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PRATT & WHITNEY'S NEXT GENERATION TURBINE PROGRAM

William H. Day
Pratt & Whitney Power Systems, East Hartford, CT

Abstract

This paper describes Pratt & Whitney's approach to a new program funded by the U. S. Department of energy: the Next Generation Turbine (NGT) Program. The NGT Program is intended to develop gas turbines intended for the intermediate load electric power market, with first cost ($/kW) lower than current aeroderivatives and efficiencies higher than any current gas turbine, and with the flexibility for rapid starts and at least 400 starts per year. P&W's candidate to meet the attributes of the NGT Program is the intercooled cycle. The paper describes the P&W product that is being studied for development and examples of technologies that would be developed under the program. Work on Phase 1 of the NGT Program has been done under DOE contract number DE-AC26-00NT40847.

Introduction

Industrial gas turbines, both frame type and aeroderivative, have become the system of choice for power generation in many of the power applications worldwide. The great majority of military marine propulsion systems, and virtually all mechanical drive systems for natural gas pipeline pumping applications are based on gas turbines. In electric power generation gas turbines provide the highest efficiency and lowest capital cost of any power generation technology available today, with extremely low emissions. Gas turbines have virtually taken over the market for new power generation installations in the U.S. The Energy Information Agency estimates that gas turbines will satisfy over 90% of new U. S. electric power demand over the next 10 years.

Current gas turbine power plants are frame type simple cycles at lowest cost / lowest efficiency (30-38%) optimized for peaking needs, higher cost / higher efficiency aeroderivatives (36-42%), and highest cost / highest efficiency combined cycles (frame type or aeroderivative) optimized for base load needs (50-60% efficiency). The ATS Program has been instrumental in achieving the 60% level of efficiency in large, frame type combined cycles.

Currently, a large number of power plants that were designed for base load are being operated in intermediate duty, at low efficiency, high maintenance cost, and high emissions. This situation will be exacerbated as new, high efficiency combined cycles displace more older plants from base load operation. Development of a gas turbine specifically designed to perform well in intermediate load duty would improve the efficiency and generation cost of the U.S. generating fleet and reduce emissions, with favorable impact on climate change issues. The U.S. market for this type of product has been estimated by A. D. Little to be between 37,000 and 160,000 MW in the 2005-2015 time period. On a worldwide basis the market for natural gas fueled gas turbines is expected to grow substantially, as shown in Fig. 1.

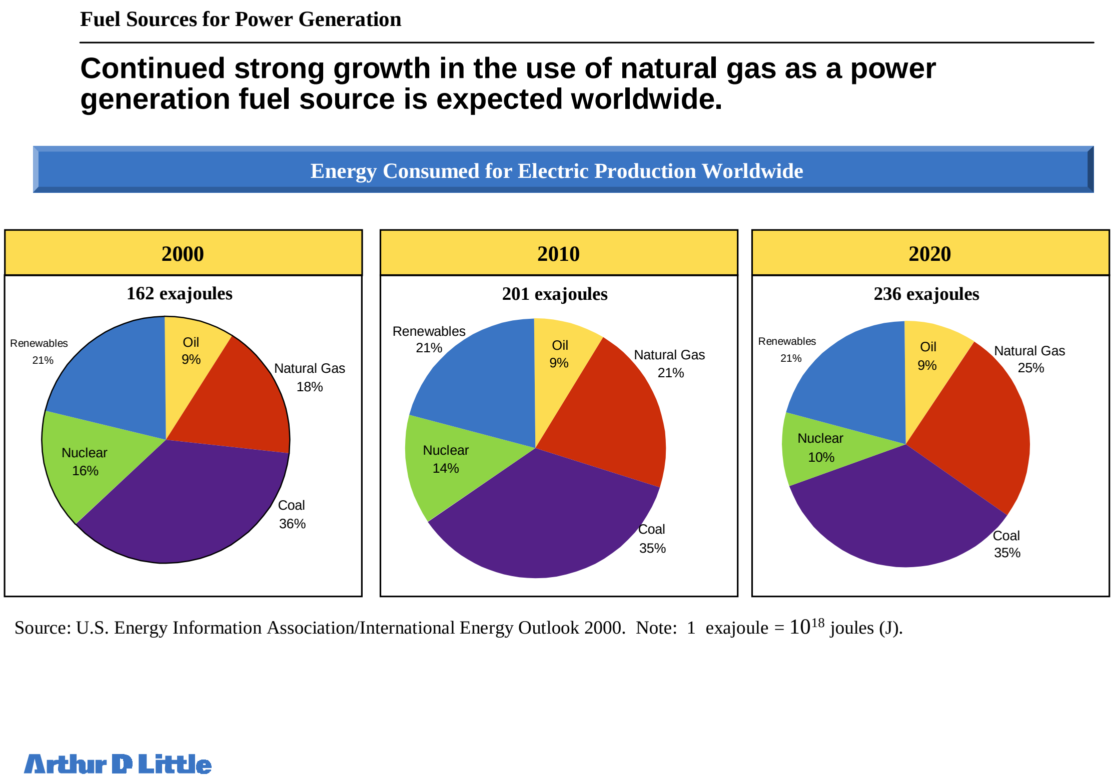


Figure 1

Goals of the NGT Program

The goals for the gas turbines to be developed under the NGT program are intended to address the needs of intermediate load demands. These goals as specified by DOE are shown in fig. 2.

NGT PHASE 1: STUDY FEASIBILITY OF TURBINE SYSTEMS > 30 MW THAT IMPROVE THE 1999 STATE OF THE ART SYSTEMS BY:

- **Increasing the lower heating value net system efficiency by 15% or higher**
- **Improving turndown ratios (using a turbine at partial capacity) by 50% or more**
- **Reducing the cost of electricity production by 15% or more**
- **Improving service life**
- **Reducing emissions of carbon and nitrogen oxide gases**
- **Reducing operations, maintenance and capital costs by 15% or more**
- **Offering flexibility for at least 400 starts per year and rapid startup capability, and**
- **Improving reliability, availability and maintainability (RAM)**

Figure 2

Current Aeroderivative Technology

Current aeroderivative industrial gas turbines are direct adaptations of aircraft engines, with the only significant new technology being in the combustor. The combustor must accommodate gas as well as liquid fuels, and the emissions requirements are considerably more severe than is feasible in an aircraft engine. This has led to the development of dry low NOx combustion systems. An example is the FT8-2 shown in fig. 3.

FT8-2 PRODUCTION ENGINE

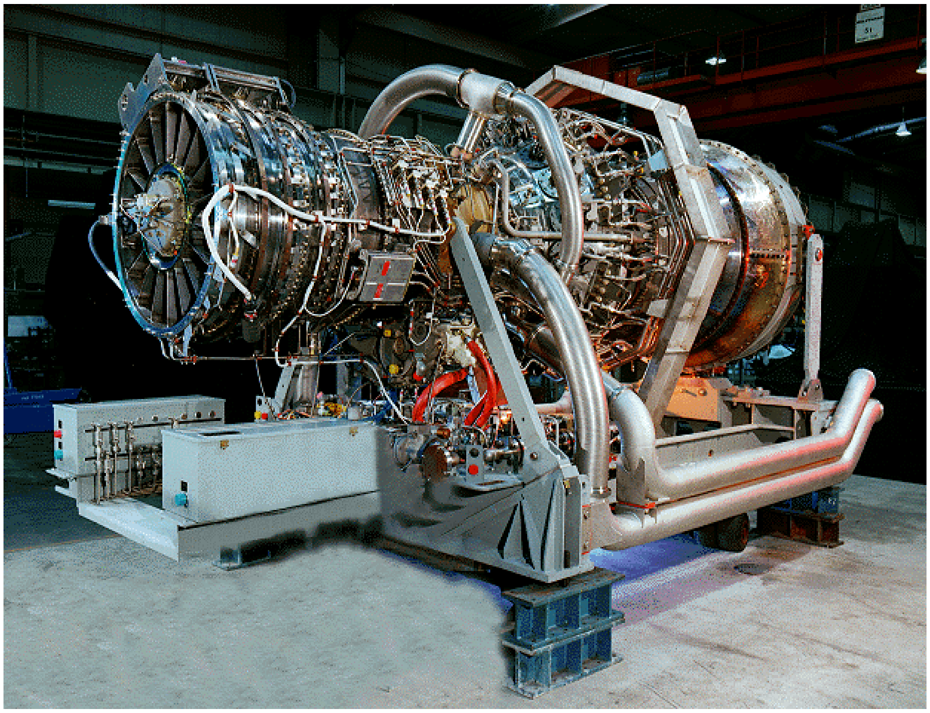
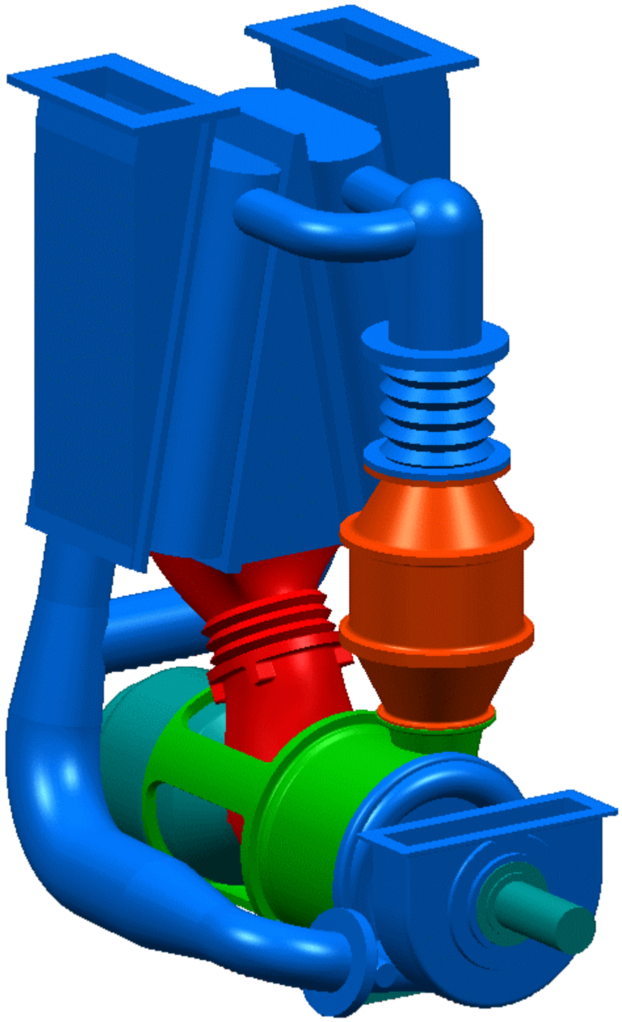


Figure 3

The FT8 is a 25 MW gas turbine consisting of a gas generator derived from the JT8D aircraft engine and a separate power turbine. Power turbines are available optimized for electric power generation (3000 or 3600 RPM) or mechanical drive (5500 RPM nominal speed). The FT8 is packaged and marketed by Pratt & Whitney Power Systems and by a number of partners worldwide. A more detailed description of the FT8, as well as the Pratt & Whitney Canada product line, is found in reference 1.

A recent addition to the PWPS product line is the FT8-3, an uprated model of the FT8 which increases hot day power (90 F ambient temperature) by 15%. On the opposite end of the size scale the ST5 microturbine is being introduced in 2002 at 400 kW and 30% efficiency, see fig. 4.



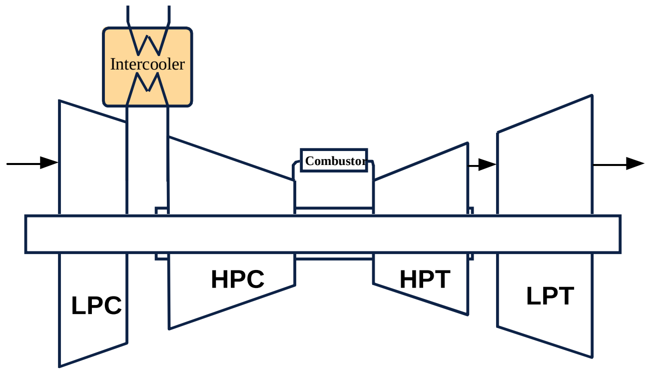
ST5 Microturbine

Figure 4

Technical Approach

In order to meet the goals specified by DOE, it is necessary to improve the efficiency and reduce the capital cost per kW of current aeroderivative technology. P&W's technical approach to provide these attributes is the Intercooled Cycle, as shown in fig. 5.

Intercooled Cycle



- Twice the output of simple cycle - Low $/kW
- Efficiency 45-50% - Competitive at midrange capacity factor
- Rapid start to full load - Quick dispatch to meet fluctuating loads with multiple daily on/off cycles

Figure 5

Intercooling achieves the doubling of output compared to its simple cycle counterpart for the following reasons:

Intercooling reduces the work of compression of the high pressure compressor, so more work is available for net output.

With the reduced temperature entering the HPC, increased mass flow must be used in order to maintain the velocity required for HPC match, which increases output. This also increases the overall pressure ratio, which increases efficiency.

The HPC cooling air is cooler, so a higher turbine inlet temperature can be maintained for acceptable parts life and emissions.

Product Description

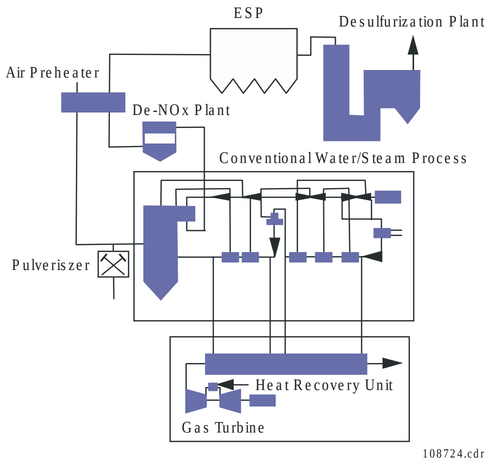
The product which was studied under NGT Phase 1 is an Intercooled Cycle. With an efficiency of 49-50% and low capital cost ($/kW) compared to existing aeroderivatives, this product is intended for mid capacity factor electric power generation applications, e.g. 500-6000 hours per year. The output is in the over 100 MW class.

Feedwater preheating of coal fired steam plants

Another application for the Intercooled Cycle is enhancing the economics of coal fired steam plants via feedwater preheating, so that the plant owner can sell power in both the on-peak and base load markets.

In a typical steam power plant, feedwater heating is accomplished by extracting steam from various stages in the steam turbine. This increases cycle efficiency, but reduces power output as the back end of the steam turbine does not see the same flow as the throttle. In the feedwater heating cycle at times of high power demand, extraction flows are reduced and the feedwater is heated by the exhaust from the gas turbine (Figure 6). This cycle allows additional power from the steam turbine and the gas turbine at increased efficiency. The steam plant is generally coal-fired, so that this increase in efficiency is achieved with only a fraction of the energy supplied by premium fuel. In Figure 7, the additional steam and gas turbine outputs are shown. If the steam turbine cannot accommodate all the additional steam, the coal input to the boiler is reduced accordingly, and some of the benefit is taken as reduced coal consumption. Another application that would benefit from using the Intercooled Cycle is the repowering of older steam stations. Repowering ranges from replacing every component and using only the site to having a gas turbine supply preheated combustion air to an existing boiler. In the repowering application, the exhaust heat from the Intercooled Cycle is used in a heat recovery steam generator to supplement the heat from the original steam boiler. The system resembles that shown in Figure 6, but the gas turbine is now part of a combined cycle that operates in midrange to base-load operating mode.

Coal Fired Steam Plant with Feedwater Preheating



FEEDWATER PREHEATING PROVIDES BOTH ON-PEAK AND BASE LOAD POWER

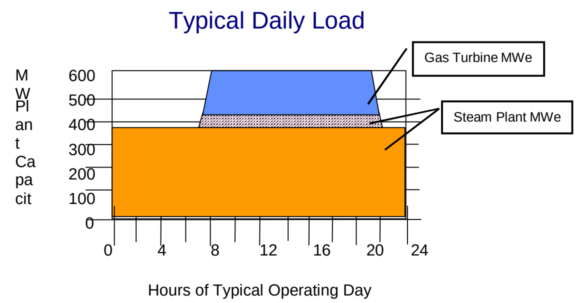


Figure 6

Figure 7

Coal Gasification

Gas turbines are the cleanest and most efficient way of using coal, via the integrated gasification combined cycle (IGCC) - - cleanest because the coal gas can be cleaned far more effectively than the stack gas of a conventional steam plant, and most efficient because the much higher efficiency of the gas turbine based system compared to a steam system more than compensates for the losses of gasification.

The biggest barrier to the implementation of the IGCC has been its relatively high capital cost compared to conventional steam plant with scrubbers. The Intercooled Cycle provides the basis for addressing this problem, under the DOE NGT and Vision 21 Programs. Development of the Intercooled Cycle would form the basis for the Humid Air Turbine (HAT) Cycle, shown in fig. 8.

In order to develop the HAT Cycle from the Intercooled Cycle, the compressors and intercooler do not need to be changed. After the HPC the air is taken off board, moisture is added in a saturator and exhaust heat is recovered in a recuperator. The humid air enters the combustor with 15-20% moisture by weight. The added mass of the water increases the turbine work with no addition in compressor work, resulting in increases in efficiency and output.

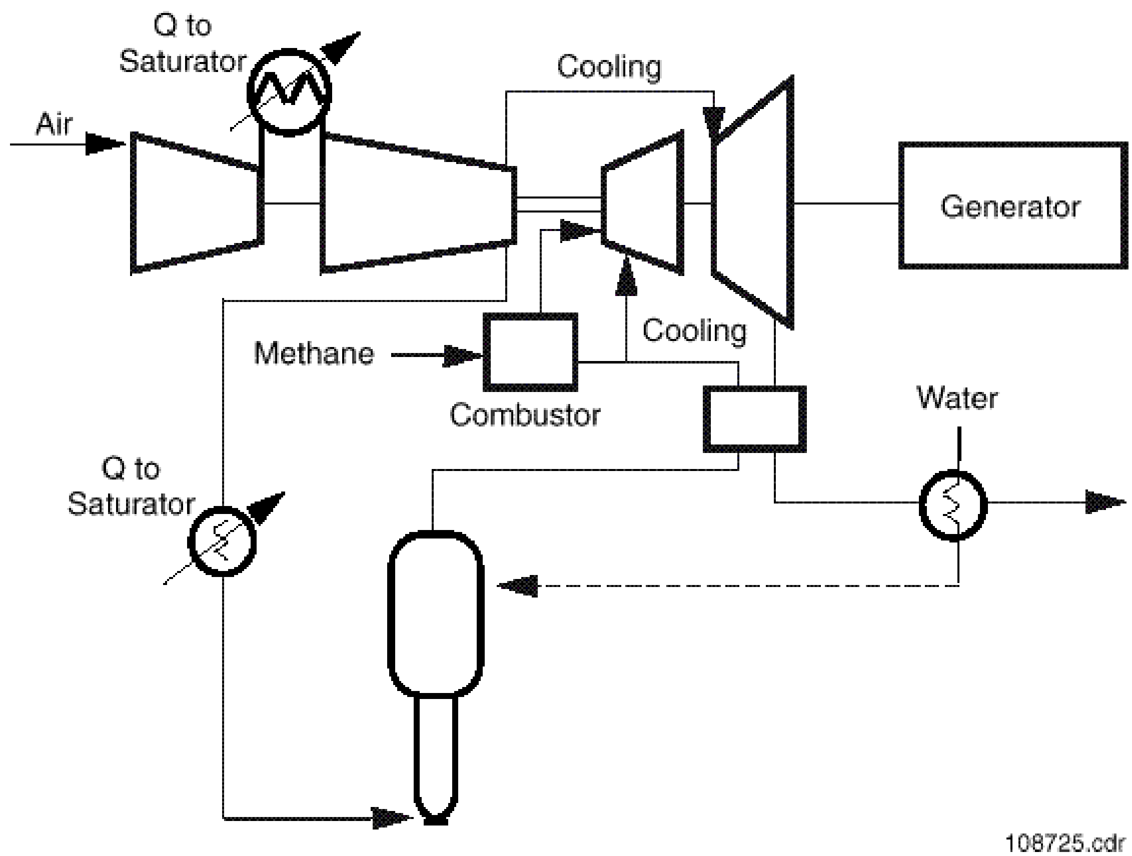


Figure 8

The HAT cycle can be integrated with a coal gasification cycle, which becomes the Integrated Gasification HAT (IGHAT) cycle, see fig. 9. In a 1993 study by Fluor Daniel, Texaco, UTC and EPRI (ref. 4) an IGHAT was compared with a state of the art IGCC. The IGHAT had comparable efficiency to the IGCC but 11% lower capital cost, resulting in a reduction of 8% in the cost of electricity. Both the IGCC and the IGHAT cycles have improved since 1993, and the comparison will be re-evaluated, under DOE contract number M00A-DE-FC26-00NT40845; UC Irvine is the prime contractor. The IGHAT cycle will be derived from the intercooled cycle that is the subject of Pratt & Whitney's NGT Program.

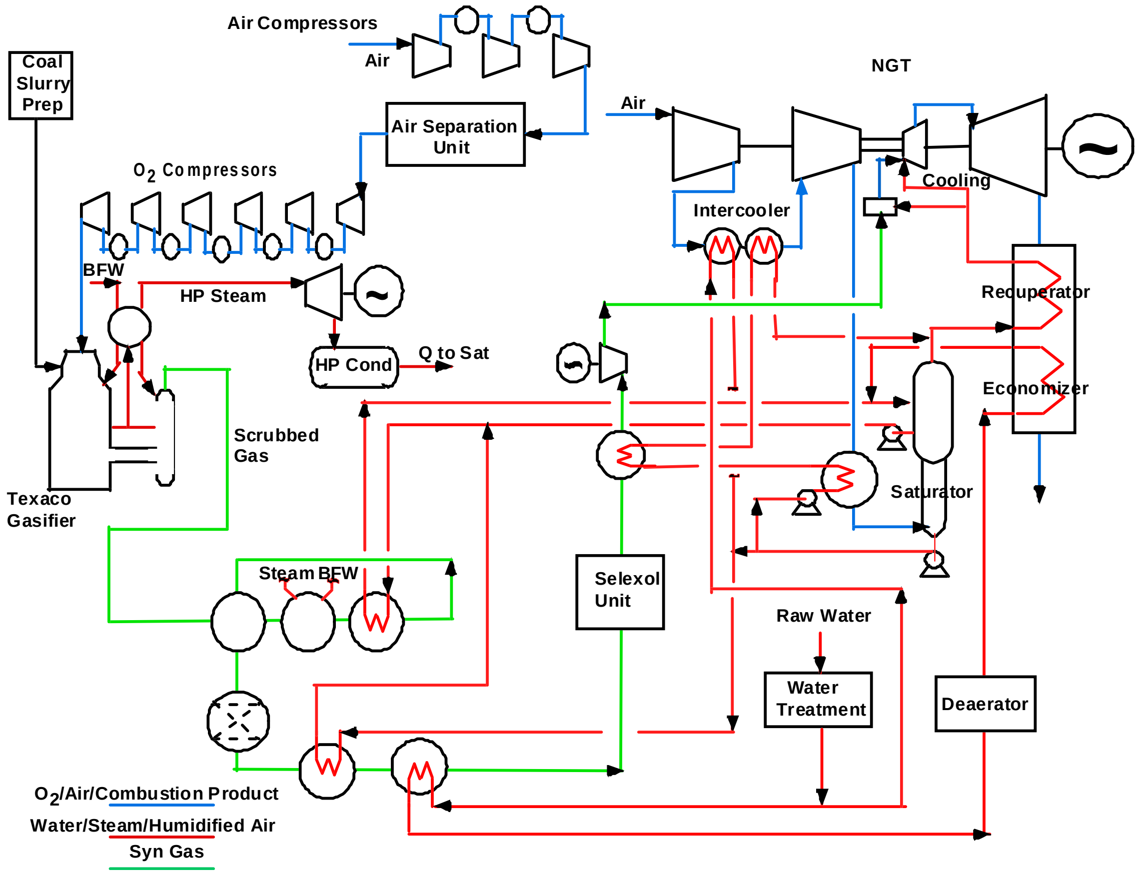


Figure 9

<u>Technology Developments Needed</u>

Intercooling itself is not new. A program has been underway since 1991 to develop an Intercooled Recuperative (ICR) gas turbine for the U.S. Navy, under a $400 million contract with Northrop Grumman to adapt a Rolls-Royce 211-535 aircraft engine to marine service (reference 3). However the pressure ratio and firing temperature planned for the NGT Program are higher than that of the development described in reference 3.

In order for the Intercooled Cycle to achieve the characteristics of the NGT gas turbine, the gas turbine pressure ratio and firing temperature have to be increased substantially compared to current aeroderivatives, while maintaining the low-life cycle cost required by end users in the electric power industry. Development work is needed in a number of technology areas. Some examples of technology developments are shown in fig. 10.

<u>Technology Development Summary</u>

- High pressure combustion
- Ceramic materials for reduced cooling air
- Improved turbine aerodynamics and cooling

- Improved turbine aerodynamics and cooling
- Advanced corrosion-resistant alloys and thermal barrier coatings

Figure 10

Some technology development is already underway. Ceramic vanes tested under a DOE contract are shown in figure 11.

FT8 sector of cooled silicon nitride vanes with an Environmental Barrier Coating

Figure 11

Synergy With Aircraft Engine Development Needs

Many of the same technology developments that will be needed for the NGT Program will be helpful in meeting the needs of advanced aircraft engines. It is the intent of DOE and DOD to have a cooperative effort between NGT and military programs such as the IHPTET (Integrated High Performance Turbine Engine Technology) Program and the VAATE (Versatile Advanced Affordable Turbine Engine) Program.

One of the public benefits envisioned for the NGT Program is its development of enabling technologies that support other missions of the federal government, such as enhancing defense capability and serving the needs of future generation military operations. By working to support other government priorities, the maximum public benefits will be attained from the program, beyond the direct benefit to the electric power end users and ratepayers.

Summary

Existing aeroderivatives have been direct adaptations of aircraft engines. In the NGT Program, new technologies are intended to be developed which will produce a highly competitive gas turbine for midrange power and coal utilization while working synergistically with the development of advanced aircraft engines.

References

1. J. B. Catlin, W. H. Day, and K. Goom, “The Pratt & Whitney Industrial Gas Turbine Product Line”, Power Gen Conference, New Orleans, LA, December 1, 1999.
2. A. W. Layne, “Developing the Next Generation of Gas Turbine Power Systems – A National Partnership”, Dept. of Energy Workshop Next Generation Gas Turbine Power Systems, Austin, TX Feb. 9-10, 1999.
3. S. Ashley, “Fuel-Saving Warship Drives”, “Mechanical Engineering” magazine, August, 1998.
4. “A Feasibility and Assessment Study for FT4000 Humid Air Turbine (HAT)”, EPRI report TR-102156, Research Project 3251-05, September 1993.