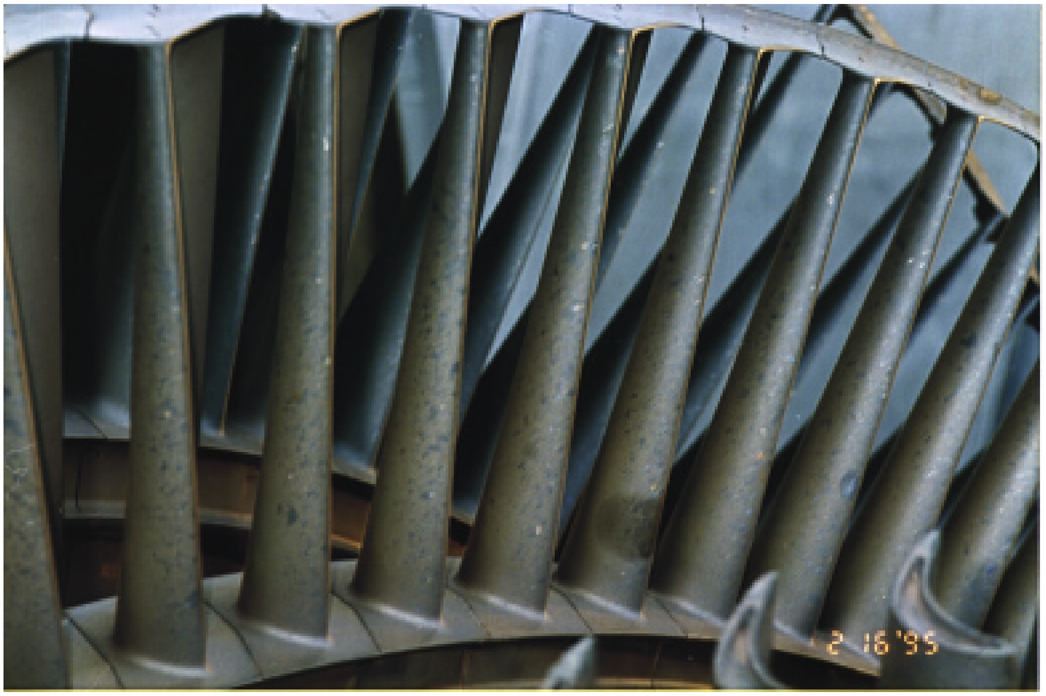


View of the 2nd stage buckets looking from the leading edge side. The shroud and the bucket coating are both in good condition.

Figure 8.12 Unit 3B 5/94, 4,082 hrs. 2nd Stage Buckets.

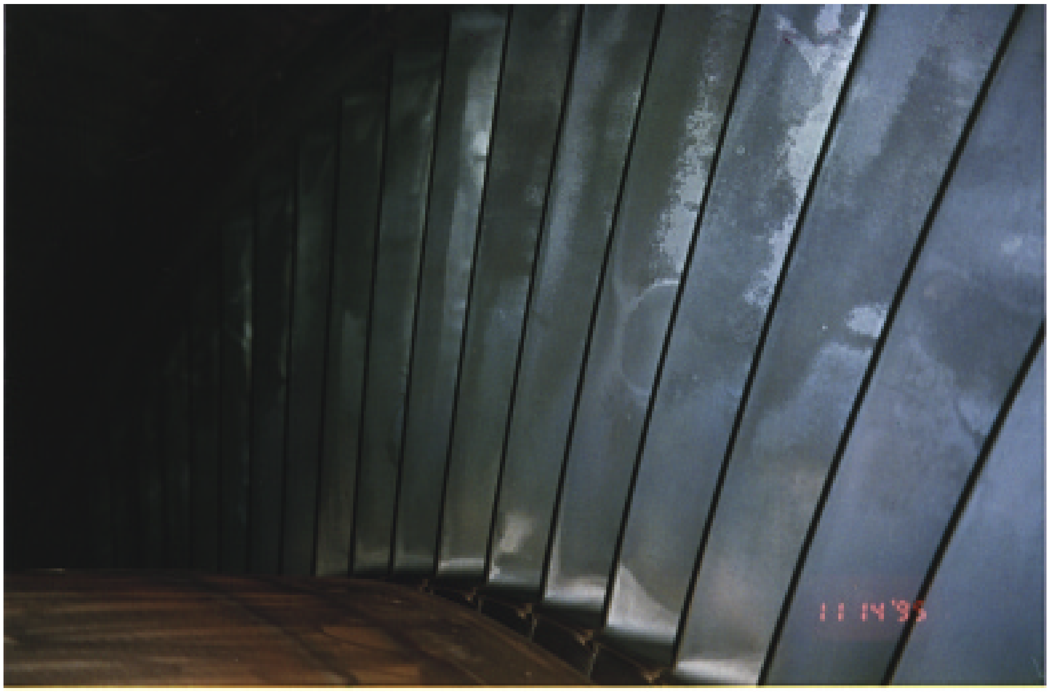


2nd stage buckets viewed from the trailing edge side.
Figure 8.13 Unit 3B 5/94, 4,082 hrs. 2nd Stage Buckets.



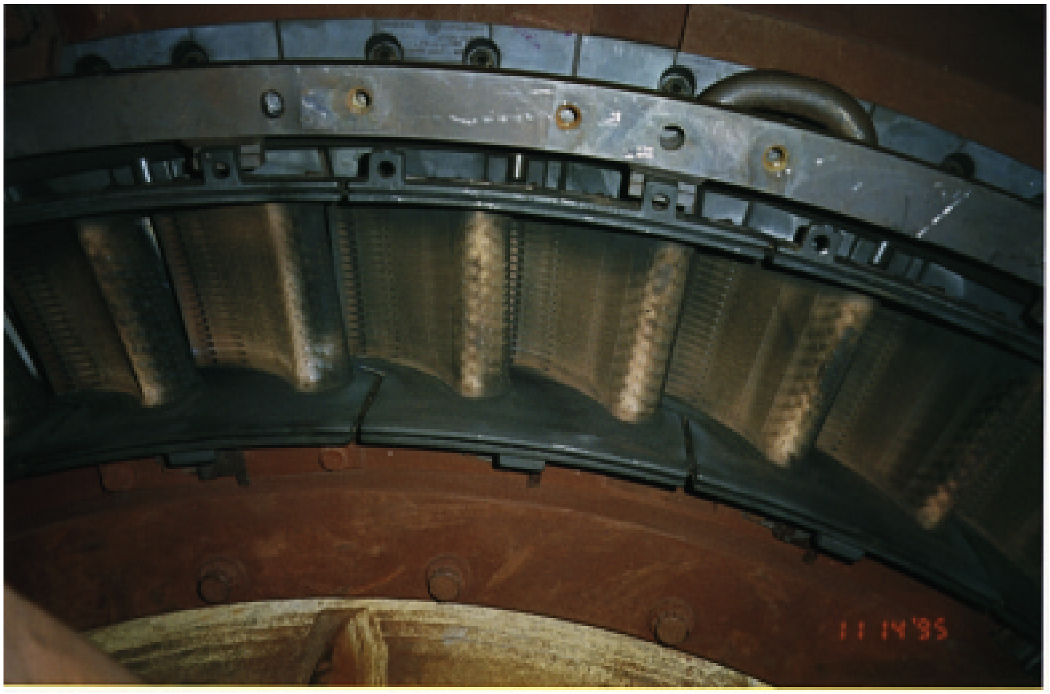
2nd stage buckets showing convex side scuffing from compressor blade impactions.
Figure 8.14 Unit 4A 2/95, 6,120 hrs. 2nd Stage Buckets.

3rd stage buckets and nozzles in good condition.
Figure 8.15 Unit 4B 11/95, 14,264 hrs. 3rd Stage Buckets.

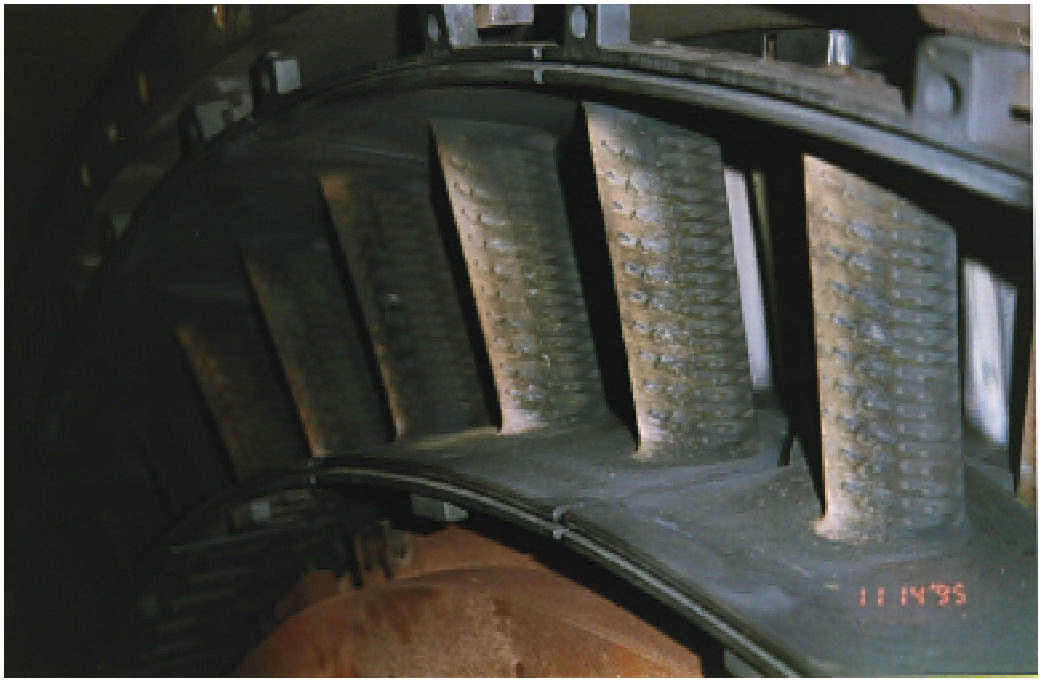


3rd stage buckets and nozzles showing local loss of coating on some vanes.
Figure 8.16 Unit 4B 11/95, 14,264 hrs. 3rd Stage Buckets.

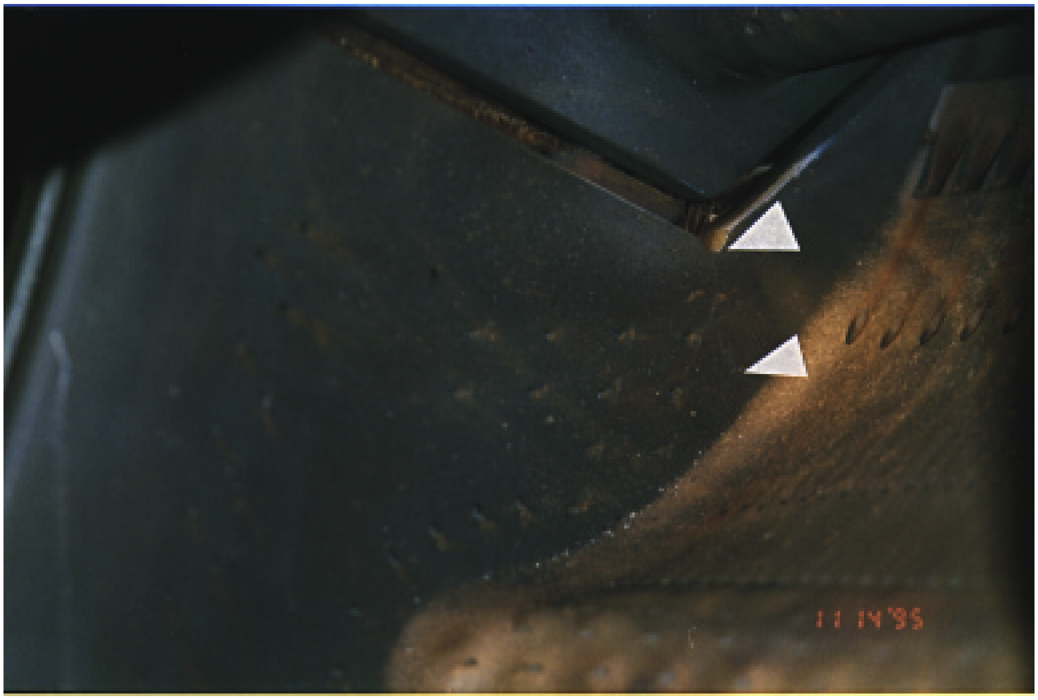
The 3rd stage buckets and nozzles are generally in good condition.
Note: The good condition of the shroud (flashlight lit).
Figure 8.17 Unit 4B 11/95, 14,264 hrs. 3rd Stage Buckets.



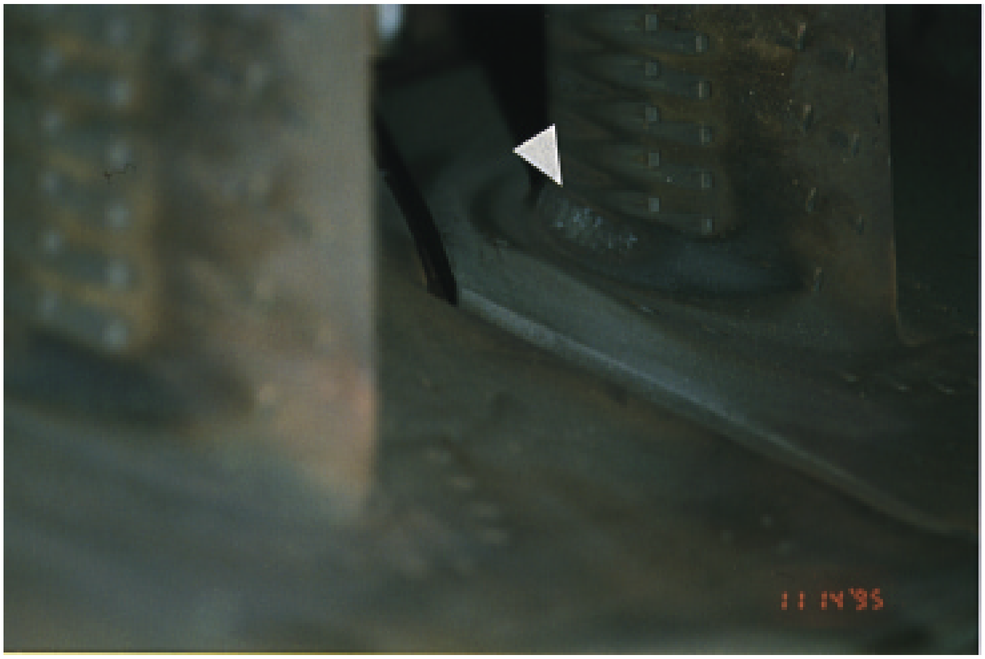
1st stage nozzle showing good condition.
Figure 8.18 Unit 4B 11/95, 14,264 hrs. 1st Stage Nozzle.



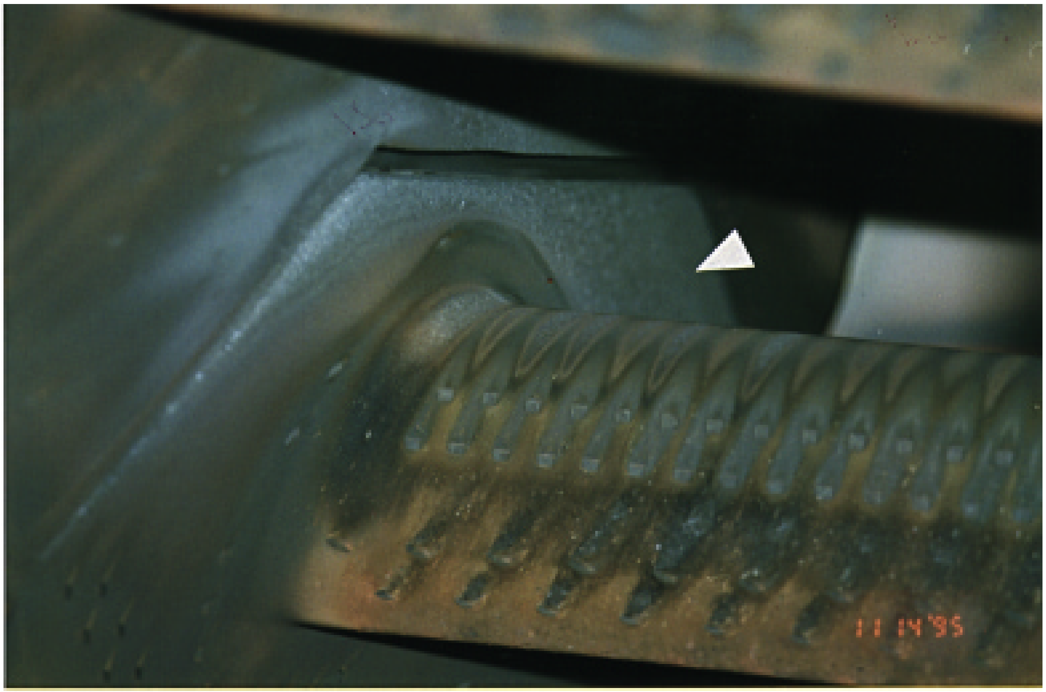
1st stage nozzle showing good condition.
Figure 8.19 Unit 4B 11/95, 14,264 hrs. 1st Stage Nozzle.



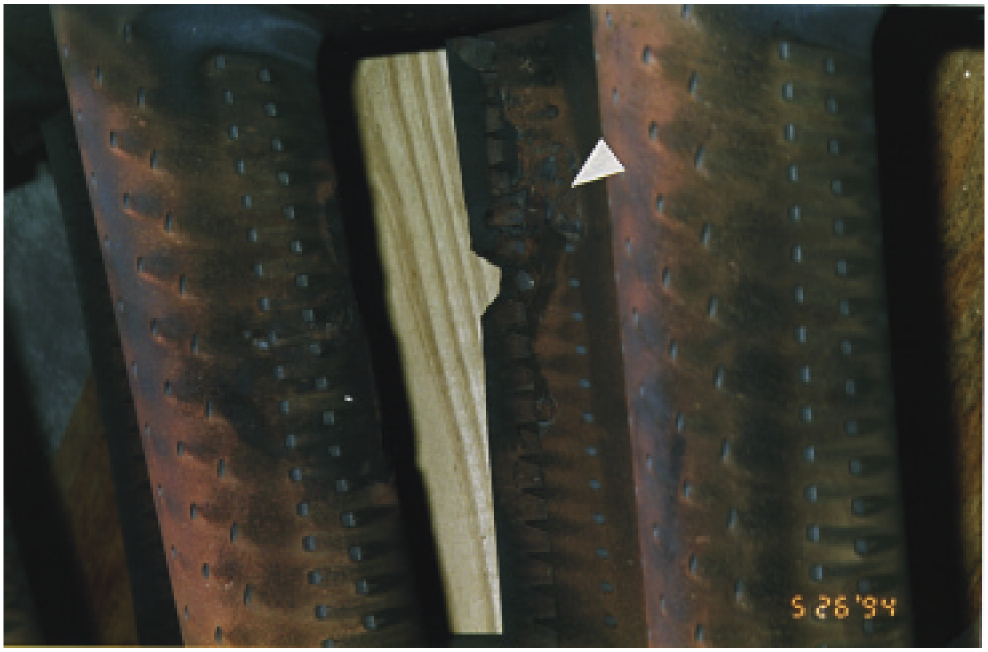
1st stage nozzle sidewall, showing fine crack at Z-Notch and slight oxidation of 2x2 and 4x4 cooling holes (flashlight lit).
Figure 8.20 Unit 4B 11/95, 14,264 hrs. 1st Stage Nozzle Sidewall.



1st stage nozzle showing slight oxidation on forward convex fillet and Z-Form.
Figure 8.21 Unit 4B 11/95, 14,264 hrs. 1st Stage Nozzle.

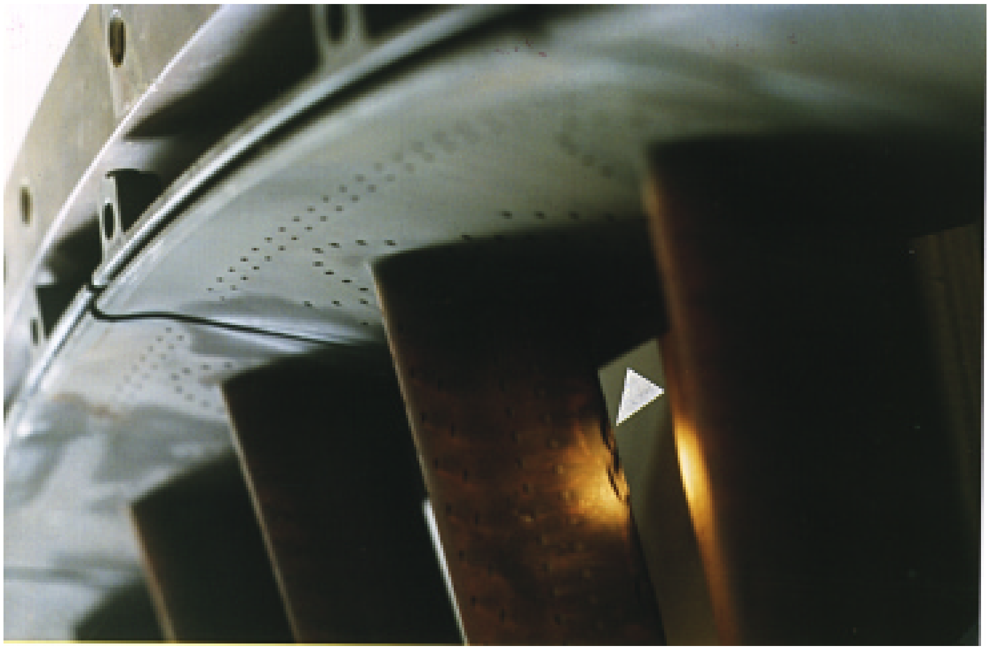


1st stage nozzle showing significant sidewall oxidation.
(Seen on two segments only to date).
Figure 8.22 Unit 4B 11/95, 14,264 hrs. 1st Stage Nozzle.



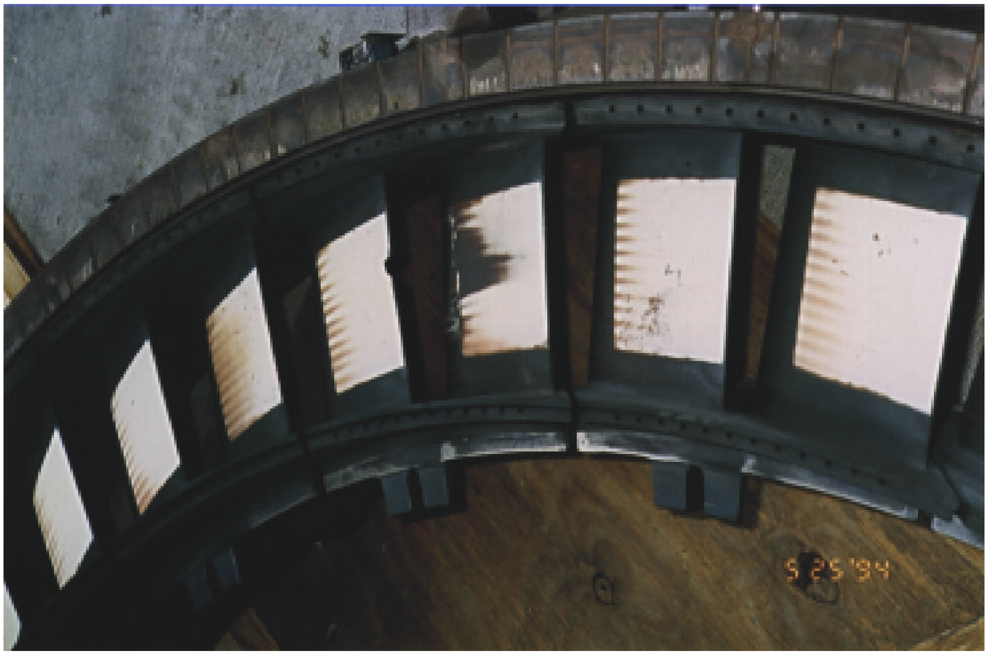
1st stage nozzle showing heavy oxidation in the single throat where the fuel nozzle tip lodged temporarily. The other nozzle throats were unaffected.

Figure 8.23 Unit 3B 5/94, 4,082 hrs. 1st Stage Nozzle.

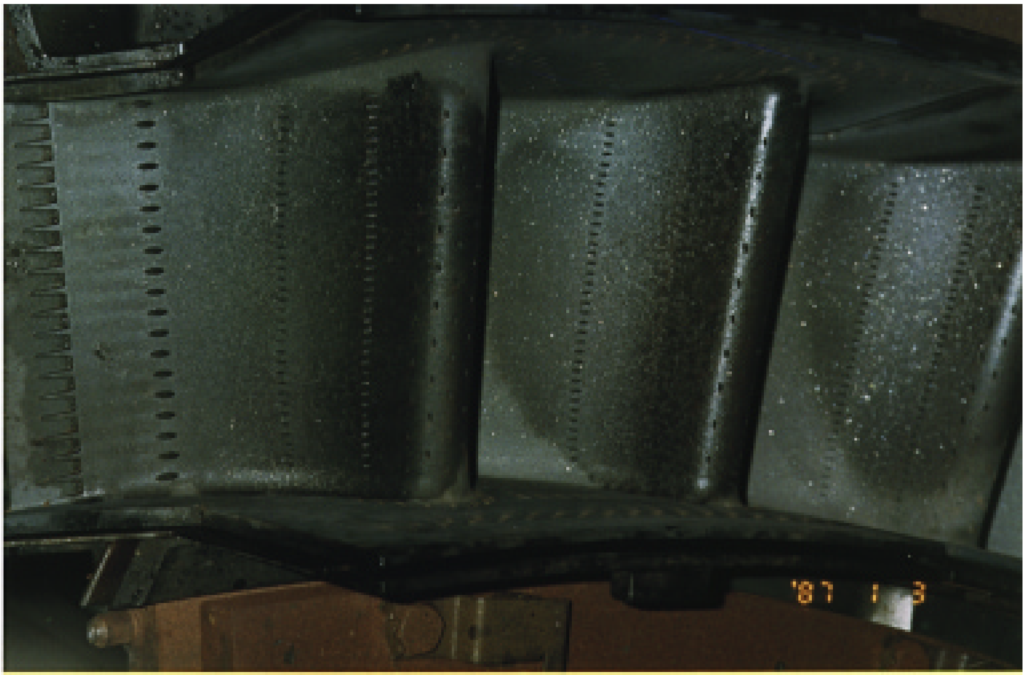


Adjacent side of nozzle throat shown in Figure 8.23.

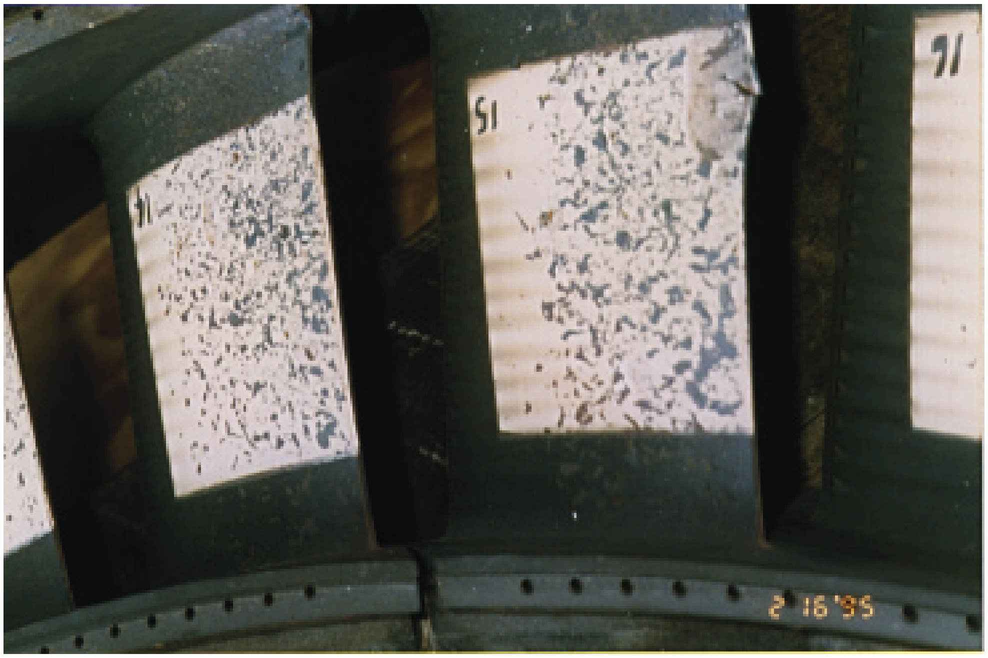
Figure 8.24 Unit 3B 5/94, 4,082 hrs. 1st Stage Nozzle.



Aft side of nozzle throat shown In Figure 8.23. The coating is in good condition except for the local deterioration where the nozzle tip lodged temporarily.
Figure 8.25 Unit 3B 5/94, 4,082 hrs. 1st Stage Nozzle.



The 1st stage nozzle shows minor concave side damage from the compressor blade impactions.
Figure 8.26 Unit 4A 2/95, 6,120 hrs. 1st Stage Nozzle.



The 1st stage nozzle showing convex side and coating damage from the compressor blade impactions.
Fig 8.27 Unit 4A 2/95, 6,120 hrs. 1st Stage Nozzle.

2nd stage nozzle showing good condition. Most spots are oil marks which occurred during the disassembly of the parts.
Figure 8.28 Unit 3B 5/94, 4,082 hrs. 2nd Stage Nozzle.

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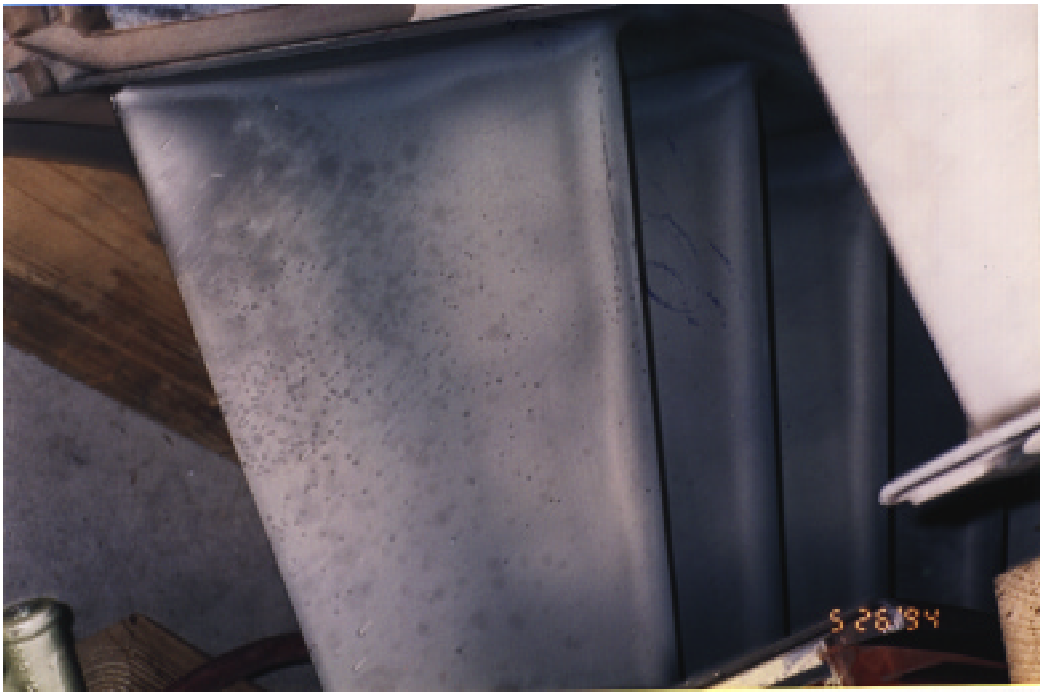
2nd stage nozzle showing minor damage from compressor blade impactions. Most large spots are oil marks from disassembly.
Figure 8.29 Unit 4A 2/95, 6,120 hrs. 2nd Stage Nozzle.



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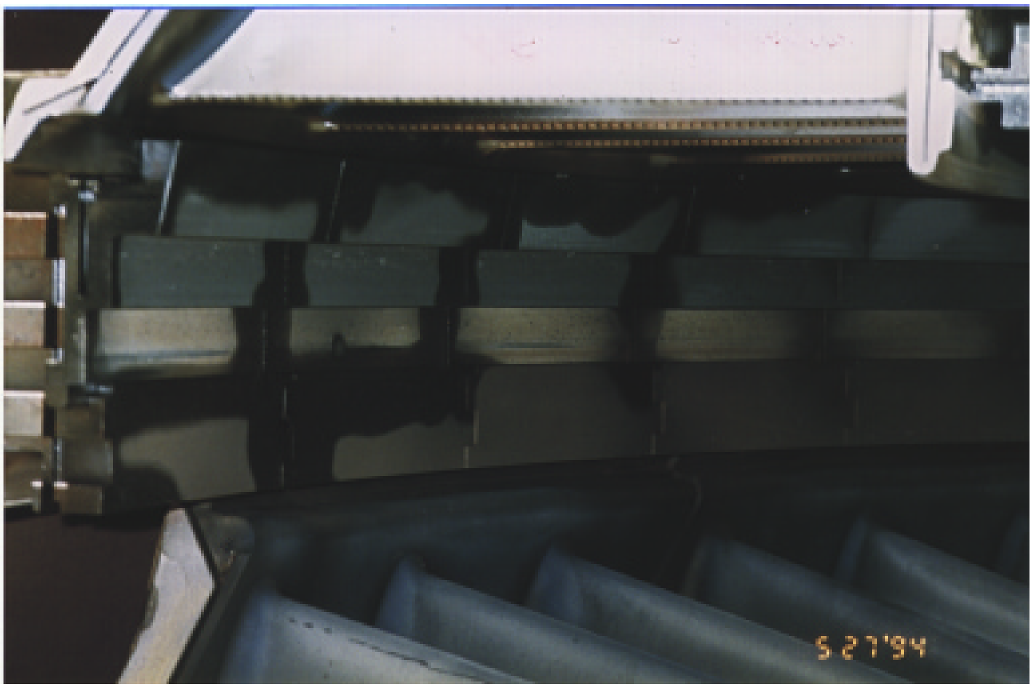
The 3rd stage nozzle is shown in good condition.
Figure 8.30 Unit 3B 5/94, 4,082 hrs. 3rd Stage Nozzle.

3rd stage nozzle showing minor damage from compressor blade impactions.
Figure 8.31 Unit 4A 2/95, 6,120 hrs. 3rd Stage Nozzle.

1st stage stationary shroud. good condition with no rubs.
Figure 8.32 Unit 3B 5/94, 4,082 hrs. 1st Stage Stationary Shroud.

1st stage stationary shroud horizontal flange shows a substantial rub.

Figure 8.33 Unit 3B 5/94, 4,082 hrs. 1st Stage Stationary Shroud.

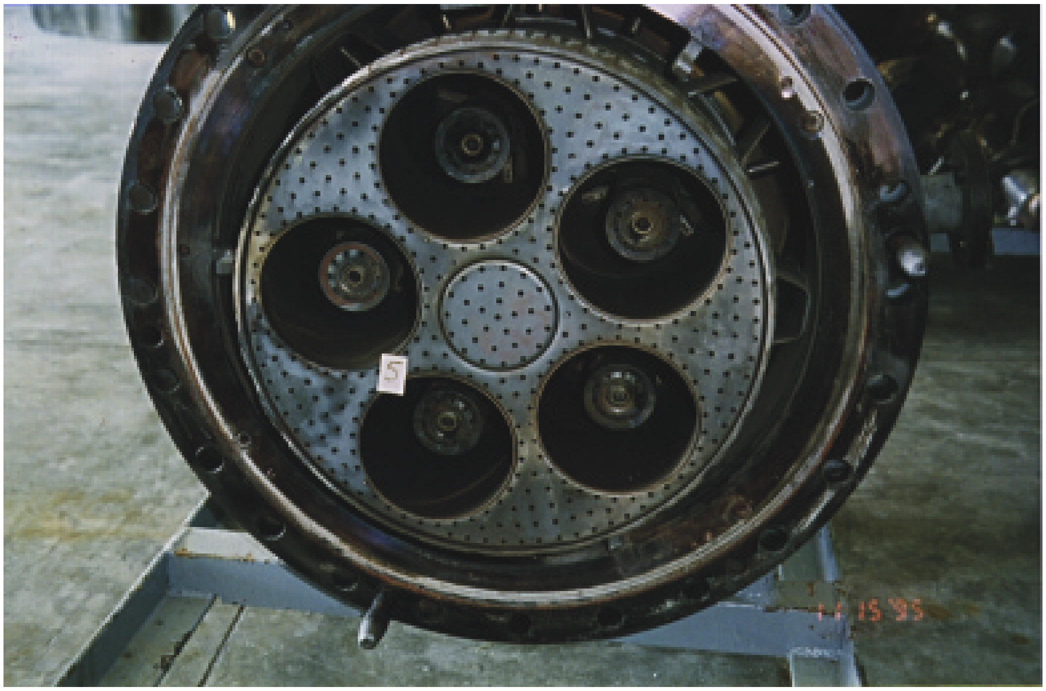


The 2nd stage stationary shroud appears to be in good condition. This is typical of others examined at the site.

Figure 8.34 Unit 3B 5/94, 4,082 hrs. 2nd Stage Stationary Shroud.

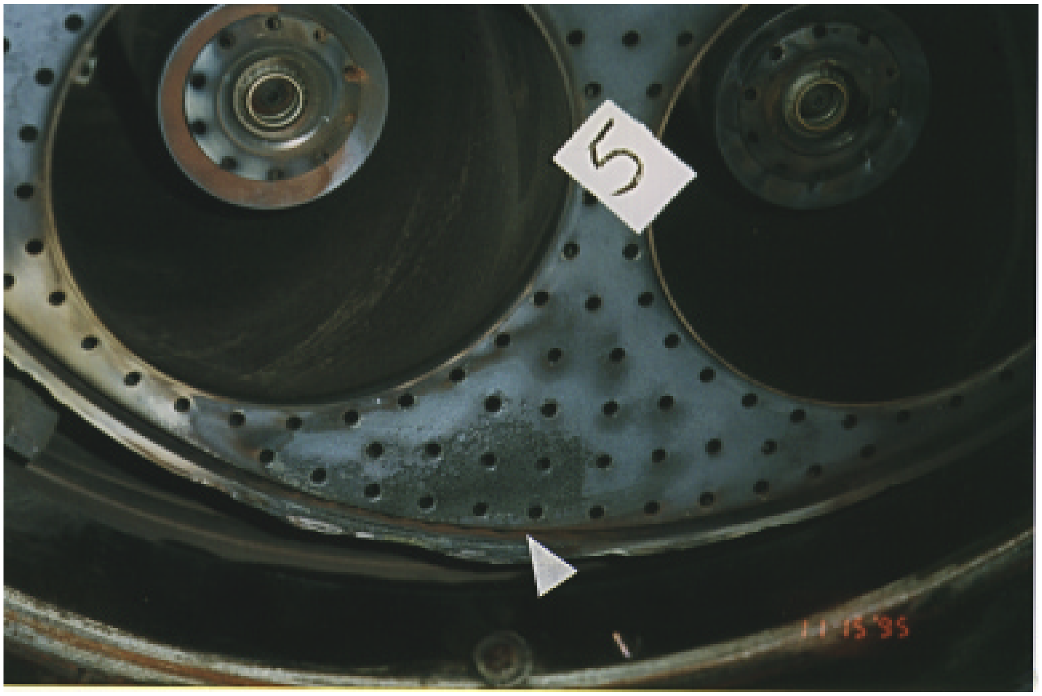
The 3rd stage stationary shroud appears to be in good condition. This is typical of others examined at the site.

Figure 8.35 Unit 3B 5/94, 4,082 hrs. 3rd Stage Stationary Shroud.



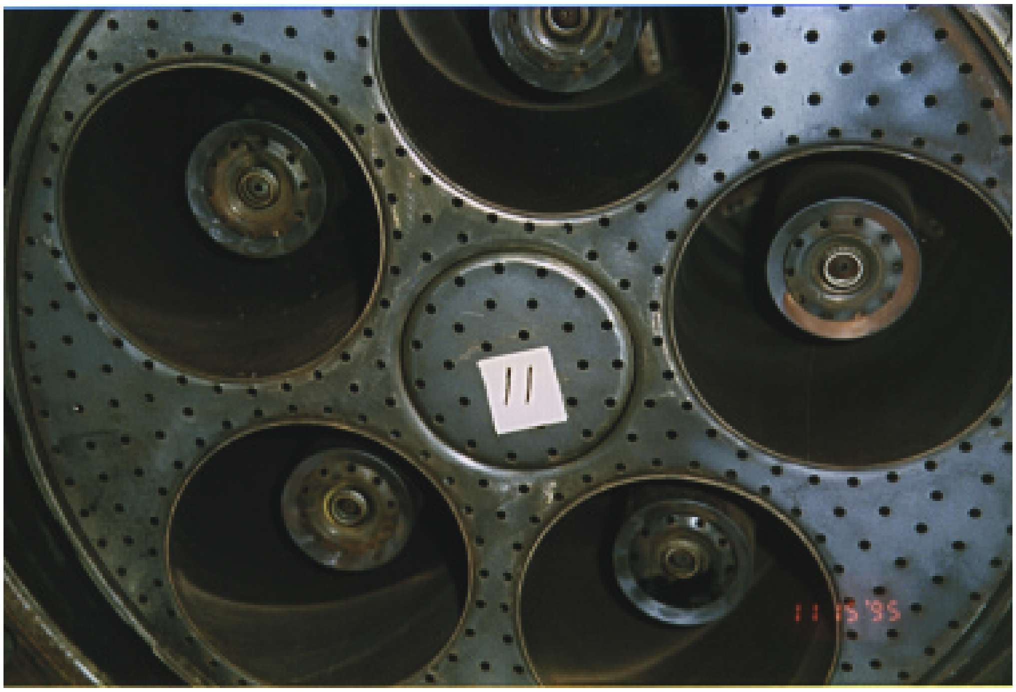
Typical condition of end cap and fuel nozzles, after 9,682 hours.

Figure 8.36 Unit 4B 11/95, 14,264 hrs. End Cap And Fuel Nozzles.



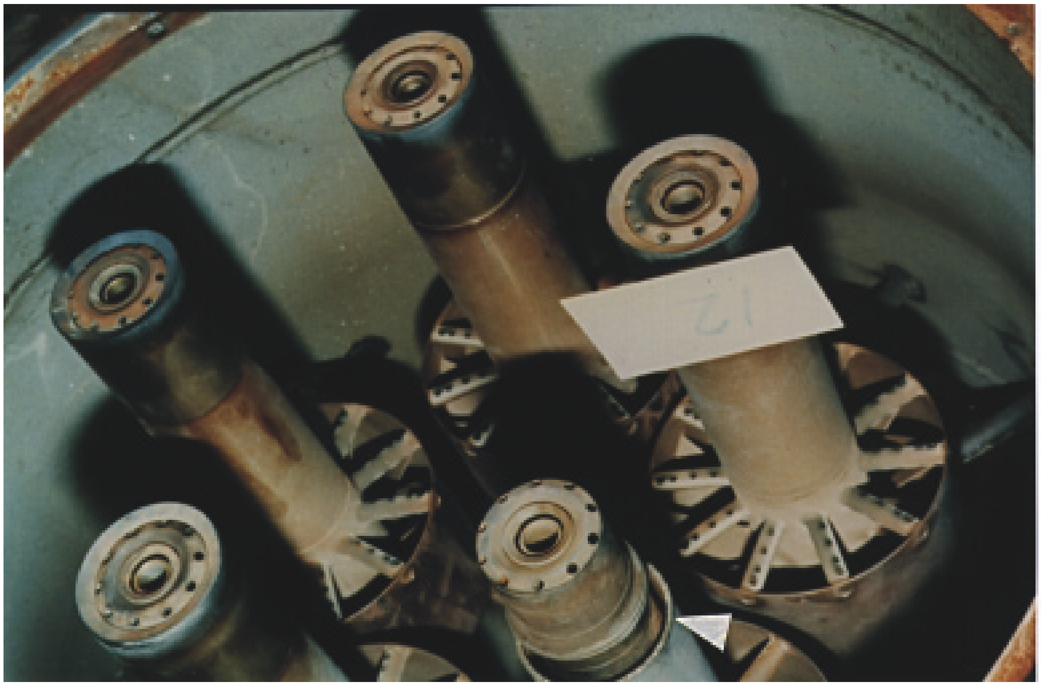
The end cap shows minor local oxidation and distortion. This degradation is seen occasionally at 9,682 hours of service.

Figure 8.37 Unit 4B 11/95, 14,264 hrs. End Cap.



Typical condition of fuel nozzles, after 9,682 hours.

Figure 8.38 Unit 4B 11/95, 14,264 hrs. Fuel Nozzles.

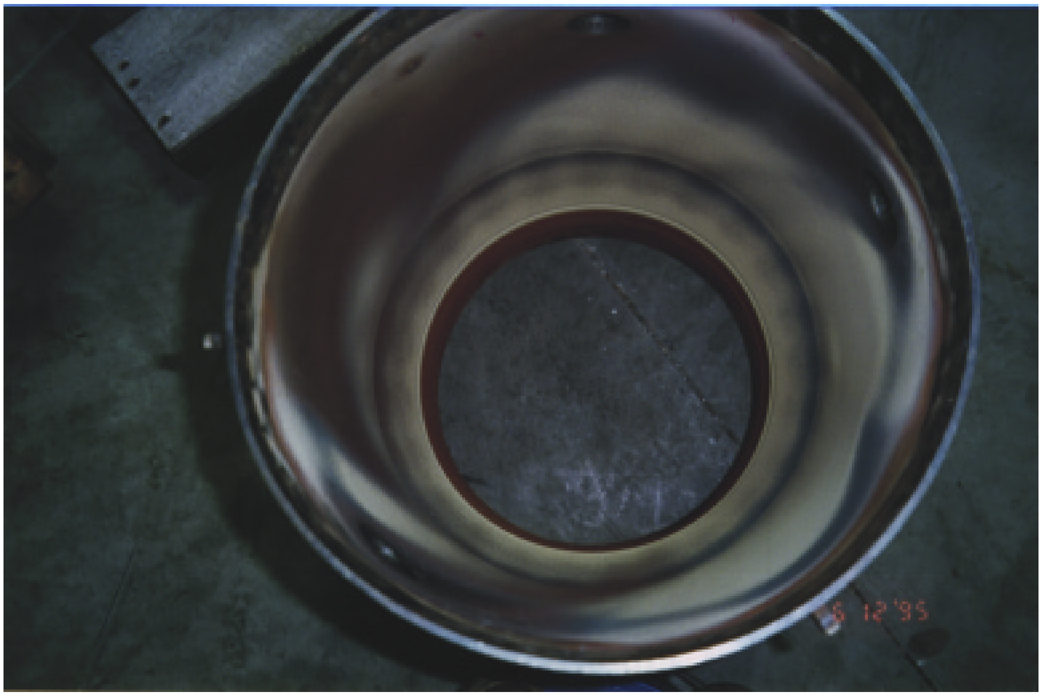


The fuel nozzle tip was lost after 2,500 hours.This failure was attributed to a fuel flashback.

Figure 8.39 Unit 3B 5/94, 4,082 hrs. Fuel Nozzle Tip.

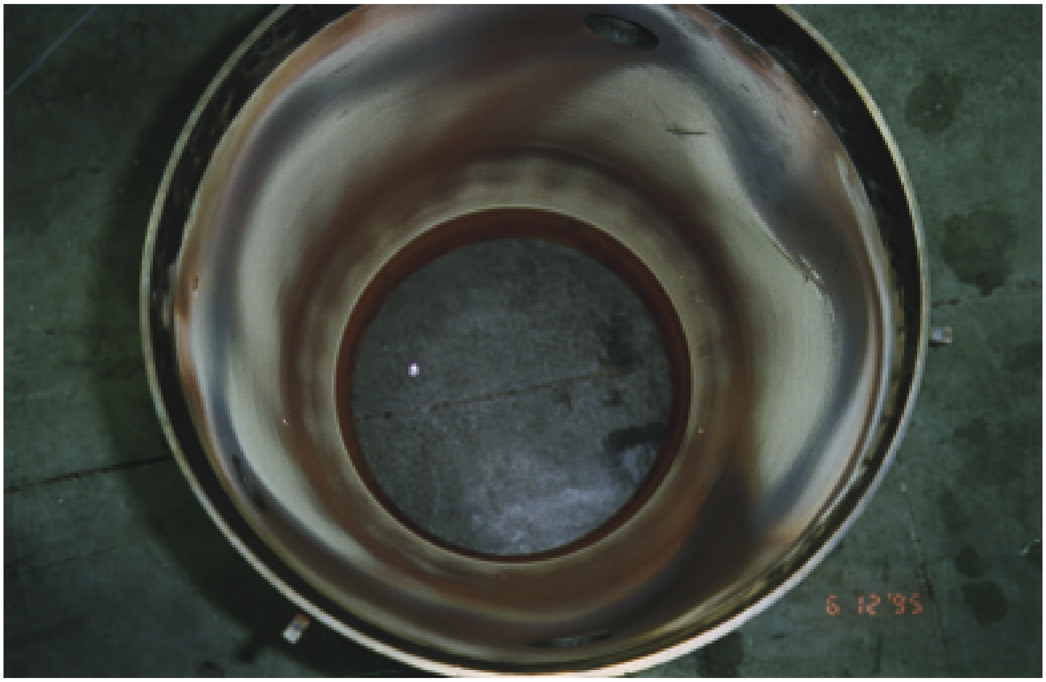
Combustion liner is in good condition, after 8,504 hours.

Figure 8.40 Unit 3B 6/95, 12,586 hrs. Combustor Liner.



The combustor liner is in good condition. The coating is shown in good condition.
Figure 8.41 Unit 3B 6/95, 12,586 hrs. Combustor Liner.

The combustion liner shows an inward bulging distortion after 8,504 hours of operation.
Figure 8.42 Unit 3B 6/95, 12,586 hrs. Combustion Liner.

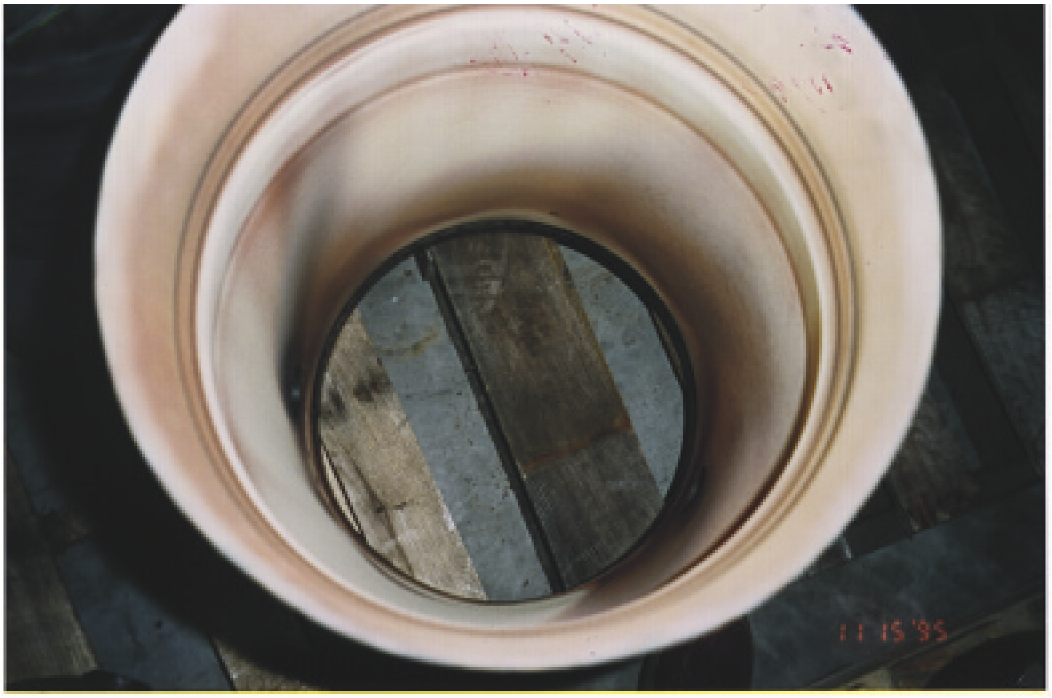


The combustion liner shows an inward bulging distortion after 8,504 hours of operation. There is a small coating deterioration in the immediate area of distortion.

Figure 8.43 Unit 3B 6/95, 12,586 hrs. Combustion Liner.

After 9,682 hours of operation the combustor liner appears in good condition.

Figure 8.44 Unit 4B 11/95, 14,264 hrs. Combustion Liner.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The interior view of the combustor liner shows the coating in good condition.
Figure 8.45 Unit 4B 11/95, 14,264 hrs. Combustor Liner.


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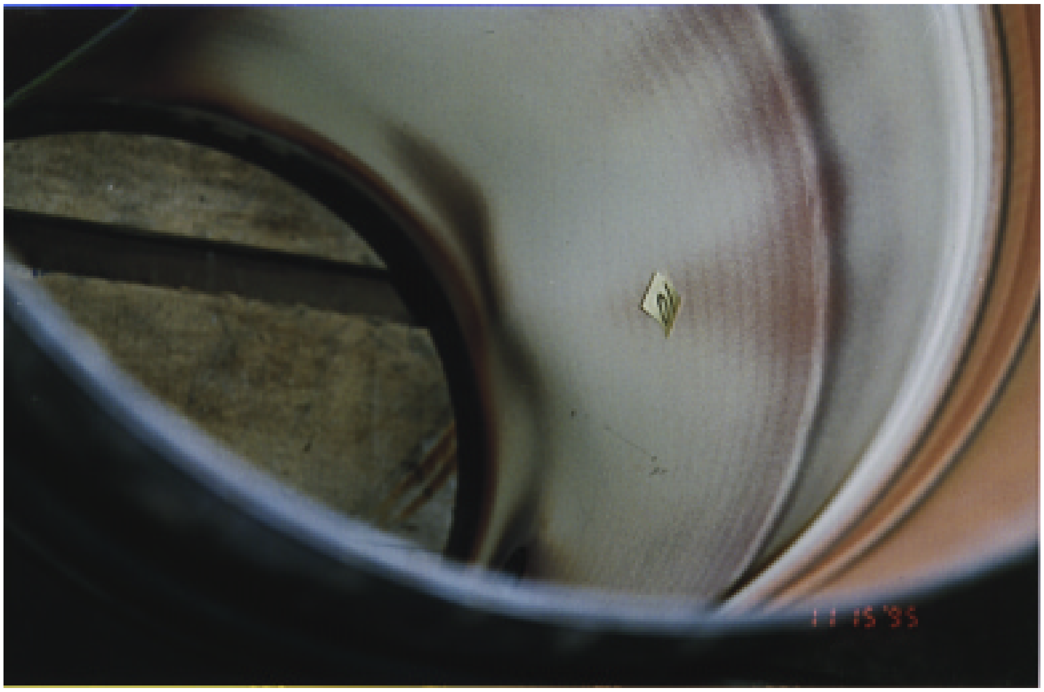
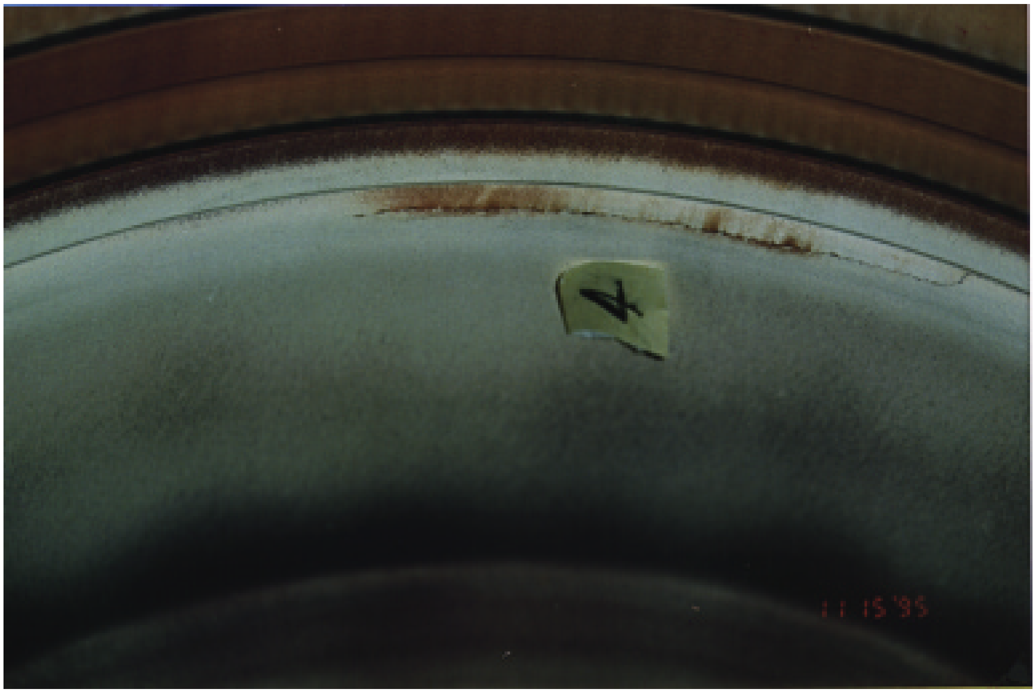
The combustion liner shows typical inward bulging distortion after 9,682 hours of operation. (seen on all liners.)
Figure 8.46 Unit 4B 11/95, 14,264 hrs. Combustion Liner.



Interior view showing coating and area of distortion of the combustor liner.
Figure 8.47 Unit 4B 11/95, 14,264 hrs. Combustion Liner.



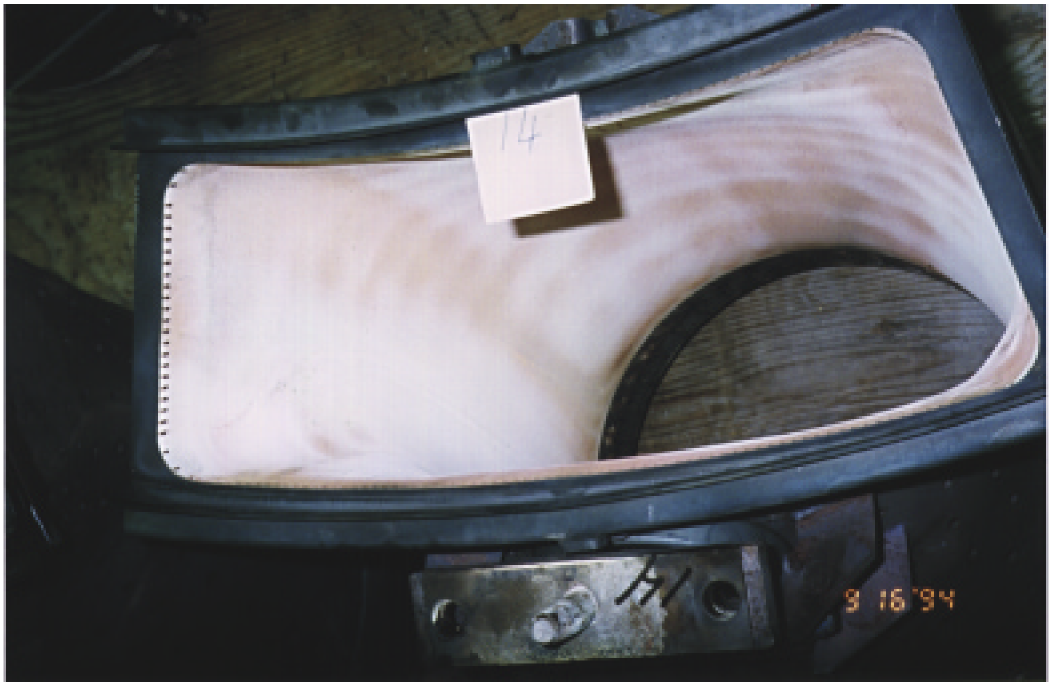
Combustion liner showing aft end crack, after 9,682 hours. (Seen in one liner only).
Figure 8.48 Unit 4B 11/95, 14,264 hrs. Combustion Liner.

Combustion liner showing body crack, after 4,868 hours. (Seen in one liner only).

Figure 8. 49 Unit 4A 11/94, 4,868 hrs. Combustion Liner.

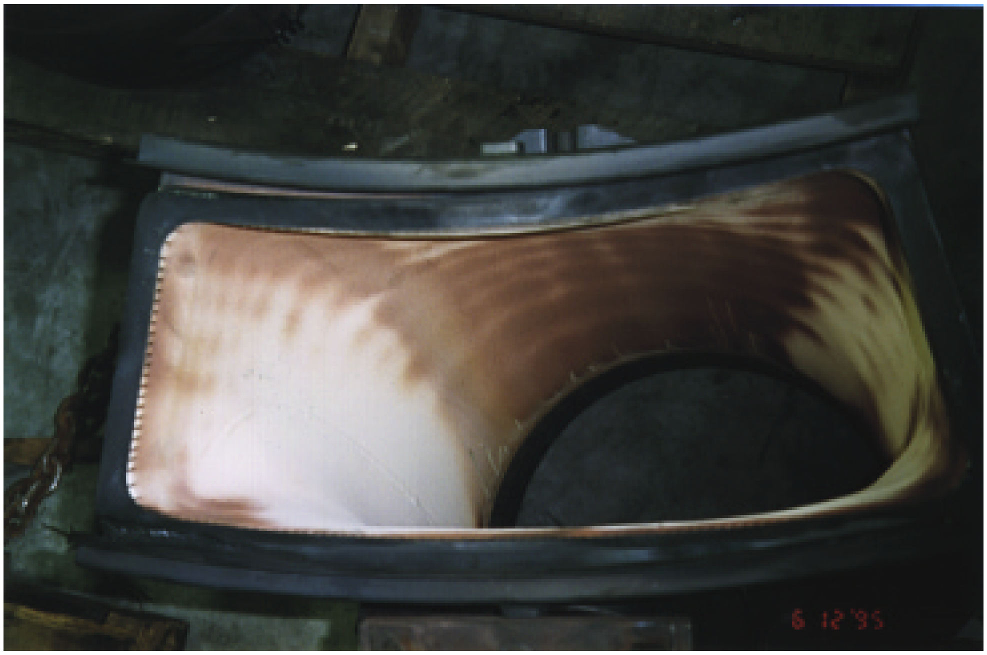
Cross fire tubes typical condition after 4,000-10,000 hours. These fire tubes had 9,682 hours of operation.

Figure 8.50 Unit 4B 11/95, 14,264 hrs. Cross Fire Tubes.



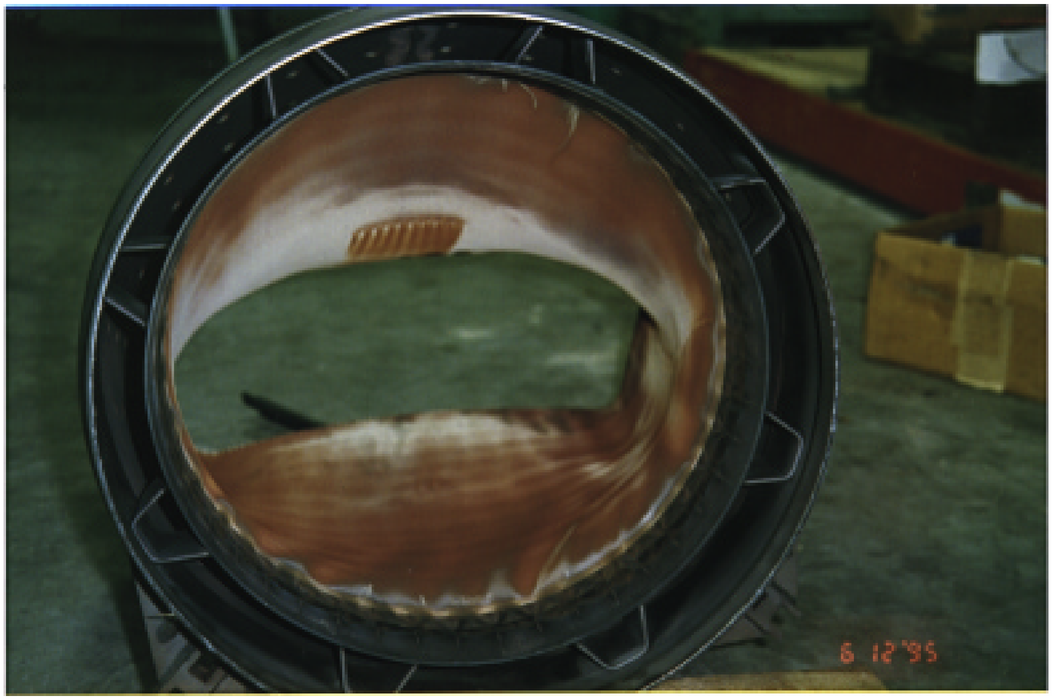
Transition piece in generally good condition after 4,402 hours, but with some wear on the end frame (without design modification).
Figure 8.51 Unit 4B 9/94, 4,402 hrs. Transition Piece.

The transition piece is in good condition, after 8,504 hours.
Figure 8.52 Unit 3B 6/95, 12,586 hrs. Transition Piece.



The transition piece and the coating are in good condition, after 8,504 hours of operation.

Figure 8.53 Unit 3B 6/95, 12,586 hrs. Transition Piece.



The transition piece is in good condition, after 8,504 hours.

Figure 8.54 Unit 3B 6/95, 12,586 hrs. Same As In Figure 8.52.

Transition piece showing design modification resulting in minimal wear.
Figure 8.55 Unit 3B 6/95, 12,586 hrs. Transition Piece.

Transition piece in good condition, after 9,682 hours.
Figure 8.56 Unit 4B 11/95, 14,264 hrs. Transition Piece.

Transition piece showing material modification to end frame (FSX-414), with no wear. There is a crack on two (of 14) transition pieces.

Figure 8.57 Unit 4B 11/95, 14,264 hrs. Transition Piece.

9

OVERALL INSPECTION SUMMARY

9.0 PLANT AND OPERATIONAL OVERVIEW

FP&L - Martin CC Station is the high time MS 7221FA site. It is a base loaded site with a DLN-2 combustion system that has used natural gas exclusively to date. The site has an 898 MW ISO rating, and has four gas turbines operating in a base load combined cycle mode.

The current operating statistics for the four Martin CC Station machines are shown in **Table 1**. The high time machine (Unit 3A) has now accumulated 16352 hours of service, with 88 fired starts and 38 trips. The four machines have now accumulated a collective total of 56906 hours of service with 278 fired starts and 108 trips. (As of November '95)

Operation prior to May 1994 was characterized by numerous shutdowns, largely due to the brand new DLN-2 technology that was being introduced. Since that time, however, it has been the more typical base load operation. Overall, operation has averaged 198 fired hours per start since installation, and about 480 hours/start since latter 1994.

All four machines were inspected on a scheduled basis, or as a result of the installation of new technology hardware or other events. There have been 5 Combustion, 1 Hot Gas Path, and 2 Major Inspections on the Martin machines since their installation in late 1993, and all are shown in **Table 2**.

9.1 HIGHEST LOGGED OPERATING HOURS

The plant is notable for being the first FA machine to reach 16000 hours service on all stages of turbine blading: having the fleet leading DLN-2 system (typically running at 10 to 18 ppm NOx levels); and being the first to demonstrate an 8000^+ hour life between refurbishment of DLN-2 combustion hardware. Operating time on all current hot gas parts is shown in **Table 3**. The high time service, and the inspection range times (not necessarily in the same machine) are:

Part	High Time Hours	Inspection Range Hours	No. of Inspections
1st Stage Buckets	16352	3549 to 14264	8
2nd Stage Buckets	16352	4082 to 14264	4
3rd Stage Buckets	16352	3549 to 14264	7
1st Stage Nozzles	16352	3549 to 14264	8
2nd Stage Nozzles	16352	4082 to 14264	4
3rd Stage Nozzles	16352	3549 to 14264	8
Combustion Hardware	9862	1253 to 9862	8
Stationary Shrouds - 1st & 3rd Stage	16352	3100 to 14264	7
Stationary Shrouds - 2nd Stage	16352	4082 to 14264	3

Table 1 Operating Statistics

	Unit 3A	Unit 3B	Unit 4A	Unit 4B
Turbine Number	295810	295851	295854	295855
Installation				
First Synchronized	Late 1993	Late 1993	Late 1993	Late 1993
Commercial	Early 1994	Early 1994	Early 1994	Early 1994
Last Inspected	Nov. 1994	June 1995	Feb. 1995	Nov. 1995
Inspection Type	Comb'n	Comb'n	Major	Comb'n
Fired Hours	16352	16062	10228	14264
Fired Starts	88	66	64	60
Trips	38	22	27	21
Total Starts	93	73	74	71
Normal Starts	116	101	79	85
Manual Starts	90	64	56	62
Compressor Surge Indications	9	9		0
Primary Mode Fired Hrs.-Gas	17	6	19	8
Primary Mode Fired Hrs. - Oil	0	0	0	0
Lean-Lean Mode Fired Hours	796	452	114	361
Secondary Mode Fired Hours		0		
Premix Mode Fired Hours	6768	11643	10082	4295
Premix Transfers	54	64	0	0

Table 2 GT's Significant History

Unit	Date	Fired Hours	Fired Starts	Trips	Comments
3A	6/93	0	0	0	First synchronized
	12/93	~450			Combustion and 1st shroud modifications
	2/94	~1200			Commercial operation
	4/13/94	3549	64	27	Combustion Inspection
	5/15/94	~4300			Load swings
	11/14/94	8079	74	32	Combustion Inspection
	7/18/95	~13600			Firing temp. readjusted from 2384 to 2365°F
	11/14/95	16352	88	38	Latest Status
3B	6/93	0	0	0	First synchronized
	12/93	~450			Combustion and 1st shroud modifications
	2/94	~1200			Commercial operation
	3/4/94	2295	40	16	Borescope Inspection
	5/15/94	~3500			Load swings
	5/21/94	~4000			Peak load test demonstration of about an hour
	5/23/94	4082	47	17	Hot Gas Path Inspect.- nozzle tip loss
	6/11/95	12586	60	21	Combustion Inspection
	7/28/95	~13500			Firing temp. readjusted from 2384 to 2365°F
	11/14/95	16062	66	22	Latest Status
4A	12/93	0	0	0	First synchronized
	2/94	~100			Combustion modifications
	4/94	~300			Commercial operation
	5/15/94	~1000			Load swings
	11/7/94	4867	42	21	Major inspection - rotor vibration
	2/16/95	6120			Major Inspection - compr. blade failure
	6/21/95	~6700			Firing temp. readjusted from 2384 to 2365°F
	11/14/95	10228	64	27	Latest Status
4B	12/93	0	0	0	First synchronized
	2/94	~100			Combustion modifications
	4/94	~300			Commercial operation
	5/15/94	~1000			Load swings
	9/14/94	4402	41	21	Combustion Inspection
	7/15/95	~11500			Firing temp. readjusted from 2384 to 2365°F
	11/14/95	14264	60		Combustion Inspection. Latest Status

Table 3 Parts Hours History (a)

	UNIT 3A		**UNIT 3B**		**UNIT 4A**		**UNIT 4B**	
Part	Current 11/14/95	Last Inspection 11/14/94	Current 11/14/95	Last Inspection 6/11/95	Current 11/14/95	Last Inspection 2/1/595	Current 11/14/95	Last Inspection 11/14/95
1st Buckets	16352	8079	11980	8504	4108/8190 (b)	6120	14264	14264
2nd Buckets	16352	8079	16062	12586	4108	6120	14264	14264
3rd Buckets	16352	8079	16062	12586	4108/10228	6120	14264	14264
1st Nozzle	16352	8079	11980	8504	4108	6120	14264	14264
2nd Nozzle	16352	8079	16062	12586	4108	6120	14264	14264
3rd Nozzle	16352	8079	16062	12586	10228	6120	14264	14264
1st Shrouds	16352	7600	11980/16062	8504/12586	4108/10228	6000	14264	14264
2nd Shrouds	16352	8079	16062	12586	10228	6120	14264	14264
3rd Shrouds	16352	8079	16062	12586	10228	6120	14264	14264
Comb. Cap	8273	4530	3476	8504	5361	1253	9862	9862
Fuel Nozzles	8273	4530	3476	8504	5361	1253	9862	9862
Comb. Liner	8273	4530	3476	8504	4108	1253	9862	9862
Trans. Piece	8273	4530	3476	8504	5361	1253	9862	9862
IGV's	16352	8079	16062	12586	10228	6120	14264	14264
Fw'd Comp. Blades	16352	8079	16062	12586	10228	6120	14264	14264
Aft Comp. Blades	16352	8079	16062	12586	4108	6120	14264	14264

(a) Hours are since installation. Most were new as installed. Some parts (mostly combustion) may have been refurbished after seeing prior service in another machine.

(b) One set of half new/half serviced buckets were installed in February 1995. 42 were new; 50 were not refurbished, but had seen 4082 hours of prior service in Unit 3B. All had GT-29IN-PLUS coating.

9.2 STATE OF THE ART TURBINE DESIGN

Four hot gas parts challenged the State-of-the Art at the time of initial design. These were the 1st stage nozzle (sophisticated cooling in large parts), 1st stage buckets (serpentine cooling in large parts), 3rd stage buckets (the largest investment cast buckets made), and the combustion system (DLN, with high exit gas temperatures). All four parts have performed quite well to date in this base load service. The same comment applies to the remaining hot gas path parts.

9.3 FIRING TEMPERATURE

The nominal firing temperature of the MS 7221FA is 2350°F (1288°C) firing at ISO full load. It was determined, however, that these FP&L units were fired at 2384°F (1307°C) until June/July 1995, at which point the temperatures were reset to 2365°F (1296°C). No particular harm was noted from this operation (up to 15000 hours per machine), although it is anticipated that inspection intervals and lives of the current hot gas parts have been reduced because of this small, but significant, elevation in firing temperature.

9.4 INSPECTION INTERVALS

GE has traditionally recommended three types of inspections. These are Combustion Inspections, Hot Gas Path Inspections, and Major Inspections in increasing order of machine disassembly and inspection coverage. Combustion hardware only is removed at Combustion Inspections, while turbine upper casings are removed at Hot Gas Path Inspections and all upper casings and the rotor are removed at Major Inspections.

The reference Maintenance Interval is the one for the most favorable case - that of a base load machine, fired on natural gas with no water/steam injections. The FP&L-Martin CC Station is therefore an example of a reference case.

The GE recommended inspection intervals for the MS 7221E/EA/F/FA reference case are as follows:

Type of Inspection	Designation	Interval Hours
Combustion Inspection	CI	8000
Hot Gas Path inspection	HGPI	24000
Major Inspection	Maj	48000

The reference Maintenance Interval is reduced according to the following formula:

$$\text{Maintenance Interval (in hours)} = \frac{24000}{\text{Maintenance Factor}}$$

where —

$$\text{Maintenance Factor} = \frac{\text{Factored Hours}}{\text{Actual Hours}}$$

and —

$$\text{Factored Hours} = G + 1.5D$$
$$\text{Actual Hours} = G + D$$

and —

G = annual base load operating hours on gas fuel
D = annual base load operating hours on distillate fuel

Nothing in these inspections suggested that the inspection intervals should be lowered for the reference case of a base loaded FP&L-Martin machine fired at 2350°F (1288°C). There might, in fact, be some optimism for increasing the Combustion Inspection interval sometime in the future (Unit 4B just completed a 9624 hour interval). Inspection intervals for the current hardware might, however, be lowered because these machines were actually fired at 2384°F (1307°C) for a significant part of their life.

A shorter Combustion Inspection interval was occasionally used to get a preliminary assessment of a new hardware design. This practice was good, and should be considered for any significant innovations in the future.

9.5 LIFE OF HOT GAS PARTS

GE references life of individual parts as multiples of the recommended standard Maintenance Intervals mentioned above. The philosophy for any new machine is to use appropriate design tools as tempered by past field experience, and then follow the fleet leaders to verify that design - as is currently being done for the MS 7221FA. GE has presented the following lives for the MS 7221E model which, at 70000 hours, is a more mature design than the MS 7221FA:

	Repair Interval	Replace Interval
1st Stage Buckets and Shrouds	HGPI	2 HGPI/3 HGPI (a)
2nd, 3rd Stage Buckets and Shrouds	HGPI	3 HGPI
1st , 2nd, 3rd Stage Nozzles	HGPI	3 HGPI
Combustion Liners	CI	5 CI
Fuel Nozzles, Cross Fire Tubes	CI	3 CI
Transition Pieces	CI	6 CI

(a) Bucket Only: 3 HGPI with refurb/recoat

It is anticipated that the lives of some current FP&L parts, particularly the 1st stage bucket, will be shorter than these because of the higher firing temperature used initially.

It is impossible to project the results of the current 4000-14000 hour visual inspections out to the 48000-72000 hour level, certainly without the benefit of destructive analyses. Most observations were encouraging, however, and didn't *disprove* the use of the above MS 7E table for an FP&L MS 7221FA fired at 2350°F (1288°C). The 1st stage bucket, however, may be the item that is most in question (see Condition of Parts).

9.6 OPERATIONAL HISTORY

The machines have basically run quite well, but have not been without incident as follows:

9.6.1 Units 3A, 3B, 4A, 4B (5/15/94) All units experienced unique load swings which were caused by a fuel gas delivery malfunction. The machines went from a fully loaded 150 MW to about 25 MW in a few seconds, reestablished at full load, possibly repeated, and then tripped. Control modifications were made as protection against a repeat occurrence, and nothing like this has been seen since.

9.6.2 Unit 3B (5/94, 4082 hours) Lost a fuel nozzle tip which was discovered at the scheduled inspection of 5/23/94 (there have been no subsequent tip losses). This is a 2”x2” (50.8 x 50.8 mm) cylinder of 60-120 mil (1.524 x 3.048 mm) wall thickness and 4 ounce (113.4 gms) weight. No defects were found in metallurgical examination and the observations were consistent with a fuel flashback. Exhaust temperature spreads were normal two months before, but were skewed within two weeks of, the inspection (no interim data was available). It is believed that the tip loss triggered the exhaust temperature shift, and both occurred from combustion flashbacks. The downstream damage was surprisingly little. The 1st stage nozzle partitions and buckets were both removed for repair; while 2nd and 3rd stage nozzles and buckets were left in the machine. Leading edges on three 2nd stage buckets and two 3rd stage buckets were carefully blended in the machine.

9.6.3 Unit 4A (2/95, 6120 hours) The rotor developed significant vibration and, because of time concerns the compressor section was replaced with another serviced compressor. The rebuilt rotor then experienced a compressor blading failure in early February 1995. There had been a loss in output (8 MW) and in compressor discharge pressure some 16 hours prior to the final shutdown trip on high vibrations. Portions of three compressor blades went downstream (stator 4, rotor 4, stator 14), and most blades downstream of stage 3 were dented and bent. Combustion parts were essentially intact; 1st and 2nd stage nozzles and buckets and some 3rd stage buckets were removed for refurbishment, and the 3rd stage nozzle was quickly refurbished and reinstalled in the same machine. The rotor is under investigation by the OEM. Interestingly, station instrumentation indicated that the machine had been producing about 7 MW more power than the other three for at least part of it operation.

9.7 CONDITION OF PARTS

To date, impactions/FOD have been the cause of most of the damage to, and limited the life of, hot gas parts. This has been a factor on three machines, and particularly affects the first stage parts.

9.7.1 1st Stage Buckets This is the most sensitive part to firing temperature. All four machines have operated for substantial time with elevated firing temperatures (about 20°F (11.1°C) elevation at the bucket). Potential concerns are the leading edges and the squealer tips.

a) Leading Edges:

The coatings have been universally protective through all 8000 hours inspections, FOD excepted. The most recent inspection of Unit 4B did show localized leading edge attack (breach and 2-10 mils (.0508 - .254 mm) metal attack) at 14264 hours. The higher firing temperatures certainly contributed, to this oxidation. Additionally, traces of sand-like foreign material were ingested into this machine, but the deposit pattern was not necessarily associated with the oxidation. It would imply that the coating breach life for a

2350°F (1288°C) fired machine might be somewhere between 14000 and 24000 hours, but this can only be verified by future inspections.

b) Squealer Tips

Trailing edge tip oxidation has been noted on all MS 7221F/FA to date and appears to be almost linear with time. It removed 120-150 mils (3.048 x 3.810 mm) of the trailing edge tip by 14000 hours. It is still felt that this oxidation will be self-limiting by virtue of the nearby trailing edge cooling holes. Both the original design, and the newer slotted tip design, oxidized at about the same rate.

Tip rubs varied from light (5-20 mils (0.127 - 0.508 mm)) to heavier (30-60 mils (0.762 - 1.524mm)), and virtually all came from the shrouds at the horizontal joint. Squealer tip cracks were not significant at FP&L - they were seen in only one machine and did not go below the cavity floor.

The tip cavity plate oxidized significantly when part of the squealer tip wall was damaged by FOD. This then let hot combustion gases into that cavity.

9.7.2 2nd and 3rd Stage Buckets The buckets, including the tip shrouds, appeared to be in good condition after some 14000 hours of service except for occasional impactions/FOD. The 2nd stage vane coating appear to have at least 24000 hours capability at this site. Significant parts of the 3rd stage coating (~ 25%) were no longer in place, but it may have been thin as originally installed. This, however, is of little significance at FP&L in that the coating was only applied for hot corrosion protection which has not been a factor at this site.

9.7.3 1st Stage Nozzles The nozzles and the aft side TBC coatings were in good condition after some 14000 hours of service other than for any impactions/FOD. Some minor potential limitations seen to date are sidewall oxidation and sidewall cracking. The high time machine also had a 2.5″ (63.5 mm) crack on two vanes. All of these have been seen on the MS 7221E. It is felt that the nozzle will satisfactorily reach the 24000 hour refurbishment point.

9.7.4 2nd and 3rd Stage Nozzles The nozzles appear to be in very good condition after some 14000 hours of service other than for any impactions/FOD. The 2nd stage coating should have at least 24000 hours capability at this site, the 3rd stage is uncoated.

9.7.5 Stationary Shrouds and Seals First, second and third stage stationary shrouds were all in good condition in inspections up to 14000 hours and had considerably more life potential. The only exception was 1st stage shrouds. 39 of the 384 1st stage shrouds have been replaced to date - all specifically due to rubs on those that were located near the horizontal joint, and variously between 10 and 50 mils (0.254 - 1.252 mm). Rubs on the discourager, angel wing, and labyrinth seals were infrequent in inspections to 6000 hours, and were more on 2nd stage than on the 3rd.

9.7.6 Combustion System Combustion hardware, particularly with the more recent modifications, was in generally good condition and has been successfully refurbished a number of times. The coatings were still intact, the cooling holes were effective, and there generally wasn't much hardware deterioration. The areas that are more potentially limiting are distortion and wear.

Distortion (inward bulging) was seen on all liners. It was in identical locations near the head end and varied in maximum depth from 0.1" - 0.8" (2.54 - 20.32 mm). Distortion at the two recent 8000^+ hour inspections was similar to that in previous 4000 hour inspections, so there is a possibility it will stabilize over time.

Three liners (of the 112 liners examined) also had a crack, but all were in completely different locations. Although of concern, the cracks suggested isolated manufacturing problems as opposed to a generic design problem. One was at an exit end weld, one was in the body, and the other was at a cross fire tube collar weld.

A number of combustor face plates also had small hot spots with limited oxidation and distortion. Although not life limiting, this could be minimized by a coating.

Life of the original transition pieces was limited by wear. It has virtually been eliminated in newer designs by two approaches - each of which had some potential side effects.

Two machines with wear strips had virtually no wear, but two (of the many) strips had cracks in the attachment weld. Neither caused the strip to be lost or damaged, and the cracks didn't look like they were propagating. They should be monitored because of their potential for downstream bucket damage.

One machine with FSX-414 end frames (the same alloy used for the 1st stage nozzle) had even less wear. Two of the 14 end frames, however, developed 1-2" (25.4 - 50.8 mm) cracks - but in completely different locations. Propagation looked as if it was very slow.

9.8 SMALL IMPACTIONS (< 60 MILS (1.524 MM) DIAMETER)

Many gas turbines, including some Martin machines, have small impacts on the 1st stage buckets leading edges (<60 mils (1.524 mm) diam. x 5-20 mils (0.127 - 0.508 mm) deep). The source of these impacts is generally not known, but comparable ones have not limited life in the earlier MS 7221E model machines. The MS 7221FA, even though of a more sophisticated design, appears to be equally tolerant to these very small impactions. They have not grown in size or oxidized significantly with 9000 hours of additional service in one FP&L MS 7221FA machine. This will be monitored as service time increases.

9.9 LARGER IMPACTIONS/FOD (> 120 MILS DIAMETER)

There have been three instances where larger parts have gone through the FP&L machines, at least two of which were known to be failed upstream components. This has been the most significant cause of damage to date, and the only reason for removal/refurbishment of the FP&L blading so far.

The damage varied between the three machines. Unit 3A resulted in small impacts on one 1st stage bucket leading edge which was left in service; Unit 3B (lost fuel nozzle tip) required that the 1st stage nozzles and buckets be removed; Unit 4A (compressor blade failure) required that essentially all three stages be removed for refurbishment. Earlier stages were generally more heavily damaged than the latter, but the reverse has occasionally happened on the MS 7221E due to ricocheting and secondary damage.

Most damaged parts were “nicked and scraped”. The coating was typically breached - locally on the leading edges and the convex vanes surfaces downstream of the throat. These parts were candidates for refurbishment. A few parts, however, were damaged more seriously, such as with tip loss or projectiles piercing the wall. Nozzles in this category were repairable, but buckets were more probably replaced.

Overall, the MS 7221FA hot gas parts were felt to be quite robust, considering the size of some parts to which they were exposed. They may not, in fact, be markedly more sensitive to initial impact than the earlier MS 7001E parts. However, the bare metal that is exposed would oxidize more rapidly, so that the parts would have to be refurbished sooner.

9.10 OTHER ITEMS OF INTEREST IN THE INSPECTIONS WERE:

Unit 3B successfully demonstrated peak load operation in a one hour test in May 21, 1994, see Section 8.5. Firing temperatures were increased 50°F (27.8°C) (2384 to 2434°F (1307 - 1334°C)) and there was a corresponding increase in the surface temperature of the 1st stage bucket leading edge of about 25-30°F (7.5 - 16.67°C), as anticipated. Not all operating parameters were completely reestablished after the test, possibly by virtue of the different ambient temperatures.

Parts have generally looked very similar to each other within, and between, stages of machines with equivalent service. The only difference was the 1st stage buckets in

Unit 3B, which looked slightly whiter and of a lighter hue than other buckets. This probably resulted from either the 1 hour peak load test or the loss of a fuel nozzle tip that occurred on that particular machine.

Most blade and combustion coatings have held up well so far at FP&L.

Distortion of the combustion liners was originally thought to be caused by a series of severe load swings on May 21st, 1994. That, however, didn't turn out to be the case because liners that have been installed subsequently had equal degrees of distortion.

1st stage bucket tip rubs were virtually all caused by rubbing with the inner shroud blocks at the horizontal joints, and less so from foreign objects that might have come downstream. The rub lips that build up on the tips are no indication as to the amount of rub - a more dependable measure seems to be the degree of coating deterioration in the area close by the rub.

Some MS 6B/7E/9E machines had oxidation undercuts on the outer sidewall of the 1st stage nozzle. This has been seen on only two segments of one FP&L MS 7221FA machine (Unit 4B, 11/95, 14264 hours). Even there, it was less than seen on the MS6B/7EA and should not limit nozzle life, but will increase the difficulty of refurbishment.

The compressor blading failure (Unit 4A, February 1995) brought out a point of interest. The compressor blading is made from GTD-450 alloy in the forward stages, and AISI 403Cb in the latter. The newer GTD-450 material was more resistant to impact damage than was the 403Cb - which has long been regarded as the tough, ductile workhorse alloy of the industry.

9.11 DATA ACQUISITION SYSTEM (DAS)/PERFORMANCE DEGRADATION

DAS has been a valuable tool for storing and retrieving operating data at the FP&L-Martin CC Station - both for standard conditions and investigation of any incidents. The base load power was typically in the 153 to 160 MW range when corrected to 59°F (15°C) conditions.

Quantitative studies of performance degradation on these machines is being prepared (See TR-106330). Nothing in the condition of the hot gas parts (distortion, surface finish, rubs etc.) to date would suggest it would be different from other machine models. Performance deterioration is more generally associated with fouled compressors than deterioration of the hot gas parts (although bucket tip rubs and oxidation can play a part).

9.12 BTMS (BLADE TEMPERATURE MEASUREMENT SYSTEM)

This has also been a very useful tool. The pyrometer does something that no other instrument does - the on-line, continuous and virtually instantaneous measurement of temperature difference between buckets in a running turbine. For example, it can identify a bucket(s) that is running substantially hotter than it's neighbors because of manufacture, partially blocked cooling passages or deterioration. That bucket, in turn, will probably have the shortest life because of the very strong influence of temperature upon material properties. The pyrometer is therefore very useful for diagnostic, trending and monitoring purposes and also as an alert against any hot buckets.

The forward pyrometer is aimed at the upper third of the 1st stage bucket leading edge, which is the hottest area seen by the pyrometer. Additional description of the BTMS is provided in Chapter 11.

10

RECOMMENDATIONS

10.0 RECOMMENDATIONS

Continue the recommended Maintenance Interval schedules for FP&L Martin CC Station hot gas parts that have been fired at 2350°F:

Combustion Inspection	every 8000 hours
Hot Gas Inspection	every 24000 hours
Major Inspection	every 48000 hours

There is the possibility to increase the Combustion Inspection interval somewhat, in the future (Unit 4B just completed a 9624 hour interval). Also, an intermediate 4000 hour mini Combustion Inspection should be considered if new technology hardware is introduced in to service. Quite possibly this could be done borescopically with little, or no, hardware disassembly.

10.1 LIFE INSPECTION OF PARTS

Projecting life of parts into the very distant future is not possible from these inspections, certainly without destructive analyses. However, most observations were encouraging and didn't *disprove* the use of the MS 7001E life table for a 2350°F fired FP&L MS 7221FA. The 1st stage bucket may be the most critical. It would be appropriate for GE to monitor these buckets. The Recommendation above shouldn't imply that all parts are perfect. Those items that might be more likely to limit eventual life are:

Impactions/FOD	From upstream pieces, and particularly to 1st stage parts.
1st Stage Buckets	Leading edge oxidation. Squealer tips - trailing edge tip oxidation, and cavity plate oxidation (when squealer walls are lost by FOD)
Combustion Liners	Distortion (inward bulging).

These items should be investigated, and monitored at future inspections.

10.2 LIFE OF PARTS AND INSPECTION INTERVALS

Lives and inspection intervals of parts currently in the machines have been reduced because they operated at 2384°F firing temperatures until mid 1995. This primarily relates to the 1st stage bucket.

Local oxidation was, in fact, seen on the high-time 1st stage buckets recently examined in Unit 4B (11/95, 14264 hours), but also might have been partially caused by small foreign material that went through that particular machine (see Section 9.7.1.A). It is felt that these particular buckets might need to be removed within the next 4000 hours (i.e. 18000 hours total) if refurbishment/recoating is to be considered. Otherwise, these parts can remain in operation provided that the effect of the early higher firing temperatures on their runout life is accounted for.

10.3 DESTRUCTIVE EVALUATION

It is suggested that a program for periodic destructive evaluation of selected hot gas path parts be conducted. From a technical standpoint, this would best involve the OEM in that they know the interaction between design and operating conditions. It is also suggested that any destructive analyses be done on the hottest bucket in a set - by pyrometer measurements. This recognizes the strong influence that operating temperature has on bucket life.

10.4 EVALUATE/IMPLEMENT

Evaluate/Implement the following:

Evaluate a cutback of twelve 1st stage inner shrouds at either horizontal joint (of the 92 total). The shrouds at this location have a history of rubbing, most probably due to a small distortion in the casing.

Continue inspecting future long time 1st stage buckets to seen whether the localized oxidation seen on Unit 4B (11/95, 14264 hours) was largely attributable to the higher firing temperatures and/or foreign material ingested into that machine.

Metallurgically examine the combustion liner crack recently found Unit 4B (11/95, 14264 hours, Liner #4). Although rare and seemingly not propagating fast, it was next to a seam weld.

Evaluate a TBC coating for the perforated plate of the combustor end cap to minimize the mild oxidation and occasional distortion that is seen on this part. Increase the resistance of the liner to distortion (inward bulging) such as by different material, fins, etc.

Evaluate (GE) the design/procedure for weld-attaching the wear strips on the transition piece end frames - unless the intent is to move to FSX-414 end frames. The (very few) cracks seen in these strips to date were all associated with these welds.

Consider using Unit 4B for running future tests such as the peak load test - assuming all other things are equal and a relatively quick redesign of the flexible hose arrangement. This is the only machine with three potential pyrometers locations.

It is felt that there is considerable value in some of the past BTMS/DAS data that has been stored over the past two years. It is recommended that this past data be surveyed and summarized - both for it’s technical value, but also for it’s background value for future inspections.

10.5 RECOMMENDATIONS FOR FUTURE INSPECTIONS

Consider/implement the following items for the next “shells-off” inspection of these machines:

Any 1st stage nozzle pyrometer boss should automatically be modified so that the IR pyrometer can function, if it has not been done already. This pertains mostly to any new 1st stage nozzles at the Martin site.

Adopt the new alignment procedure for the IR pyrometer.

Improve borescope access. Some borescope ports have frozen plugs or are mismatched with the shroud hole - both of which prevent borescope access through that port. It is suggested that these ports all be checked at the next casings-off inspection.

Additional inspection ports would be useful for quick borescope access. Examples are on the casings (to improve accessibility to the buckets and nozzle segments), and on the combustion system (to monitor condition and liner distortion).

Measure the 2nd and 3rd stage nozzle clearance readings (2F1, 3F1) at any future inspections for downstream creep. Nothing suggested that they are not acceptable, but the readings would be a good baseline for future reference.

10.6 IMPROVEMENTS SUGGESTED FOR THE DATA ACQUISITION SYSTEM (DAS)

Improvements that can be considered for this, or future, Data Acquisition Systems (DAS) are:

Include DAS entries that have been corrected to ISO site conditions (megawatts, exhaust flow, heat consumption). It minimizes variables associated with changes in ambient temperatures**.**

Revisit the protocol for storing/averaging/deleting data on DAS. The purpose is to maintain the more critical data as long as possible before it is time-averaged.

Four approaches are

- Add additional computer storage capacity.
- Extend the averaging protocol for more useful information - like key operating parameters, temperature spreads, and bucket ABPT values. Less useful information could be quickly averaged (like the shape of the pyrometer trace valleys).
- Include an option to prevent deletion/averaging of the most critical data unless manually initiated. This would prevent loss of data in case of an unscheduled event or failure, and aid in diagnostic work.
- Permanently record certain operating parameters for trending analysis. An initial suggestion is that this be done weekly, and at similar load and ambient temperature conditions. Readings could include such items as: load, IGV angle, pressures (ambient and compressor discharge), temperatures (ambient, nominal firing, average exhaust), 1st stage bucket pyrometer traces, exhaust thermocouple traces.

10.7 IMPROVEMENT SUGGESTED FOR THE BTMS

BTMS improvements that are recommended:

a. Reactivate the optical pyrometers in Units 3B, 4A and 4B at the next applicable inspection. This involves a redesign of the flexible hose arrangement and may also involve drilling some first stage nozzle bosses. Useful information is lost without these pyrometers.

b. Determine whether the BTMS pyrometer “spot” diameter can be reduced below 0.25” without causing unacceptable electronic noise This would improve accuracy by virtue of averaging temperatures over a smaller area.

c. Include a permanent and positive way of correlating the *exact* location of any bucket while it is in the machine. This requires a clear correlation between wheel position and BTMS position - both for inspections and in case selected buckets need to be examined destructively.

11

EPRI BLADE TEMPERATURE MEASUREMENT SYSTEM ("BTMS") AT MARTIN COMBINED CYCLE

Introduction

A brief description of EPRI's Blade Temperature Measurement System ("BTMS") is included here for reference purposes only. Some BTMS results are referred to in this guideline when analyzing the effects of blade surface metal temperature on the life of the blades. The detailed description of BTMS is presented in EPRI Guideline TR-103895, Rotating Blade Temperature Measurement System.

One area of interest when monitoring advanced gas turbines is the operating metal temperature of the first stage rotating turbine blades, where the firing temperatures are higher than the current operating fleet gas of turbines.

The most important feature of the BTMS is its ability to pinpoint a blade operating at a higher temperature than the other blades on the wheel (turbine stage). Elevated blade metal operating temperature is an alert to investigate and possibly replace the affected blade(s), in order to prevent a very expensive failure in the loss of the hot gas parts.

BTMS Description

As part of the EPRI Durability Surveillance Project, Land Infrared supplied a BTMS employing six (6) optical pyrometers which take continuous thermal-radiation readings for each blade. Fiber optic cable ("light guide") relays blade temperature data to electronic processing units, which generate up to forty (40) temperature data points per blade per revolution of the turbine shaft. These "thermal signatures" can then be displayed in graphical form, for analysis. The Schematic Diagram for the BTMS is shown in **Figure 11.1**. Site installation photographs are shown by **Figures 11.2, 11.3, and 11.4.**

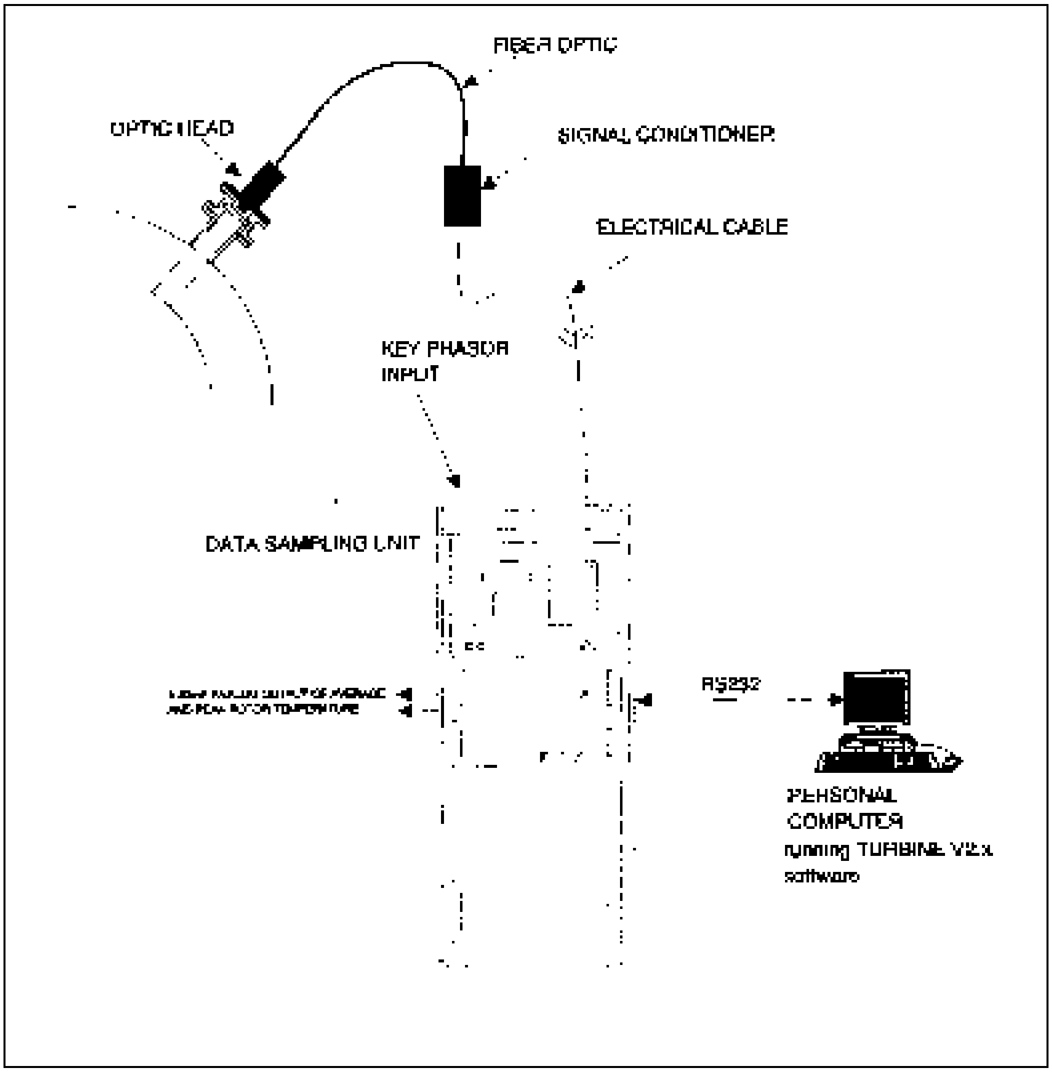


Figure 11.1
BTMS Schematic Diagram

SITE INSTALLATION PHOTOGRAPHS

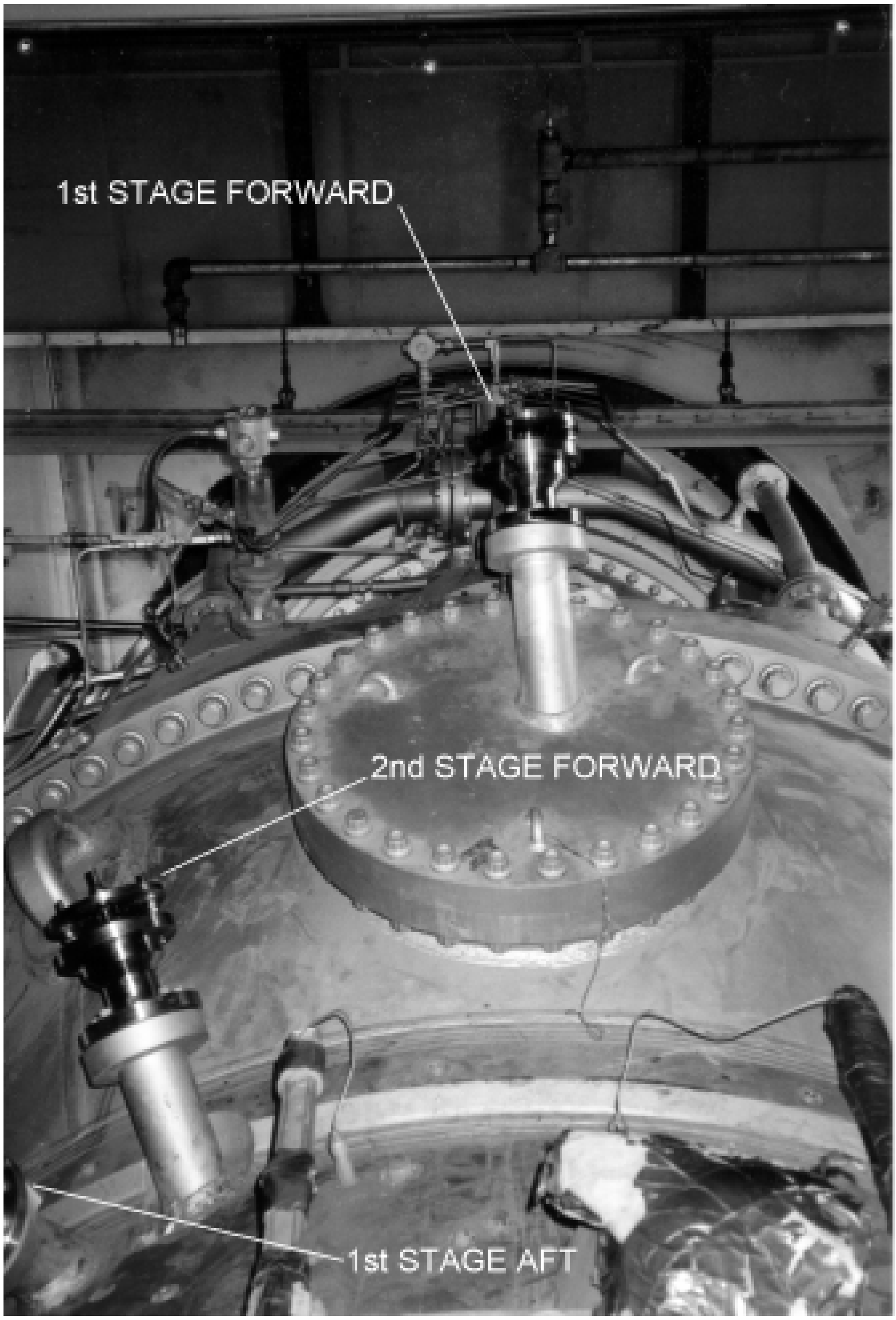


Figure 11.2
Pyrometers installed on MS 7221FA at Martin Station

SITE INSTALLATION PHOTOGRAPHS

Figure 11.3
BTMS Cabinet at Martin Station

SITE INSTALLATION PHOTOGRAPHS

Figure 11.4
BTMS Cabinet at Martin Station

Blade Related Degradation/Failure

Gas turbine buckets (particularly 1st and 2nd stage) are the most burdened components of the gas turbine due to high heat, intense stress and the harsh environment. The first stage turbine bucket must withstand the most severe combination of temperature, stress and environment. It is generally the limiting item on the machine. The following blade related problems can occur in an advanced industrial gas turbine:

- Thermal Fatigue (cracking)
- Alloy Hot Corrosion
- High Temperature Oxidation
- Blocked cooling passages/Loss of Cooling
- Loss of Material

Blade related problems are often result in changes in blade surface temperatures. BTMS on-line monitoring and analysis can be highly effective in identifying and trouble shooting blade related degradation or failure.

Turbine Blade Cooling

Modern turbine designs, such as the MS 7221FA, achieve improved efficiency through higher inlet gas temperature which was made possible by the introduction of blade cooling **(Figure 11.5)**. If not properly cooled, these blades are exposed to temperatures well above their operating limit. Turbine blade cooling is critical for effective operation of advanced (firing temperature above 2300°F) combustion turbines. Since most superalloys begin to melt at about 2200°F, hot gas components (including turbine blades) must be cooled to maintain temperatures well below this target.

Blade temperature information is extremely valuable to the operator of advanced (or current fleet) gas turbines equipped with cooled blades since it may pinpoint any blade(s) operating at elevated blade surface temperature(s). A blade operating at an elevated temperature may indicate the possibility of loss of cooling. This may be an indication of blade quality problems (cooling air restriction) or some operating degradation due to loss of coating, blade cracks, loss of material, cooling air starvation due to gradual deposits and other causes. **Figure 11.6** is a sketch of the first stage bucket cooling passages of the GE 7221FA.

Extensive trials have shown that blade-to-blade temperature differences can be significant for cooled blades. In addition, blade cooling introduces new life-limiting processes, such as oxidation and / or blockage of cooling passages which are not detectable by traditional instrumentation methods.

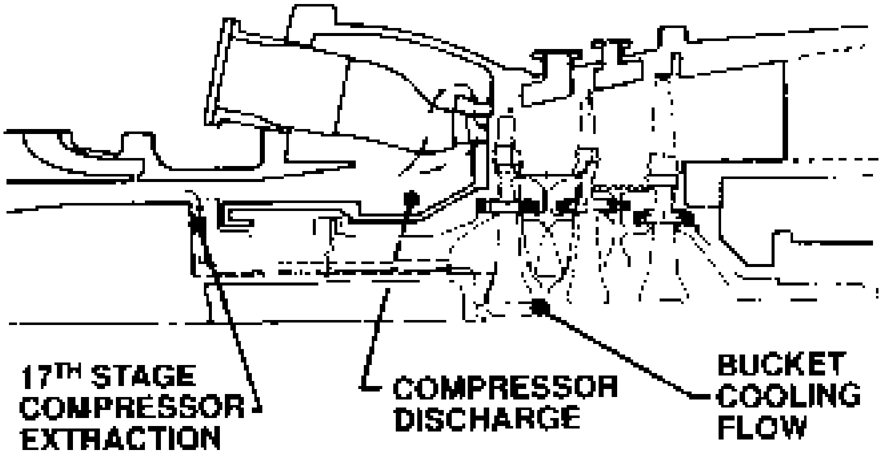


Figure 11.5
Blade Cooling Air of First Stage Bucket via
Extraction Air from 17th Compressor Stage

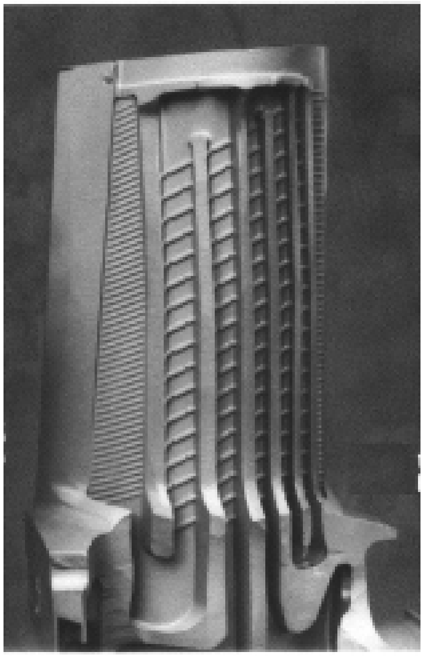


Figure 11.6
Serpentine Cooling Passages of the 1st Stage Bucket

Predictive Maintenance

BTMS is also effective in predicting future failure or degradation of blade performance. The BTMS has the ability to store blade surface temperature data over long periods of time. By trending blade temperature data over time, small increases in blade surface temperatures (at similar operating conditions) can be indicative of blade related problems.

Prevention of Catastrophic Failures

Cooling integrity is critical since stress creep life is a strong function of temperature, and operation at over temperature conditions can lead to damage or even possible catastrophic failure in the multi-million dollar range.

Implementation of BTMS at Martin CC Station

The application of a Turbine Blade Temperature Measurement Evaluation System ("BTMS") at Martin Station was the second application of BTMS equipment on an advanced industrial gas turbine. The first use of BTMS equipment was in 1992 at Potomac Electric Power Company's ("PEPCO") Station "H". To implement the BTMS equipment at Martin Station the following tasks needed to be completed:

- Working with the GT manufacturer to make the required penetration for optical pyrometers, installing guide tubes, and welding to the gas turbine casing mounting bosses.
- Selecting a supplier and specifying a system for operation in a commercial utility gas turbine power plant.
- Providing a signal from the pyrometer head through a light guide to an electronics box.
- Providing a signal from the electronics box to the Data Sampling Unit / Data Management Unit ("DSU/DMU") located in the electrical room under the control room.
- Developing the data analysis and display screens needed to present the data.

APPENDIX A
UNITS CONVERSION TABLE

English Unit		**Metric Units**
Length		
1 mil (or $1x10^{-3}$ inch)		00.0254 mm
10 mils (or $1x10^{-2}$ inch)		00.254 mm
100 mils (or 0.1 inch)		02.54 mm
1000 mils (or 1.01 inch)		25.4 mm
Mass		
1 ounce		28.35 grams
1 pound		453.6 grams (0.4536 kgm)
Temperature		
1° Celsius (C.) (incremental)		1.8°Fahrenheit (F.)
y°C (temp. level)	←	[(x°F + 40)/1.8 - 40]
[(y°C + 40) * 1.8-40]	→	x°F
Thermal Energy		
1 BTU (British Thermal Unit)		1.05486 K-joules