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INDUSTRIAL APPLICATION OF GAS TURBINES COMMITTEE

IAGT™

Mercury™ 50 Field Evaluation and Product Introduction

by

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Education

B.S. (Mechanical Engineering) University of Illinois- Champaign-Urbana
M.B.A. (International Management) University of Antwerp- Belgium

Experience

1989 to present, SOLAR TURBINES INCORPERATED San Diego.

2002 - 2005	New Product Introduction Team Leader. Program Manager for the Mercury 50 and Taurus 65.
1997 - 2002	Japan/Asia Sales Manager. Director of Solar Turbines Services Company- Japan
1994 - 1997	R&D Program Manager
1991 - 1994	Business Development Manager
1989 - 1991	Senior Design Engineer

1983 to 1989, GENERAL ELECTRIC CO., AIRCRAFT ENGINE GROUP, Cincinnati, Ohio.

1986 - 1989	Senior Design engineer
1983 - 1986	Program Engineer

ABSTRACT

The *Mercury* 50 product development program originated as a cooperative effort between Solar Turbines Incorporated (Solar) and the U.S. Department of Energy (DOE) to develop gas turbine systems for the 21st century that would be more efficient, cleaner and less expensive to operate than previously available equipment. The primary program goals were to achieve single digit NO_x emissions, increase thermal efficiency by 15 percent, and reduce the relative cost of electricity by 10 percent. Achieving these goals would open up new opportunities for gas turbine systems in the power generation market. Solar launched the *Mercury* 50 product in 1997 and installed six field evaluation units that entered commercial operation beginning in 2000. All of these field evaluation units are still available for commercial operation and, along with two development engines, have accumulated more than 60,000 operating hours as of March 2005. The *Mercury* 50 gas turbine was commercially launched in December 2003. The *Mercury* 50 gas turbine produces 4600 kW of electricity, with a thermal efficiency of 38.5% and guaranteed NO_x emissions of less than 5 ppmv (15% O2). The first production unit was commissioned at the San Diego Veterans Administration Hospital (see Figure 1) in November 2004 and has over 3000 operating hours as of May 2005.

Figure 1. *Mercury* 50 at San Diego Veterans Administration Hospital

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RECUPERATED GAS TURBINE

Solar evaluated several turbine performance cycles to meet the product and market requirements, and the optimal choice was a recuperated cycle. The recuperation of the classic Brayton cycle gas turbine is a well-established method of improving cycle efficiency by recovering some of the turbine exhaust heat otherwise lost in a simple cycle design. The pressure ratio, mass flow and firing temperature were optimized for the recuperated cycle. The engine flow path was changed from that of a traditional industrial gas turbine to accommodate for the recuperated cycle at the lowest cost to the overall system (see Figure 2).

The new flow path and recuperated cycle also resulted in a combustion system design that could meet the low emissions requirements and allow for easy maintenance in the field. The *Mercury* 50 recuperated cycle yields a higher combustor inlet air temperature than a simple cycle turbine resulting in a lower flame temperature. The lower flame temperature yields lower NOx emissions. The turbine includes a 10-stage compressor, ultra low emissions combustor utilizing augmented backside cooling and thermal barrier coating technology, and a two-stage turbine. The recuperator, designed and manufactured by Solar, is an Alloy 625 primary surface design. A detailed description of the *Mercury* 50 turbine/recuperator and performance are outlined in table 1.

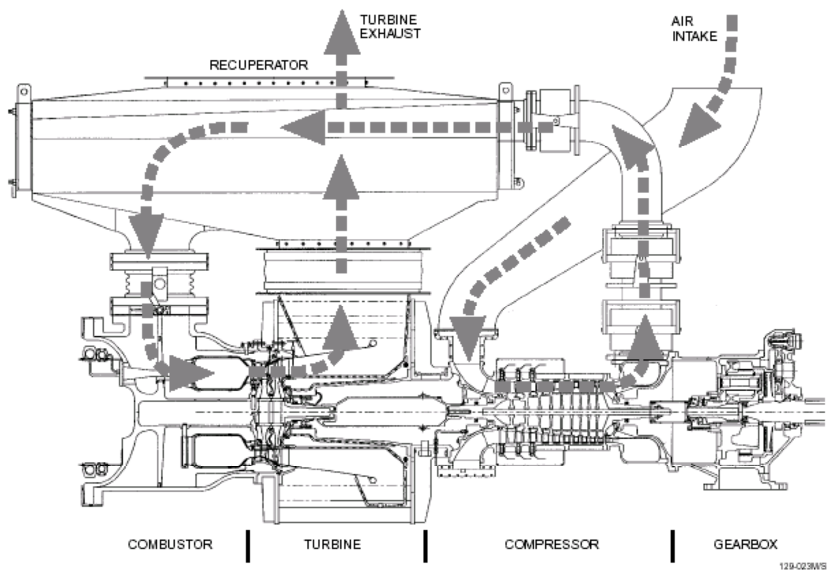

Figure 2. *Mercury* 50 Engine Flow Path

Table 1. *Mercury* 50 Gas Turbine

ENGINE

- Compressor	10 stages
- Turbine	2 stages
- Combustor	Annular
- Fuel Injectors	8 ultra-lean premix
- Rotor	Single shaft
- Bearing	2 viscous rolling
	1 viscous ball

RECUPERATOR

- Primary surface design
- Material: Alloy 625

ENGINE CYCLE

- Power	4600 kWe	
- Heat rate	9349 kJ/kWe-hr	
- Thermal efficiency	38.5% at generator terminals	
- Pressure Ratio	9.9:1	
- Inlet flow	17.9 kg/sec	
- Exhaust flow	64,161 kg/hr	
- Exhaust temperature	374 C	
- TRIT	1163 C	
- Rotor speed	50 Hz: 14,179 rpm	
	60 Hz: 14,186 rpm	
- Emissions (15% O2)	NOx	5 ppmv
	CO	10 ppmv
	UHC	10 ppmv

PRODUCT DEVELOPMENT PHASE

The *Mercury* 50 gas turbine was designed with the latest finite element, computational fluid dynamic (CFD), and heat transfer analytical codes. Solar leveraged past turbine and recuperator experience along with completing component rig testing to insure a high performing and durable product design. Two development test engines have been run over 10,000 hours and 2500 starts to verify durability and performance. No major issues were identified during engine development but recuperator durability and performance issues were identified. Figure 3 shows one of the development test generator-sets. In addition, robust engineering methodologies included a rigorous design review process through out the design and development phases.

Figure 3. *Mercury* 50 Development Test Unit

FIELD EVALUATION PHASE

Six field evaluation units were placed in operation from 2000 to 2001, four units in the United States, one unit in France and one unit in Australia. All six units are operational today and have accumulated more than 55,000 hours and 3,000 starts as of March 2005. The high time unit has over 19,000 hours. The field evaluation turbines have not experienced any major issues but the recuperator durability has not met original product requirements. The Mercury 50 thermal efficiency fell short of the original target primarily due to the recuperator issues. But the emissions results were excellent with NOx and CO emissions below 5 ppmv (15% O2), and well below the original target of 9 ppmv (15% O2). Solar has completed a major redesign effort on the recuperator to resolve all durability and performance degradation issues.

PRODUCT IMPROVEMENTS

Recuperator durability and performance issues were identified during development testing and the field evaluation phase. These durability issues did not prevent the unit from running but accelerated the performance degradation. The recuperator performance loss was primarily due to air cell creep and leakage. Material testing confirmed that the 347 SS material used in the original design did not have the required life margin to meet the turbine operating conditions. The recuperator material was upgraded to Alloy 625, a material with superior creep, oxidation and tensile strength to 347 SS. In addition, the recuperator size was increased to improve the performance. These two design changes resolved the issues identified during field evaluation testing. The new alloy 625 recuperator has completed extensive development testing with over 3000 operating hours and 1500 starts. The recuperator predicted time before inspection overhaul is now 60,000 hours.

Figure 4. *Mercury* 50 Field Evaluation Unit

Although no major turbine issues were identified during the development test and field evaluation period, product improvements were incorporated in the turbine. The product upgrades included improved performance and rotor dynamic margin. Performance improvements included reduced flow path pressure losses in the compressor and exhaust diffuser and optimized compressor and turbine tip clearances. The rotor dynamic margin was improved by shortening the rotor and stiffening the turbine casing. The improved turbine has over 5000 hours in development test. The turbine predicted time before inspection overhaul is 30,000 hours. These product improvements improved power output by 10% and thermal efficiency by 6%.

Figure 5. ***Mercury*** **50 turbine and recuperator**

GENERATOR SET PACKAGE

The *Mercury* 50 generator set package (see Figures 5 & 6) was designed for ease of operation and maintenance. The engine, recuperator, generator and auxiliary equipment are completely enclosed within the generator set package. Auxiliary equipment includes the fuel module, lube oil module, control system, start system, ventilation system, and base and enclosure assembly. The unique *Mercury* 50 engine layout also allows for combustion system and hot section maintenance on site without removing the turbine.

Figure 6. Mercury 50 Generator Set

RELIABILITY AND AVAILABILITY

Extensive analysis, component testing and development testing have been completed on the *Mercury* 50 product to verify the product reliability. Minimal inspection maintenance is required on the turbine, recuperator and package systems resulting in higher availability. In addition, these turbine and package systems have been designed to allow fast component replacement if maintenance is required. The modular turbine design allows a broader range of field maintenance options. All these features allow for improved availability. The *Mercury* 50 product reliability and availability is predicted to meet or exceed gas turbines and other power generation technologies in the 5 MW size range.

PERFORMANCE

The *Mercury* 50 thermal efficiency of 38.5% at the generator terminals is superior to other turbines in the 4 MW to 8 MW size range as shown in Figure 7. Steam injected gas turbines can produce similar thermal efficiencies but require a waste heat boiler and the overall system efficiency is greatly reduced in steam injection operation mode.

The NOx, CO and CO2 emissions are much lower than competing turbines and gas fired reciprocating engines in its size range. Figure 8 shows a NOx emission comparison between the *Mercury* 50 product and other competing products. The *Mercury* 50 also generates good exhaust heat that can produce 5.6 tonnes/hour of steam unfired and over 48 tonnes/hour with a fired Heat Recovery Steam Generator (HRSG) for cogeneration applications.

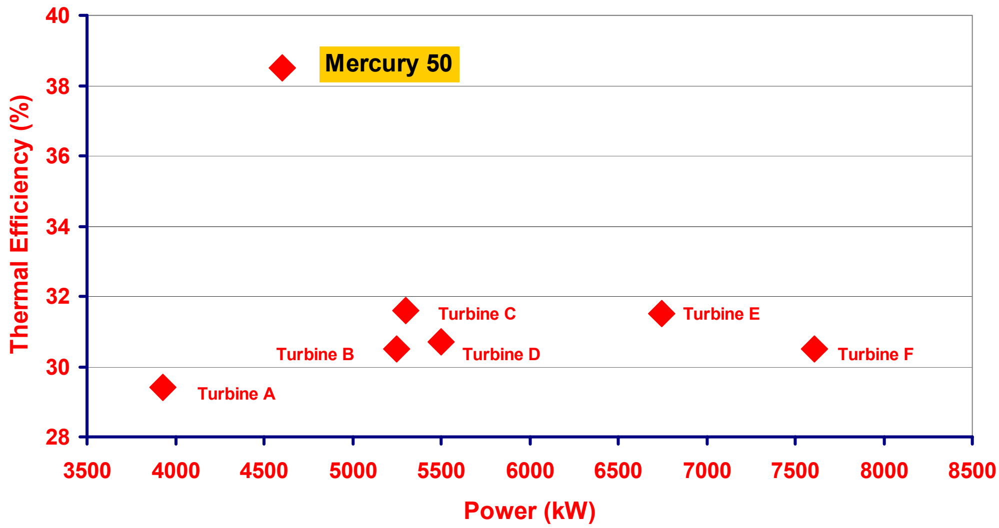

Figure 7. *Mercury* 50 Thermal Efficiency Comparison

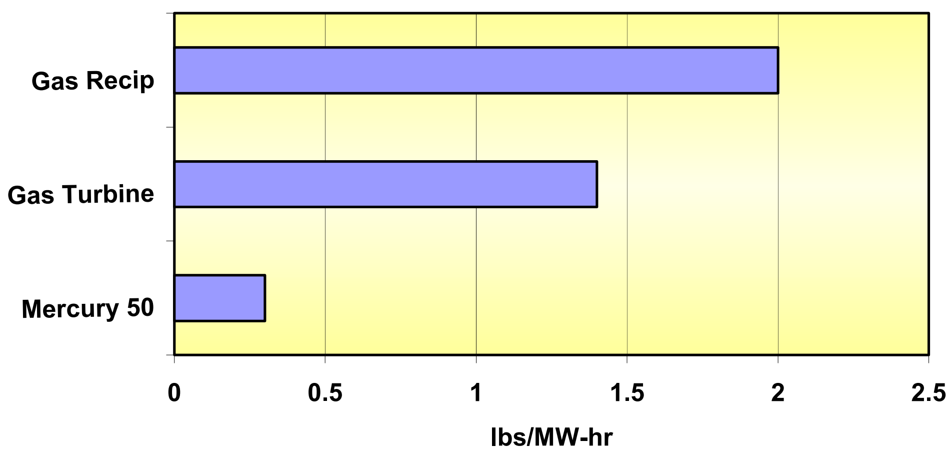

Figure 8. *Mercury* 50 NOx Emissions Comparison

SUMMARY
The *Mercury* 50 product has successfully completed the development and field evaluation phases and the first production unit is now operating in San Diego, California. The *Mercury* 50 product has accumulated over 60,000 operating hours confirming its reliability and durability. The *Mercury* 50 products high efficiency, low emissions, and a compact size and weight give it a competitive advantage over other products in its size range.