LM2500+ BRUSH SEAL CASE STUDY

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Abstract

The LM2500+ industrial aeroderivative gas turbine, a 25% enhanced power derivative of the LM2500 gas turbine, recently completed its development test program during the period of 5/96 - 10/96. Early in the engine program a Quality Function Deployment (QFD) process was used to determine customer needs for this product. The feedback obtained from the QFD process showed without doubt that gas turbine customers now emphasize product reliability and availability at the very top of their needs. One area of development on the LM2500+ was to investigate the use of a brush seal as a means to reduce undesirable turbine cooling leakages within the turbine mid frame in order to enhance part life. This presentation presents a case study on the factors that went into evaluating a brush seal during engine test, test results, and the ultimate decision to not implement the brush seal for cost and other reasons.

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- ➢ LM2500+ Gas Turbine Description
- ➢ LM2500+ Development Program
- ➢ Quality Function Deployment (QFD)
- ➢ Brush Seal Investigation
- ➢ Engine Test
- ➢ Brush Seal Case Study Summary

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LM2500+ Gas Turbine Description

- LM2500+ is a 25% power increased (ISO conditions) version of the LM2500 gas turbine.
- Straight forward development of the well-proven LM2500
  - Total LM2500 production in excess of 1,500 engines
  - More than 925 marine and 575 industrial LM2500 engines delivered
    - Over 23,000,000 operating hours
    - Average installed engine time over 38,000 hours/high time engine 107,700 hours
- LM2500+ is available in 3 variants: Gas Generator, Gas Turbine with Six Stage Power Turbine, and Gas Turbine with Two Stage Power Turbine.

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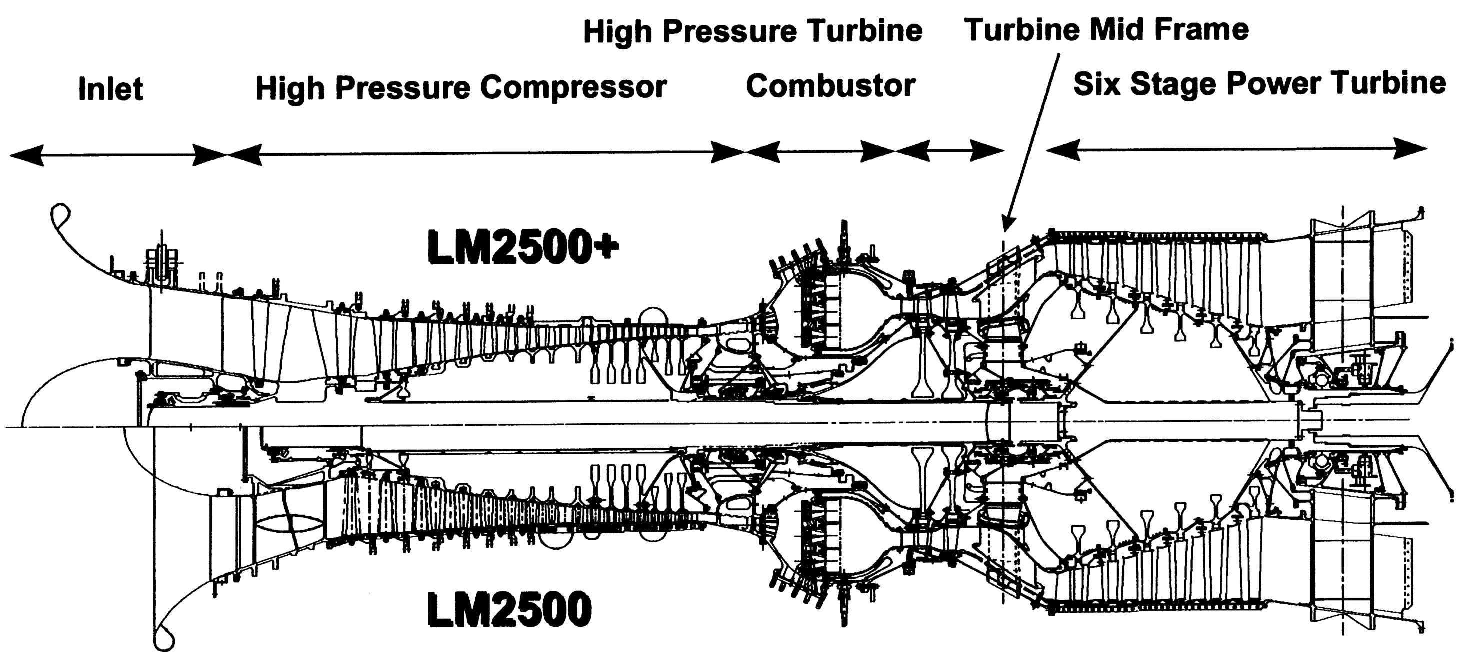
Figure 1 - Comparison of LM2500+ to LM2500



LM2500+ is 25% Power Enhanced LM2500
Using Zero-Staged HP Compressor

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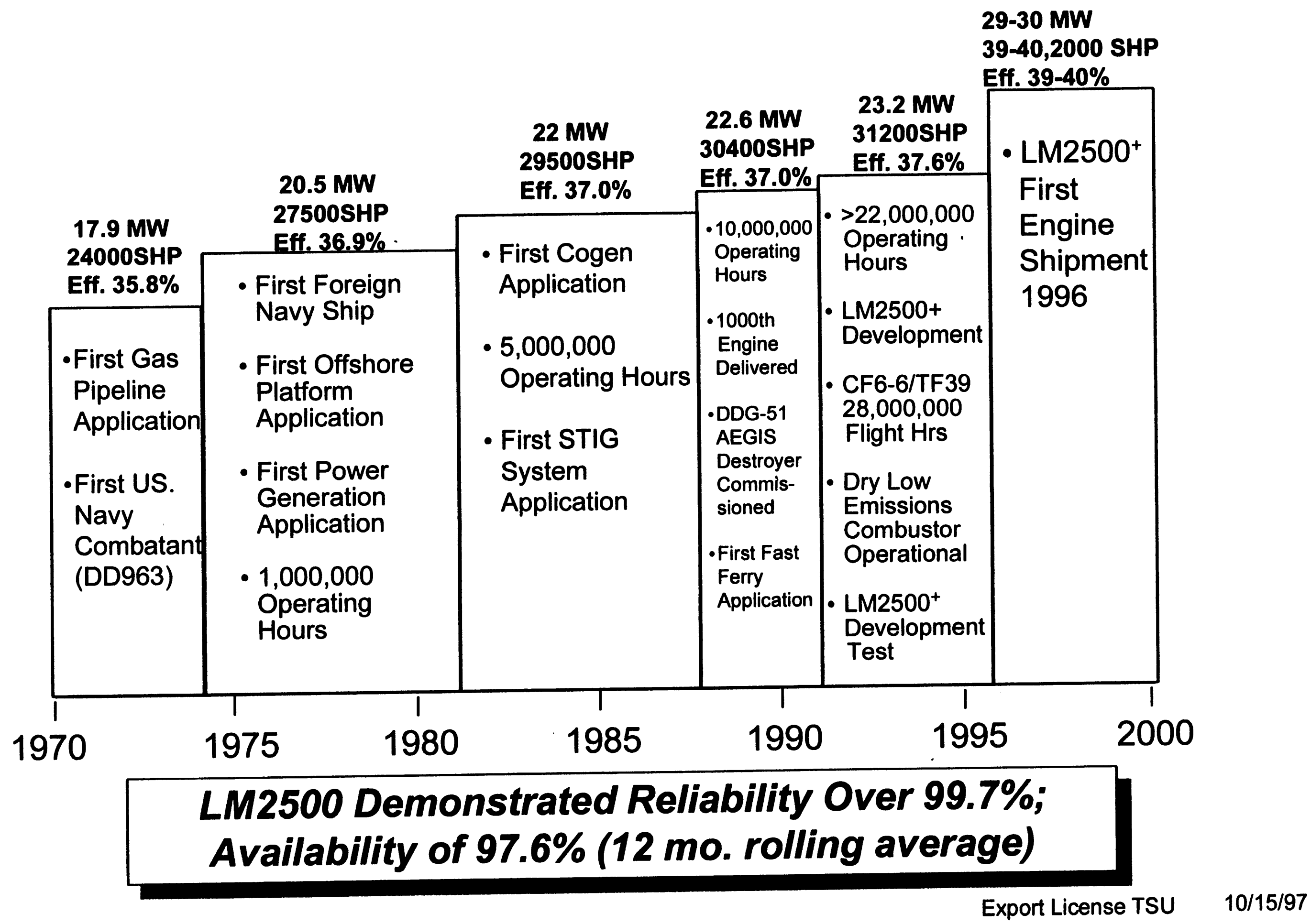
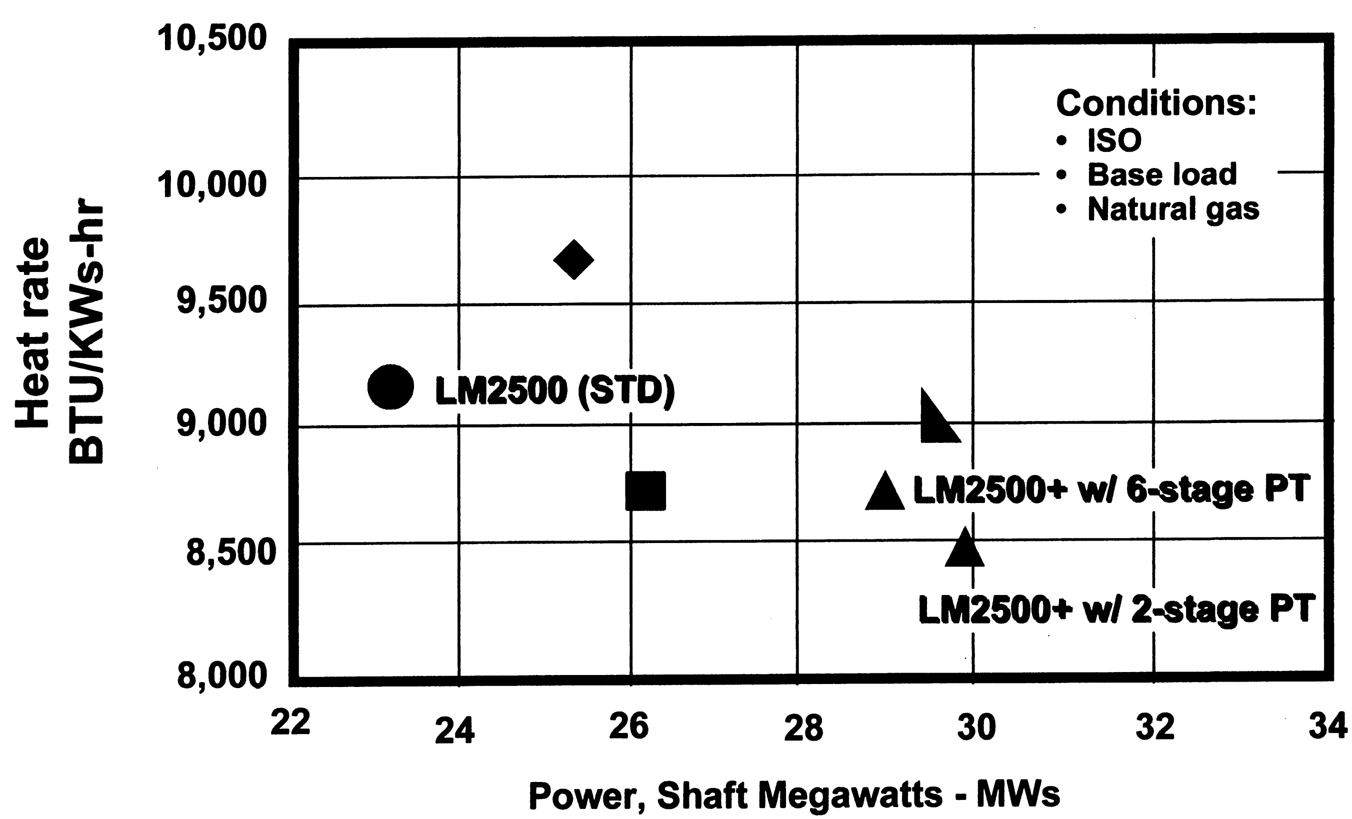
Figure 2 - Historical Synopsis of the LM2500



LM2500+ Performance vs. Other Products



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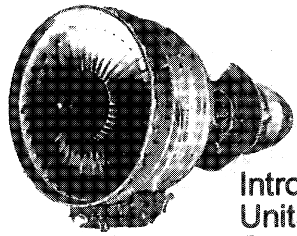
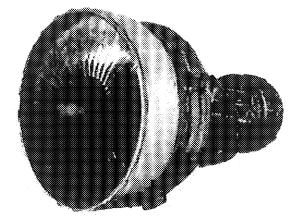
PPT-83308-022196 (LM2500+)

Genealogy



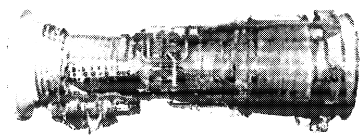
CF6-6

Introduced - 1965
Units in service - 1,152
Operating hours - 29,957,000



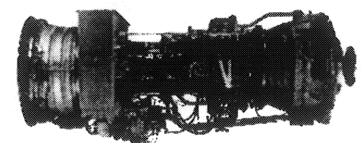
CF6-80C2

Introduced - 1985
Units in service - 2,238
Operating hours - 33,728,000



LM2500

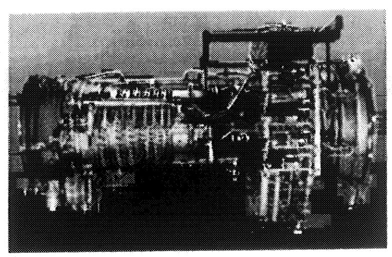
Introduced - 1969
Units in service - 1,500
Operating hours - 23,000,000
Reliability - 99.7%
Availability - 97.8%



LM6000

Introduced - 1991
Units in service - 108
Operating hours - 735,000
Reliability - 99.1 %
Availability - 97.3 %

Design experience & commonality



Technology advancements

Experience data as of 12/31/96

LM2500+ Derived from Proven Technology

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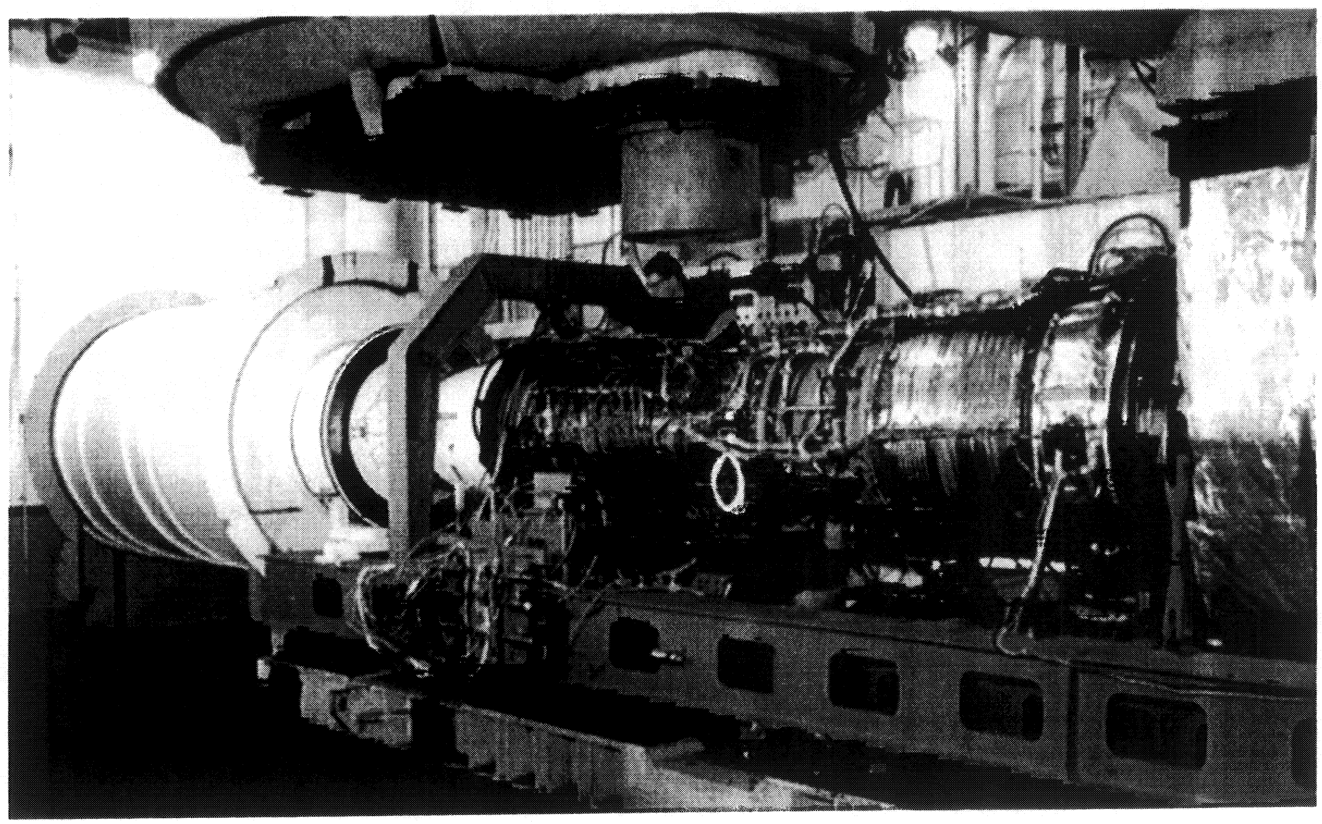
LM2500+ Gas Turbine (Second Engine to Test)



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LM2500+ Development Program

- Program launched March, 1994 on basis that LM2500 was not as competitive as in previous years
  - competition providing larger, more fuel efficient , less costly engines
- Many best practices applied to development effort, such as critical path scheduling, target costing, risk assessment & management, scorecards, concurrent product development, and others.
- Best practice used to determine customer needs was Quality Function Deployment ….

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Quality Function Deployment (QFD)

- ❑ Process where *customer input is used to determine and quantify requirements for new products.*
- ❑ Early in program the time-honored approach of verbal survey (talking) to gas turbine customers was used to obtain input on what changes to make.
- ❑ QFD process shows this method is no longer adequate to capture important customer needs
  - Time-honored approach - discussed LM2500+ <u>new</u> features only
  - QFD approach - obtain feedback on <u>basic product needs</u> as well as new features using written survey

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Quality Function Deployment Results

Table 1 - Comparison of Verbal Interviews vs. QFD Surveys

Ranking	Time-Honored Verbal Survey	QFD Survey
1	Power	**Availability***
2	Lower Price	**Reliability***
3	Noise Level	Pricing*
4	Efficiency	Power
5	Length	Efficiency
6	Emissions	Emissions
7	Weight	**Maintainability**
		(*tied)

Key Message from Customers: Availability & Reliability are Top Quality/Design Features

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Design Approach - Post QFD

- QFD survey pointed out => *customers no longer want high tech or pure power anymore .... they want*
  - Availability & Reliability & Pricing and then Power
  - Direct quote "Machine needs to be running when we want it to be running."
- To achieve these requirements LM2500+ Engineering adopted the following rules:
  - only mature, demonstrated technology allowed
  - only mature materials and suppliers used
  - extra design margins imposed - above the product requirements in order to hold reliability & availability at highest possible level during LM2500+ introduction
  - Lessons Learned from the base LM2500 incorporated

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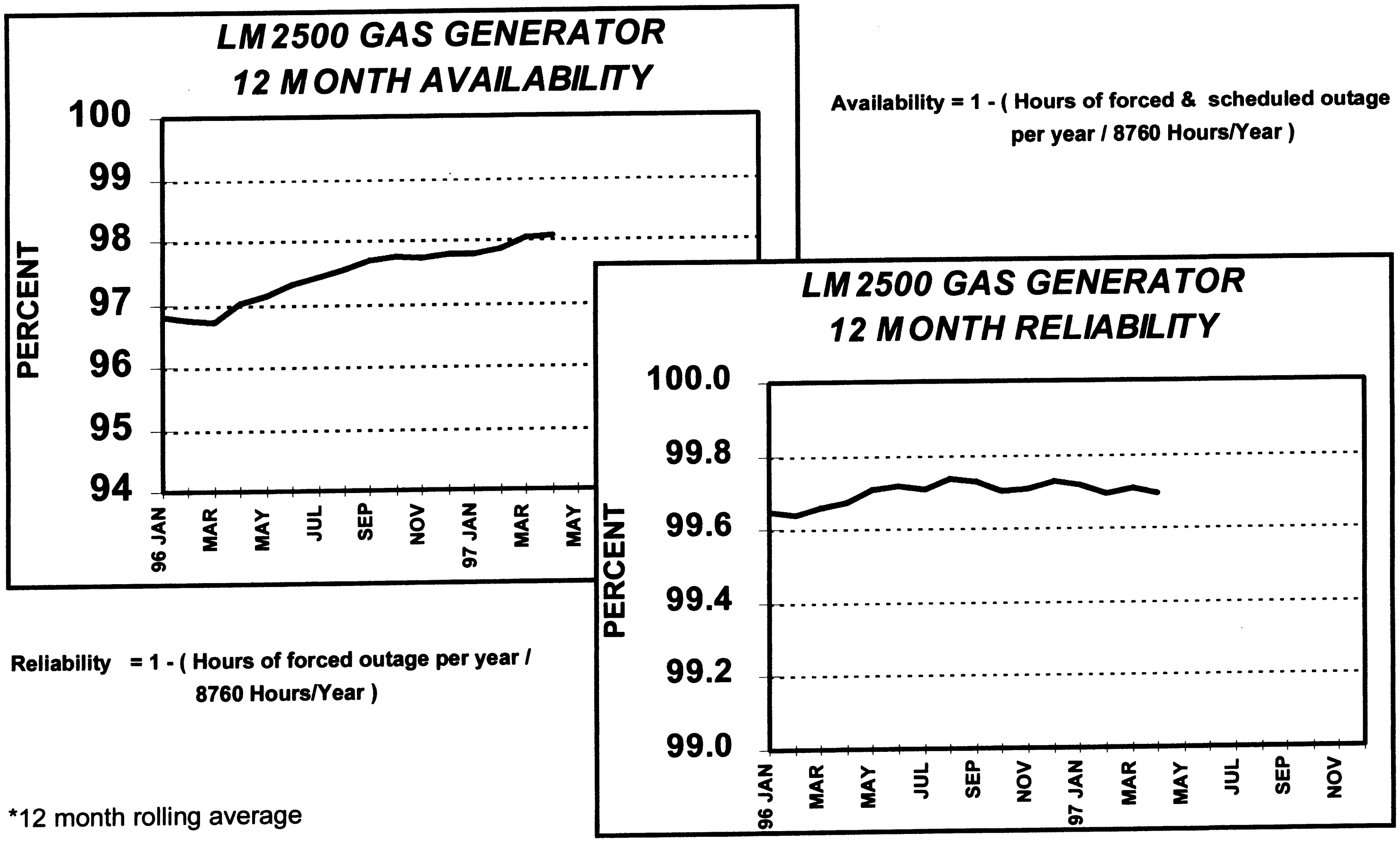
LM2500 Reliability & Availability*



Availability = 1 - (Hours of forced & scheduled outage per year / 8760 Hours/Year)

Reliability = 1 - (Hours of forced outage per year / 8760 Hours/Year)

*12 month rolling average

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Brush Seal Investigation

- Both LM2500/LM2500+ Turbine Mid Frame (TMF) designs use “HP Recoup” vent air from Compressor Rear Frame to purge region between TMF casing and flowpath liner
  - to minimize hot gas ingestion into these regions
- Design goal is positive pressure drop of 0.5 psi (3447 Pa). Too little pressure drop results in flowpath ingestion and reduced casing/flange life.
- Experiences on LM2500 TMF indicated that additional pressure differential margin could improve the robustness of the frame.

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Brush Seal Investigation (cont.)

- Calculation shows the LM2500 TMF total liner leakage area to be 10.59 in^2 (68.32 cm^2).
- Program decided to test both "J" seal and Brush seal as part of the development effort.
- Significant other sealing improvements made to TMF leakage paths to reduce total leakage areas.
- LM2500+ TMF liner reduced total leakage areas to:
  - 6.45 in^2 (41.61 cm^2) with "J" seal, or
  - 3.69 in^2 (23.81 cm^2) with Brush seal.

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Figure 3 - Brush Seal Details

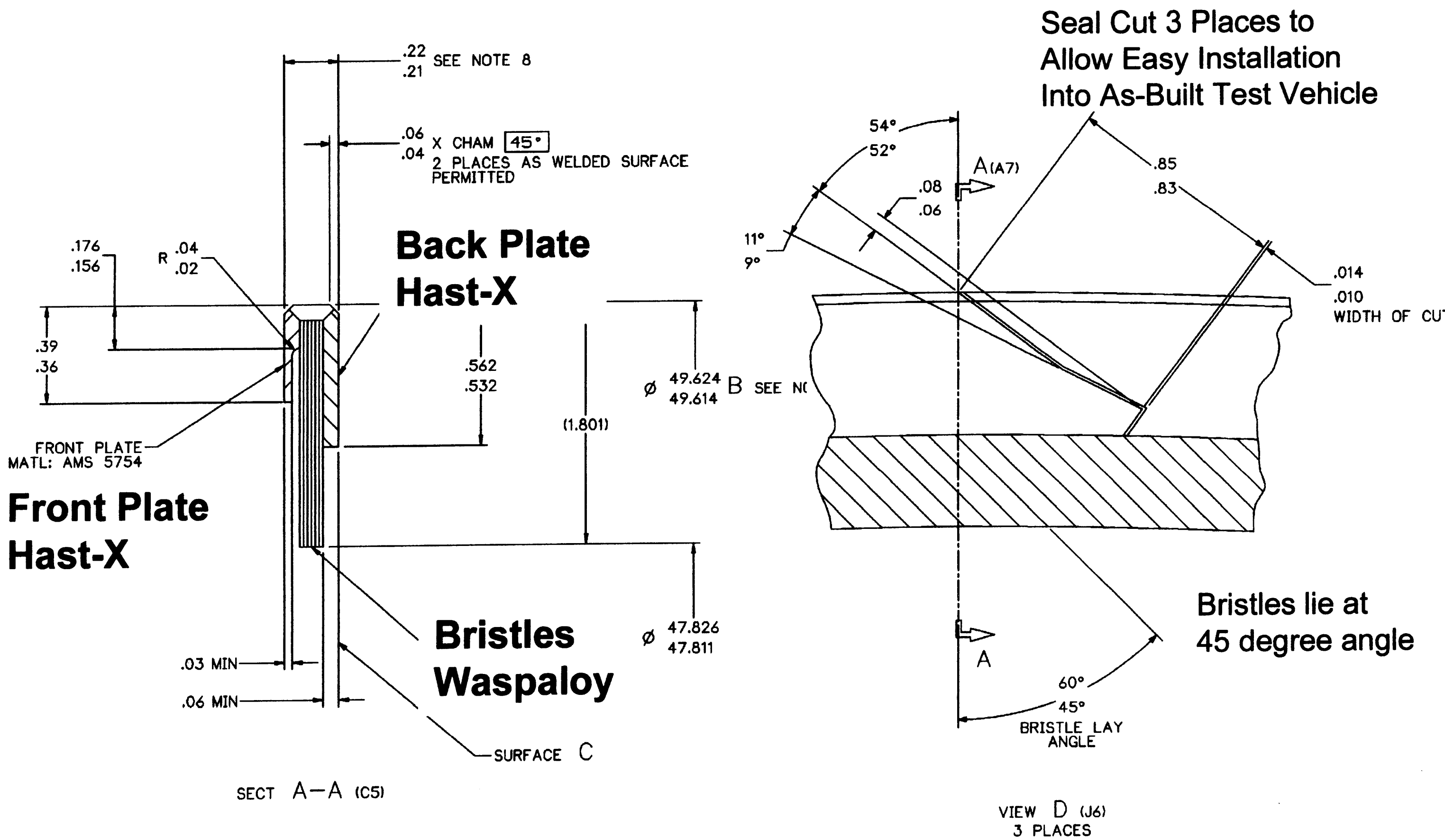

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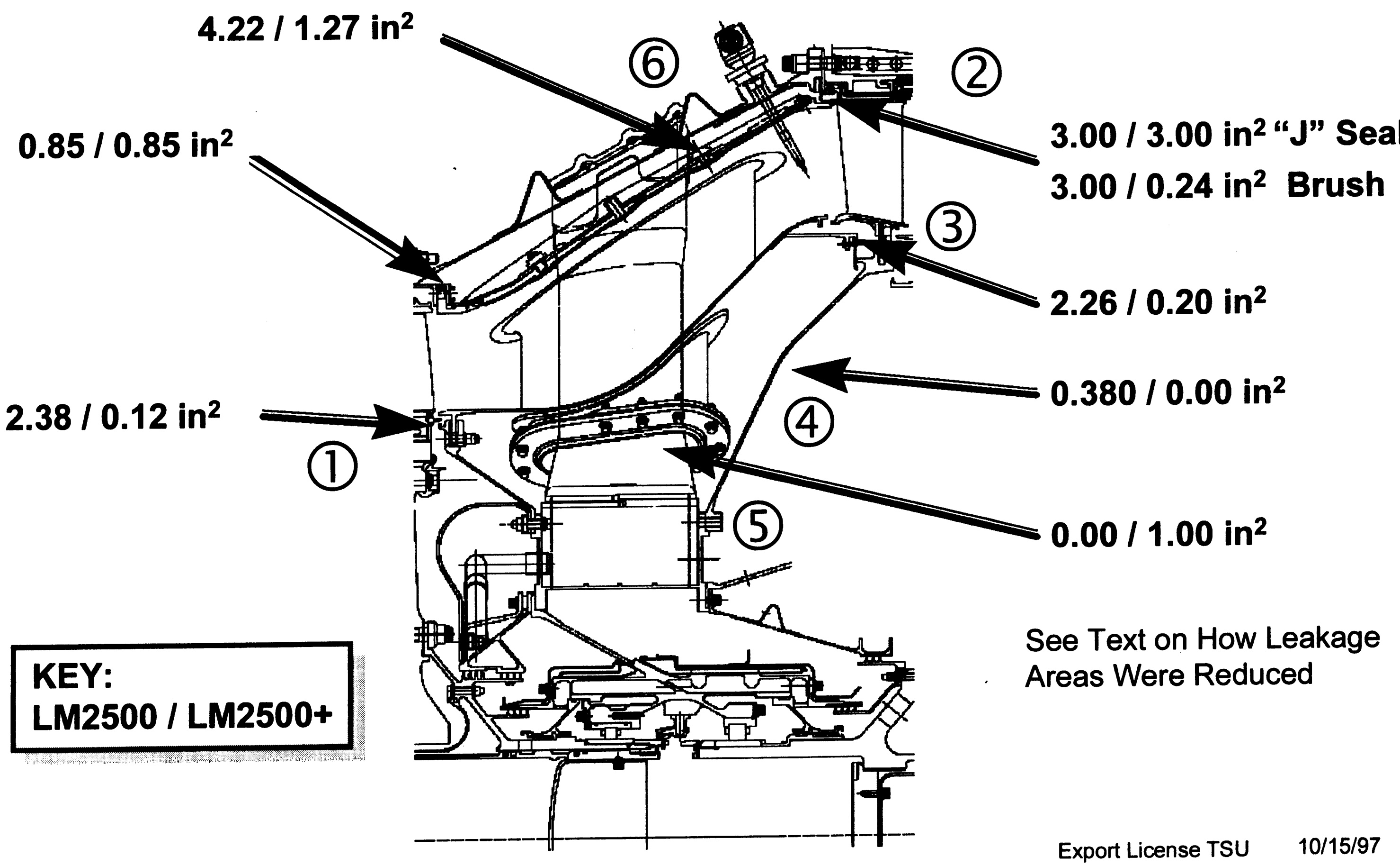
Figure 4 - Turbine Mid Frame Leakage Areas



Brush Seal Investigation (cont.)

Sealing Redesign on TMF Liner & Flanges

① Fwd Inner Location - Machined vs. Fabricated Joint

② Aft Outer Seal - Brush vs. “J” Seal

③ Aft Inner Seal - Leaf vs. Fish Mouth Seal

④ Aft Cavity Wall - Eliminated Fastener Lead @ 8 Loc

⑤ Fairing - Double Sliding Ring Seals Added

⑥ Flowpath Liner Probe Penetrations

- Reduced thermocouple flowpath probes (T48) from 11 to 8 probes
- Probe diameter reduced 0.35 in. (0.89 cm) max to 0.28 in. (0.71 cm) max
- Reduced flowpath pressure probes from 5 to 1

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Engine Test

- LM2500+ First Engine to Test was heavily instrumented (Figure 5).
- Began testing first with “J” seal installed.
- Prior to test completion the turbine mid frame aft flange bolts were loosened, the “J” seal cut away, and the Brush seal installed in 3 segments.
- Pressure test data obtained therefore with “J” seal and Brush seal
  - data plotted (see Figure 6)

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Figure 5 - Turbine Mid Frame Instrumentation

Notes:
- **Shown with "J" seal**
- **FETT used conic exhaust cone to simulate power turbine flow function**
- **Liner delta pressure measured as P2-P1**

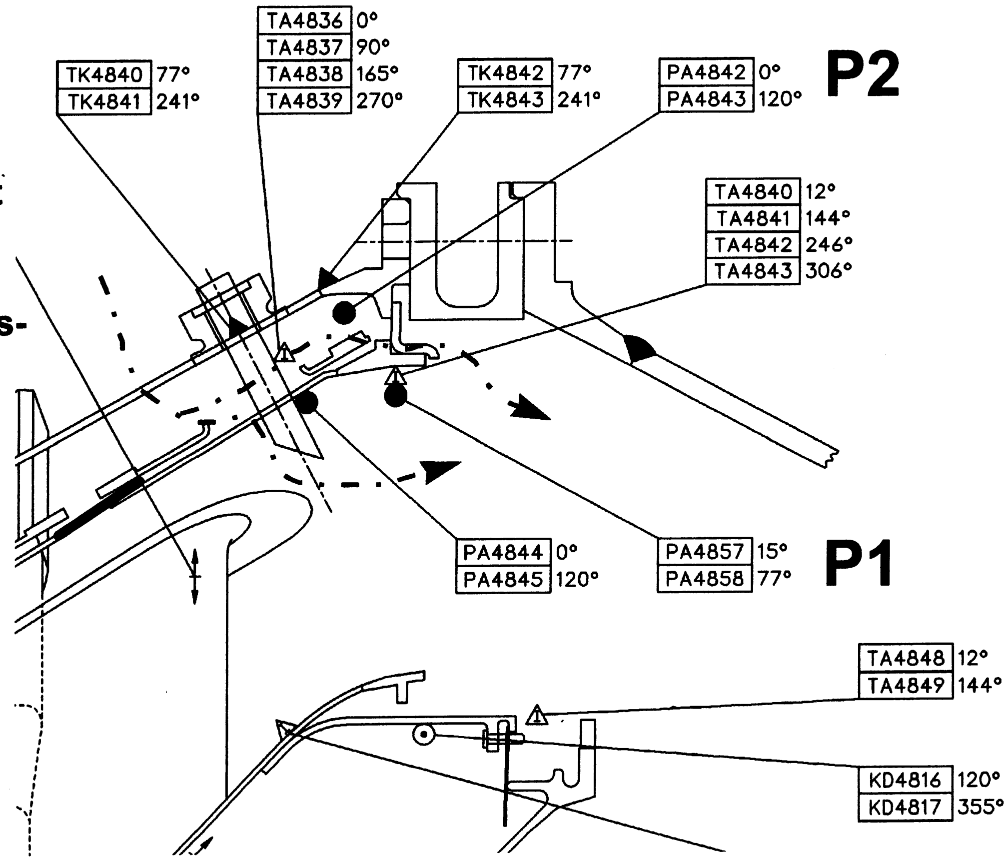

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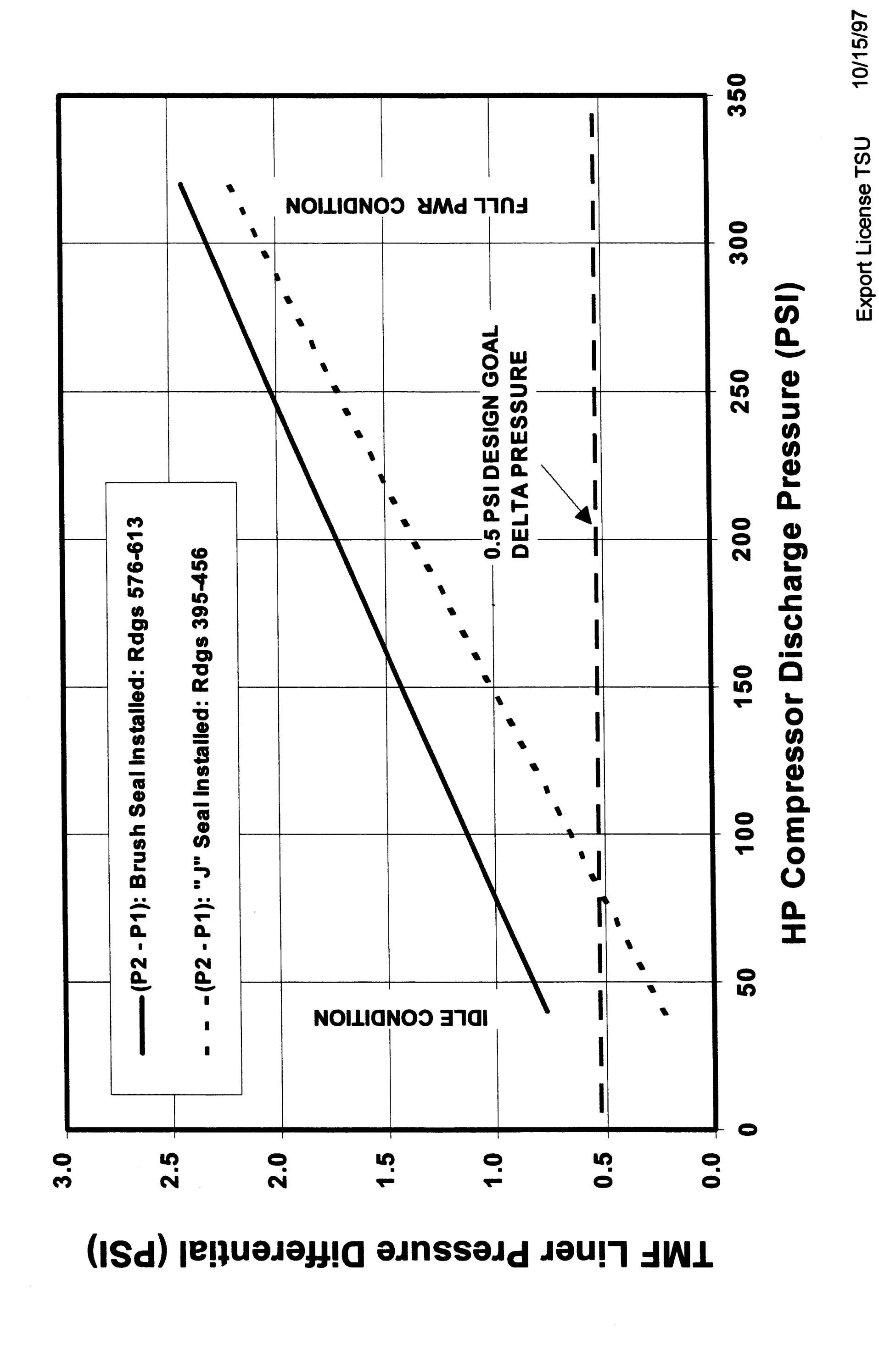
Figure 6 - TMF Liner Pressure Differential Test Results



Brush Seal Case Study Summary

- Brush seal successfully installed and tested on LM2500+ First Engine to Test.
- Reduced leakage for Brush seal did reduce overall leakages vs. “J” seal, however, at power conditions the extra benefit was greater than required.
- Ultimately decided that extra cost and complexity of Brush seal not appropriate for this turbine mid frame design given the extent of other sealing improvements.
- Brush seal may still be appropriate in other situations but must account for total fluid system and heat transfer environment.

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Brush Seal Pros & Cons

Brush Seals ...

↑ Can significantly reduce leakage areas

↑ Conform extremely well to irregular surfaces

↑ Can easily absorb thermal motions/deflections

↓ Are more costly ($7000 vs. $650 for "J" seal)

↓ Are somewhat heavier than other seal types

↓ Suppliers are somewhat limited

↓ Raise concern over bristle durability and weld damage during construction

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Biography: Fred G. Haaser

Current Position:

Responsible for leading all engineering efforts on the LM2500/LM2500+ family of industrial gas turbines at GE Aircraft Engines, Marine & Industrial programs. This includes integrating the engineering effort with the product line management, manufacturing, sales, and customer service organizations.

Background:

Fred Haaser received a BSME in Mechanical Engineering from the University of Notre Dame in 1976, and MS in Nuclear Engineering from the Pennsylvania State University in 1979. He worked in mechanical design for 1 1/2 years at Westinghouse's Bettis Atomic Power Lab prior to joining GE Aircraft Engines, where he has worked since 1980. A registered professional engineer and ASME member, Mr. Haaser was the Engineer Program Leader for the development of the LM6000 gas turbine, which entered production in 1992. His GE experiences prior to managing engine development programs includes managing engine secondary air systems, compressor stator design, and engine systems engineering. He is the author/co-author of four ASME papers.

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