

**Selection of Natural Gas Fired Advanced  
Turbine Systems (GFATS) Program  
Task 3**

**Topical Report**

June 1994

Work Performed Under Contract No.: DE-AC21-93MC29257

For  
U.S. Department of Energy  
Office of Fossil Energy  
Morgantown Energy Technology Center  
Morgantown, West Virginia

By  
Allison Engine Company  
Indianapolis, Indiana

**MASTER**

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TURBINE SYSTEMS (GFATS) PROGRAM  
TASK 3**

**USDOE**

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Indianapolis, Indiana 46206

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## I. INTRODUCTION

The objective of Task 3 was to perform initial trade studies and select one engine system (Gas-Fired Advanced Turbine System [GFATS]) that the contractor could demonstrate, at full scale, in the 1998 to 2000 time frame. This report describes the results of the selection process.

The requirements placed on the ATS by the contract Statement of Work (SOW) were as follows:

1. 15% improvement in thermal efficiency over Allison 1991 state of the art (SOA) 571K engine
2. firing temperatures equal to or greater than 2600°F
3. environmentally superior
  - NOx less than 8 ppmvd at 15% O<sub>2</sub>
  - 20 ppmvd for CO and UHC
4. RAM levels comparable with today's systems
5. fuel flexibility
6. COE 10% less than 1991 systems at bus bar

A review by the Allison team revealed that several other requirements were needed to properly reflect the industrial market:

7. family plan concept for complete market coverage
8. cold end drive
9. steam injection capable for power augmentation
10. synergism with future Allison products
11. cost of ownership at current levels

This task, including Allison internal management reviews of the selected system, has been completed. Allison's approach to ATS is to offer an engine family that is based on the newest T406 high technology engine. This selection was based on a number of parameters including return on investment (ROI), internal rate of return (IRR) market size and potential sales into that market. This base engine family continues a history at Allison of converting flight engine products to industrial use.

### 1.1 ALLISON SELECTED ENGINE

The selection process developed during the current ATS Concept Development Phase identified a high technology simple cycle engine as technology demonstrator with an intercooled recuperated (ICR) engine as a preferred final ATS product, both based on the T406 family of aircraft engines presently entering production. This ICR product engine will be extremely competitive in the major mechanical drive/gas compression market. The T406 engine family will be used to power military aircraft such as the Bell-Boeing tiltrotor and C-130J cargo aircraft and commercial applications such as the Saab 2000 50-passenger regional turboprop aircraft, an Indonesian 70 passenger turboprop and a Cessna business jet. The selected ATS engine will use the existing core compressor aerodynamics, a product of nearly 8 years of development effort. An ultra-low emission combustor of a lean premixing design will be used in this engine. The first two turbine stages (high pressure [HP] or HP turbine) use an industrialized version of an advanced aircraft turbine designed to operate at rotor inlet temperatures in excess of 2600°F. The thermal efficiency of this ATS engine more than 50% better than current state of the art. These engines (Table 1-I) will fulfill industry need for electrical power generation, cogeneration, mechanical drive, and marine markets.

Commonality of components between the simple cycle demonstrator and the product ICR will be very high to reduce cost. Selection of an aeroderivative system for ATS continues the traditional Allison approach: industrializing aero products for use in industrial markets.

**Table 1-I.**  
**ATS forms basis for family of engines.**

<u>Configuration</u>	<u>TRIT—°F</u>	<u>Thermal efficiency compared to 571K engine</u>
ATS Demonstrator engine	2600	+24.
ICR ATS	2600	+52.2

## 1.2 CRITICAL TECHNOLOGIES

Two engine components, the combustor and high pressure (HP) turbine, are key to a successful ATS. While the compression system will also require a significant step forward in technology relative to current industrial engines, technology breakthroughs relative to current aero-engine technology are not needed. The compression system is within the current state of the art, and the core compressor is already developed for the T406 engine family.

Allison's approach to the combustor and HP turbine development is as follows:

1. A very low emission combustion system capable of operation at the 2600°F firing temperature is required.
  - Allison has ongoing programs funded both internally and through GRI and DOE initiatives to develop low emissions technology at current firing temperatures. These programs will provide a basis for making the transition to 2600°F.
  - Task 8.4 of this contract will define the combustion configuration to be further developed in the next phase of the ATS program.
  - Success at the ATS firing temperature will require concentrated effort at program start. A lean/premixing system is the configuration of choice. To achieve truly lean combustion, cooling air usage must be minimized in the combustor liner, transition duct, and exit vanes; ceramics and ceramic matrix composites are the materials of choice to accomplish this. Allison water vapor cooled turbine technology under development in Task 8.6 of this contract can also be applied to the combustor exit vane to effectively reduce required cooling flow.
2. A 2600°F rotor inlet temperature turbine with 30,000 hr life and low cooling airflow is required to achieve high thermal efficiency and power density.
  - Generation 4 single crystal materials as well as the latest directionally solidified (DS) materials will be applied to achieve reduced cooling airflow and high reliability at these elevated temperatures.
  - Task 8.1 of this contract includes an engine test of the prototype 2600°F HP turbine. This turbine includes the first set of Castcool®\* vanes manufactured with the Castcool process. Allison, with significant investment over the last several years, has developed manufacturing processes for Castcool vanes and blades.
  - Task 8.1 of this contract will also provide the design information required to industrialize this technology. This information includes research on the internal patterns used in Castcool, material properties, including long-term exposure to oxidizing and corrosive environments, and creep rupture strength.
  - The Component Development Phase of ATS will concentrate on maturing this technology through design and test of critical components at full scale.

\* Castcool is a registered trademark of Allison Engine Company.

Allison has the capability to develop these critical components to a schedule that ensures a successful 8000-hr demonstration at a selected site by the end of the year 2000.

### 1.3 SIGNIFICANCE OF 2600°F HOT SECTION TECHNOLOGY

As noted, Allison believes the hot section (combustor and HP turbine) holds the key to achieving a revolutionary step in industrial engine performance. The hot section technology will have three basic impacts on the future industrial engine marketplace:

- Successful development of the low emissions combustor system and the significant reduction in fuel burned will result in a marked reduction in emissions of the noxious gases NOx, CO, and CO<sub>2</sub>. Allison has estimated the reduction in emissions of NOx, CO, and CO<sub>2</sub> resulting from introduction by U.S. manufacturers of ATS low emission combustors. Table 1-II shows these results for the 15-year period following introduction of ATS into the marketplace. These calculations assume a 5-year phase-in period for ATS low-NOx combustion systems to capture 100% of the world market. Figure 1-1 shows a year-by-year calculation for avoided NOx. These values are certainly significant to the environment but represent only a small percentage of total world emissions. Also shown in Table 1-II are the fuel savings on a per-year basis for the same time period. The reduced NOx emissions in particular will allow sale of engines into markets currently not served by gas turbines thus expanding the sales potential of gas turbines worldwide.
- The increase in turbine temperatures to 2600°F, 400°F higher than current technology engines in this size class, allows use of high compressor pressure ratios, which results in a significant improvement in engine thermal efficiency and associated fuel burn.

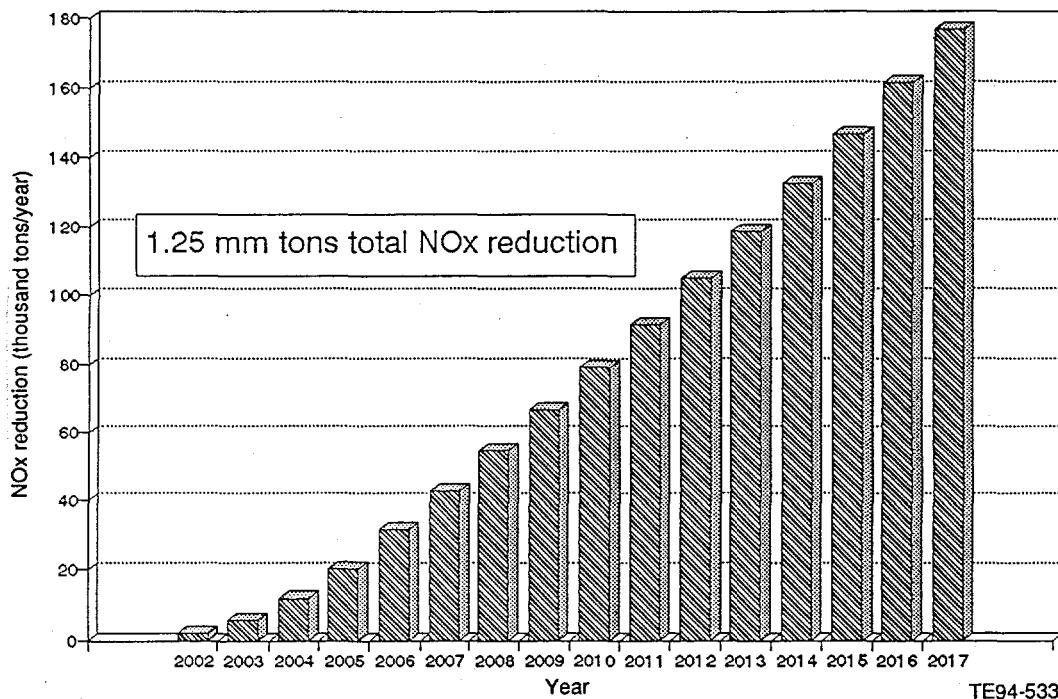


Figure 1-1. Projected worldwide reduction in NOx emissions for 4,000 to 12,000 hp ATS turbines.

**Table 1-II.**  
**Worldwide emissions reduction industrial engine market.**

<u>Emission type</u>	<u>15 year total reduction</u>
NOx	1.25 mm tons
CO	0.72 mm tons
CO <sub>2</sub>	169 mm tons**

\*\*Corresponds to 61.5 mm tons reduction in natural gas usage

- Higher turbine temperature results in higher specific power engines. These units produce significantly more power from a given size engine. This has a twofold positive effect on the purchaser of these units:
  1. The purchase price on a dollar per horsepower basis will be reduced by nearly 20% for the ATS engine relative to an equivalent current technology engine.
  2. The purchaser will also see a much improved internal rate of return (IRR) when studying the efficacy of buying a new technology engine. There is therefore no penalty for buying a cleaner (low emission) unit, but instead, a monetary incentive when sold as a package. Table 1-III shows a summary of the IRR improvement projected for the fully developed ATS engine relative to current technology.

In conclusion, combining the high temperature turbine technology with the requirement for a low emissions combustion system allows an effective reduction in cost per horsepower produced and a significantly improved customer IRR in spite of the basic cost penalty of the low emissions system.

**Table 1-III.**  
**Significantly improved customer internal rate of return (IRR).**

	<u>% change IRR</u> <u>power generation</u>	<u>% change IRR</u> <u>cogeneration</u>
ATS improvement		
Over SOA with cleanup	+112%	+57%
Over SOA without cleanup	+47%	+23%