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Allison Engine ATS Program Technical Review

Author:

D. Mukavetz

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Contractor:

Allison Engine Company
P.O. Box 420
Indianapolis, Indiana 46206-0420

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2.5 Allison Engine ATS Program Technical Review

D. Mukavetz (iedwm@agt.gmeds.com; 317-230-2575)
Allison Engine Company
P.O. Box 420
Indianapolis, Indiana 46206-0420

Introduction

Gas turbines in industrial and utility applications can help meet future national and worldwide power generation requirements. Turbine systems burning natural gas offer environmentally sound and economical power generation and cogeneration. Since U.S. demand alone will require up to 15 gigawatts per year of new and replacement capacity after the year 2000, the availability of Advanced Turbine Systems (ATS) to fill a share of this need will save significant amounts of fuel and benefit the environment. Implementation of the ATS Program will also keep U.S. manufacturers on the cutting edge of turbine technology for power generation applications and enhance the nation's economic competitiveness (Ref 1).

Allison's ATS addresses the program goals in the following manner:

- **Efficiency** — The turbine selected for the ATS uses Allison's latest single crystal alloys incorporating the most efficient component cooling technology Allison has developed. These features allow the turbine to operate at a rotor inlet temperature (RIT) of 1427°C (2600°F). The compression system for this engine has an overall pressure ratio of more than 20:1 and is based on technology previously demonstrated at Allison. The engine that uses these components will demonstrate a thermal efficiency that is 18% better than the best in class today.
- **Environment** — The combustion system selected for this engine incorporates a catalytically stabilized, lean premix system with ceramic components requiring no significant wall cooling. This system will achieve acceptance in severe nonattainment areas, producing less than 8 ppm for oxides of nitrogen (NOx), with acceptable carbon monoxide (CO) and unburned hydrocarbon (UHC).
- **Fuel Flexibility** — Allison has production engines in commercial service that are operating on biomass fuels. Previous DOE-funded programs have allowed Allison to develop and demonstrate coal-fueled gas turbine technology. The ATS program will use this experience to create a design that will be adaptable for the use of these fuels in the future.
- **Cost of Power** — The busbar cost of energy for the Allison ATS ranges from 23.6 to 27.6% lower than the current state of the art for systems meeting ATS environmental requirements. The requirement of the program is a 10% reduction in busbar cost. This improvement is the result of the high efficiency and the low emissions inherent in Allison's system design.
- **Reliability, Availability, and Maintainability** — The Allison ATS will be designed to have high reliability and low maintenance costs. Critical components will be designed using Allison's latest life analysis methods. Component and materials tests will

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be conducted to verify these analyses. The engines and skids will be modular by design to allow field maintenance and service in the minimum time possible.

Objectives

Allison was awarded an ATS Phase 2 program in August 1993 with an 18-month period of performance. The specific primary objectives for this program were:

- select the design thermodynamic cycle for the ATS
- complete the preliminary design of the engine components
- complete preliminary design of the engine skid and all ancillary components
- test the prototype high pressure turbine section to 2600°F and analyze the resultant data
- validate and refine the fabrication of turbine blades using the existing Castcool®* process
- accomplish sufficient testing of combustor components to determine the best approach to achieving the emissions requirements
- perform laboratory tests on a turbine vane design utilizing two-phase cooling to reduce airflow requirements
- select coating systems for turbine blades and vanes for oxidation/corrosion protection

Results

Previous reports and papers (Ref 2, 3, and 4) have presented results of Phase 2 program effort in the following areas:

- selected ATS configuration
- tested prototype to 2600°F
- completed testing of low NOx combustor components
- provided ATS long-term planning document to DOE
- completed all program reporting requirements

This paper summarizes the accomplishments finalized during the past year, in particular:

- analyzed test data on 2600°F prototype turbine
- completed development of casting process for Castcool high pressure turbine blades
- finalized configuration of low NOx combustor
- completed preliminary design of engine
- completed preliminary design of skid for demonstrator phase
- completed 5000-hr oxidation test and long-term corrosion test
- provided market study
- rig test of two-phase cooled turbine vane
- defined a direct coal-fired "ruggedized" configuration
- completed all reporting requirements

Test of 2600°F High Pressure Turbine Component

Figure 1 shows the major ATS prototype high pressure turbine components tested in late 1994. This turbine was previously designed under combined Allison/U.S. Navy sponsorship. Allison's goal of achieving a design incorporating Castcool hardware and capable of operating at 1427°C (2600°F) was achieved. This test also proved proper turbine performance, both from a cooling effectiveness and thermodynamic point of view. The tested full-scale prototype included the Castcool turbine vane in its first test in an engine at full operating conditions.

The Castcool process is a method by which extremely complicated cooling configurations can be cast in single crystal components in a one-step process. Minimal machining requirements of these components result in a very cost effective part.

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* Castcool is a registered trademark of Allison Engine Company.

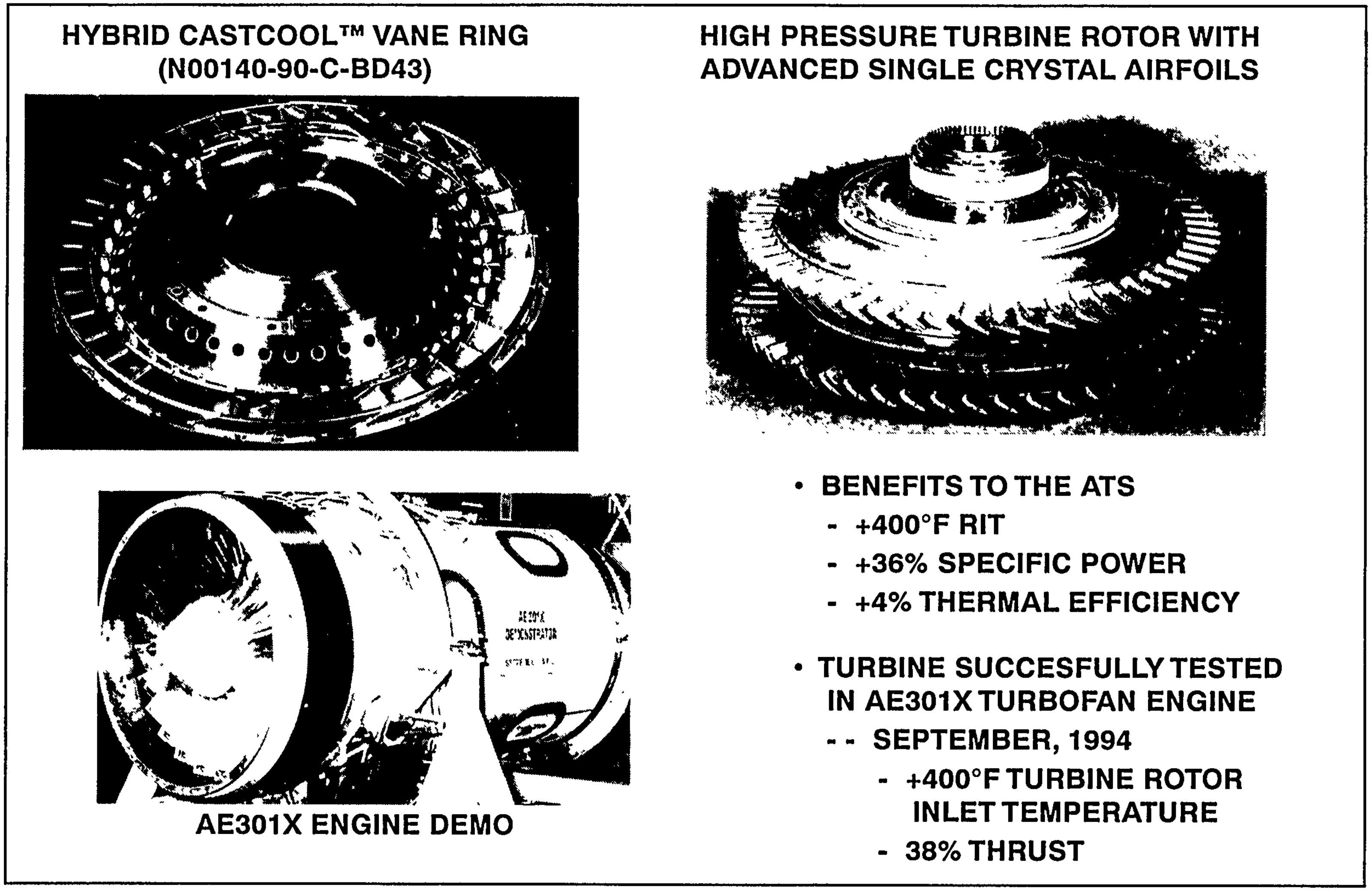

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Figure 1. Allison Successfully Tested the Prototype ATS Turbine to 2600°F

One primary goal of this test was to prove performance of the Castcool vanes. Figures 2 and 3 show that the predicted vane leading edge metal temperature agrees very well with measured values and the coolant pressure ratio across the vane leading edge (the critical section of the vane) agrees with design calculations. These test results confirm all aspects of the Castcool design process from the heat transfer calculation through the casting process to the prediction of in-engine operating conditions. This provided the basis to proceed to the next step in incorporating Castcool into this turbine — manufacture of Castcool high pressure turbine rotor blades.

Castcool Turbine Rotor Blade Process Development

Castcool blade process development efforts performed during this program focused on pattern assembly and shelling process adjustments. A total of 7 molds were cast during this effort, resulting in a total of 56 blades. A photograph of the resulting blades from molds designated M/N 014 to 017 is shown in Figure 4, both in as-cast and finished form. The results of this effort increased yield by 60%. This effort resulted in a process with a production rate and yield acceptable for making initial engine sets of blades to rigorous quality standards.

Finalize Configuration of Low NOx Combustion System

The low NOx combustion system presents a significant challenge in terms of NOx and CO requirements, and in terms of achieving these requirements at very high firing temperatures. The following technologies were evaluated under this program:

- lean premix modules
  - mixing efficiency
  - velocity field
  - combustion characteristics
- catalytic element
  - bench reactor combustion efficiency
  - operability window definition
- combustor-to-turbine transition
  - aerodynamic integration

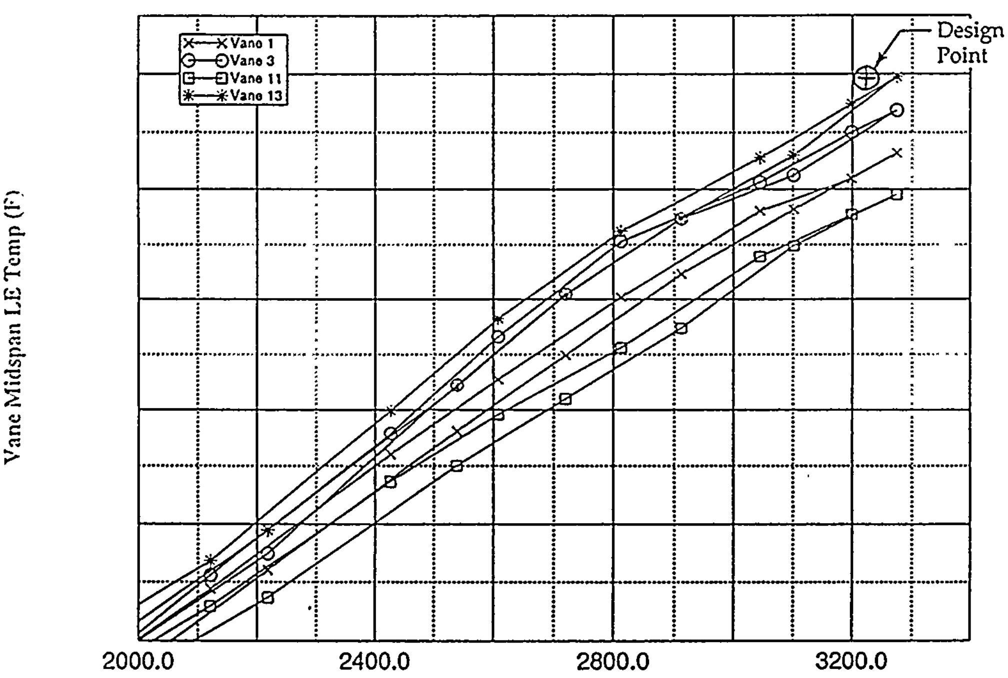


Figure 2. Measured Castcool Vane Leading Edge Midspan Temperature Data Within Predicted Levels

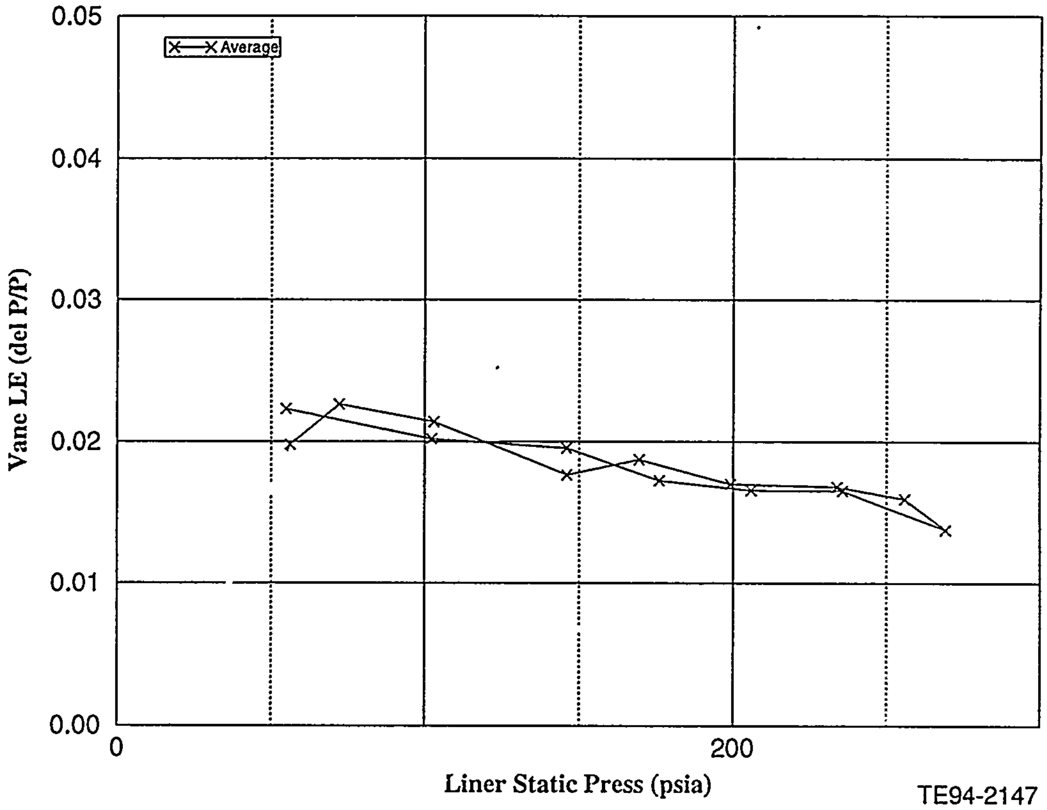


Figure 3. Measured Castcool Vane Leading Edge Supply Pressure Data Show Adequate Margin

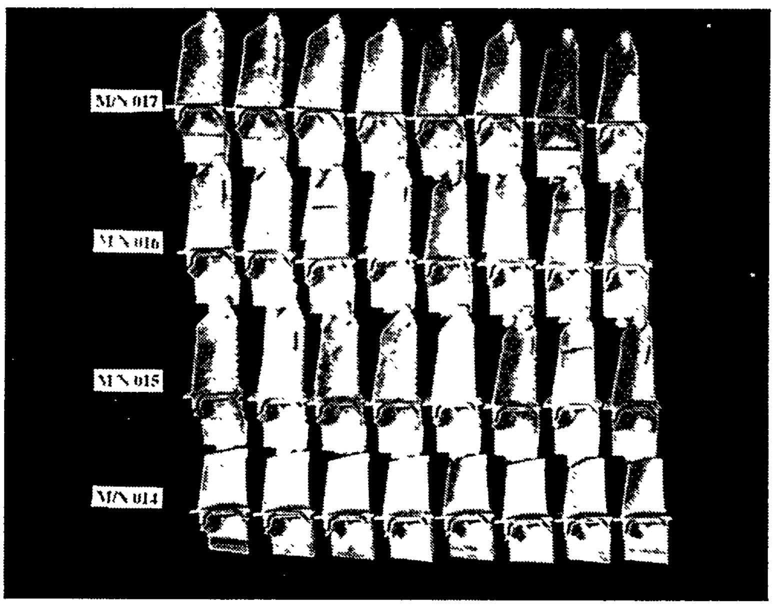


Figure 4. Process Development for Castcool Turbine Blade Increased Yield by 60%

Figure 5 shows that a lean premix system can achieve an 8 ppm NOx goal within the required CO goal at the ATS level of firing temperature. The module testing indicated, however, that sufficient margin to guarantee 8 ppm in production was not available. A catalytic reactor was selected as the best approach to achieving sufficient production margin. Figure 6 shows the test results of a candidate catalyst system at Catalytica, Inc. This system provides sufficient NOx production margin and has the potential to provide sufficient life at low enough cost to be used competitively in production engines.

Allison has selected a silo combustor configuration for ATS that requires a diffuser to transition to the silo and a hot transition duct to accomplish the 90-degree turn into the turbine annulus. Minimal cooling of this hot transition duct is required to achieve very low NOx levels. Computational fluid dynamics analyses of this system showed that aerodynamic design of these transition sections are also critical to proper distribution of any hot spots exiting the combustor into the turbine section.

Preliminary Design of the Gas-Fired ATS Engine Configuration

The key elements in the design Allison selected for ATS are:

- high pressure ratio/simple cycle unit at 2600°F rotor inlet temperature
- metallic Castcool first turbine vane and rotor
- reduced internal leakage with advanced brush and film-riding face seal
- silo configured lean premix system with catalytic section
- single crystal and advanced directionally solidified alloy for turbine
- ceramic matrix material for combustor liner and transition duct

Allison concluded this configuration not only met the program technical goals but provided a system which:

- could be demonstrated for 8000 hr in the year 1999-2000

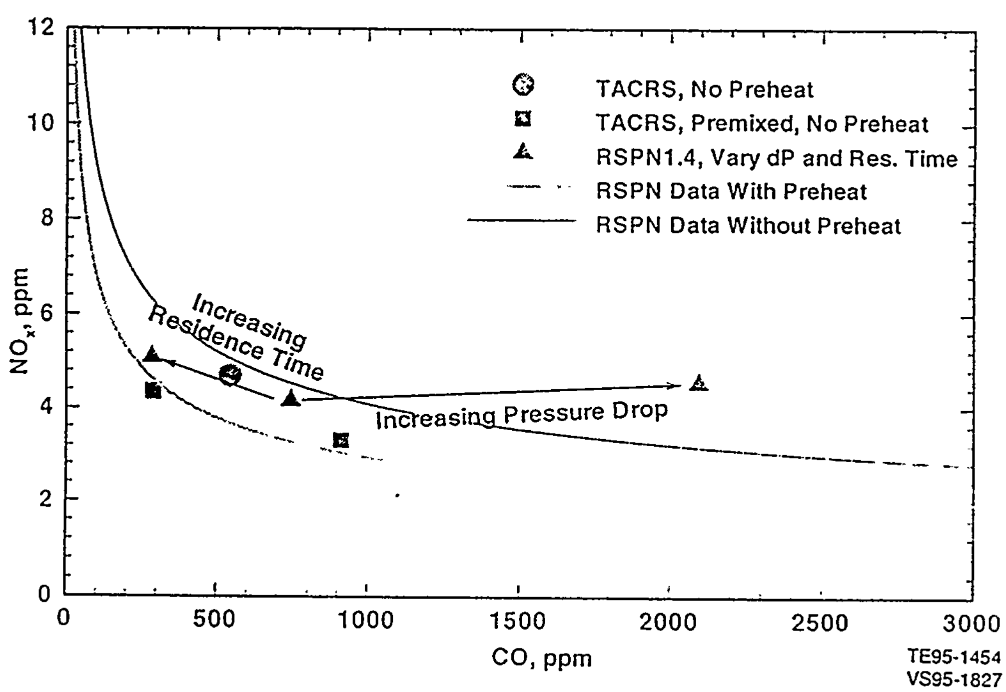
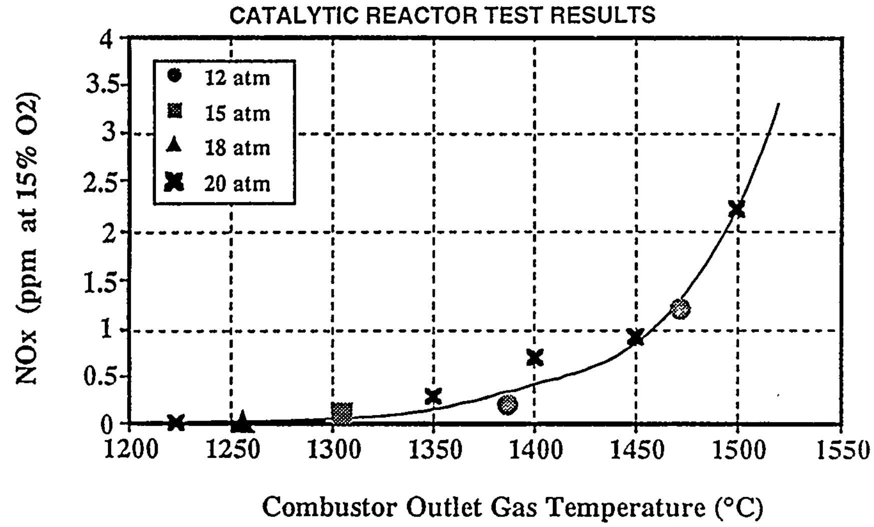


Figure 5. Atmospheric Bench Test of Lean Premix Modules



- NOx FORMATION INDEPENDENT OF PRESSURE
- NOx~2ppm FOR ATS APPLICATION GIVEN TEST DATA AT 1500°C (2730°F) BOT

TE95-1455
VS95-1828

Figure 6. Catalytic Reactor Test Results

- would result in no new requirements for the end user to operate the system effectively
- would provide a family of engines to increase market penetration

The ATS engine design is sufficiently defined to proceed into full-scale development.

Preliminary Design of Engine Skid

The engine is only one key to a successful final product. The customer buys a system and expects the system to provide value. Allison works very closely with high quality and low cost suppliers to optimize engine skid configuration and components for the customer. Figure 7 shows a side view of the skid design for the ATS. This preliminary design not only considers component layout but also design improvements, which increase value to the customer. The ATS skid is sufficiently defined to proceed into full-scale development.

Turbine Blade/Vane Oxidation and Corrosion Coating Selection

One advantage of the use of high strength materials such as single crystal and improved directionally solidified alloys is that they can be operated at higher metal temperatures than current practice with no decrease in life. This operation at higher metal temperatures requires reassessment of oxidation/corrosion coatings. As part of this program Allison performed a 1000-hr accelerated corrosion test and a 5000-hr dynamic oxidation test of various turbine blade/vane materials and coating combinations. Figure 8 shows the results of this test. We have selected the PtAl coating for single crystal components and the standard aluminide coating for the CM-186 improved vane directionally solidified (DS) material.

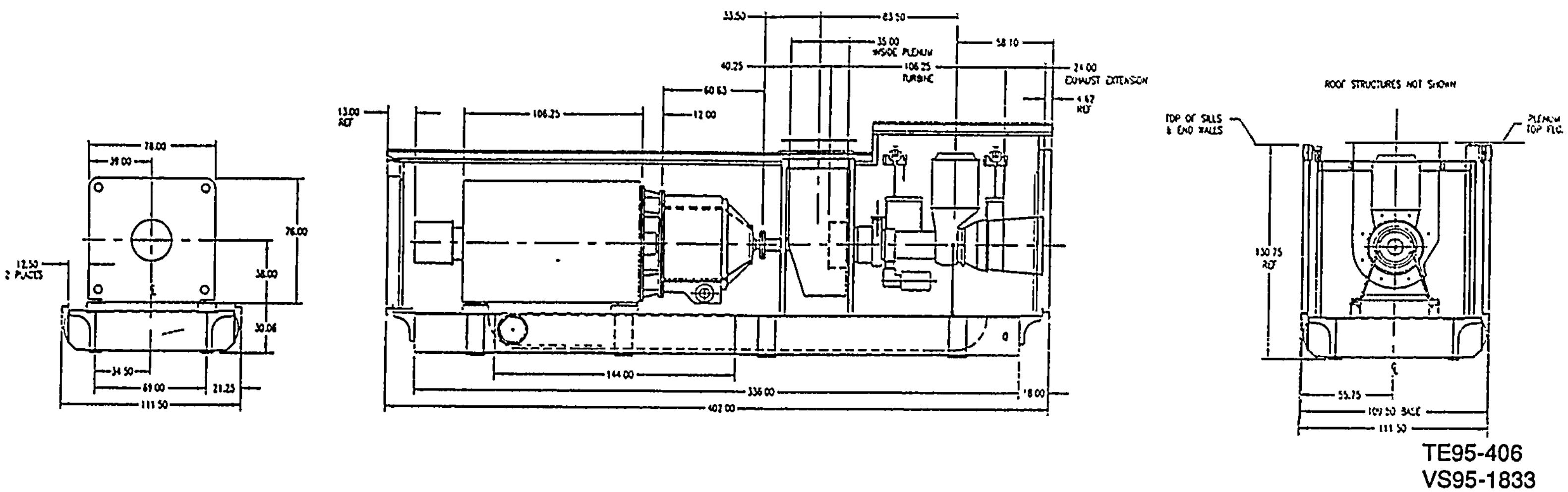


Figure 7. Preliminary Engine Skid Design

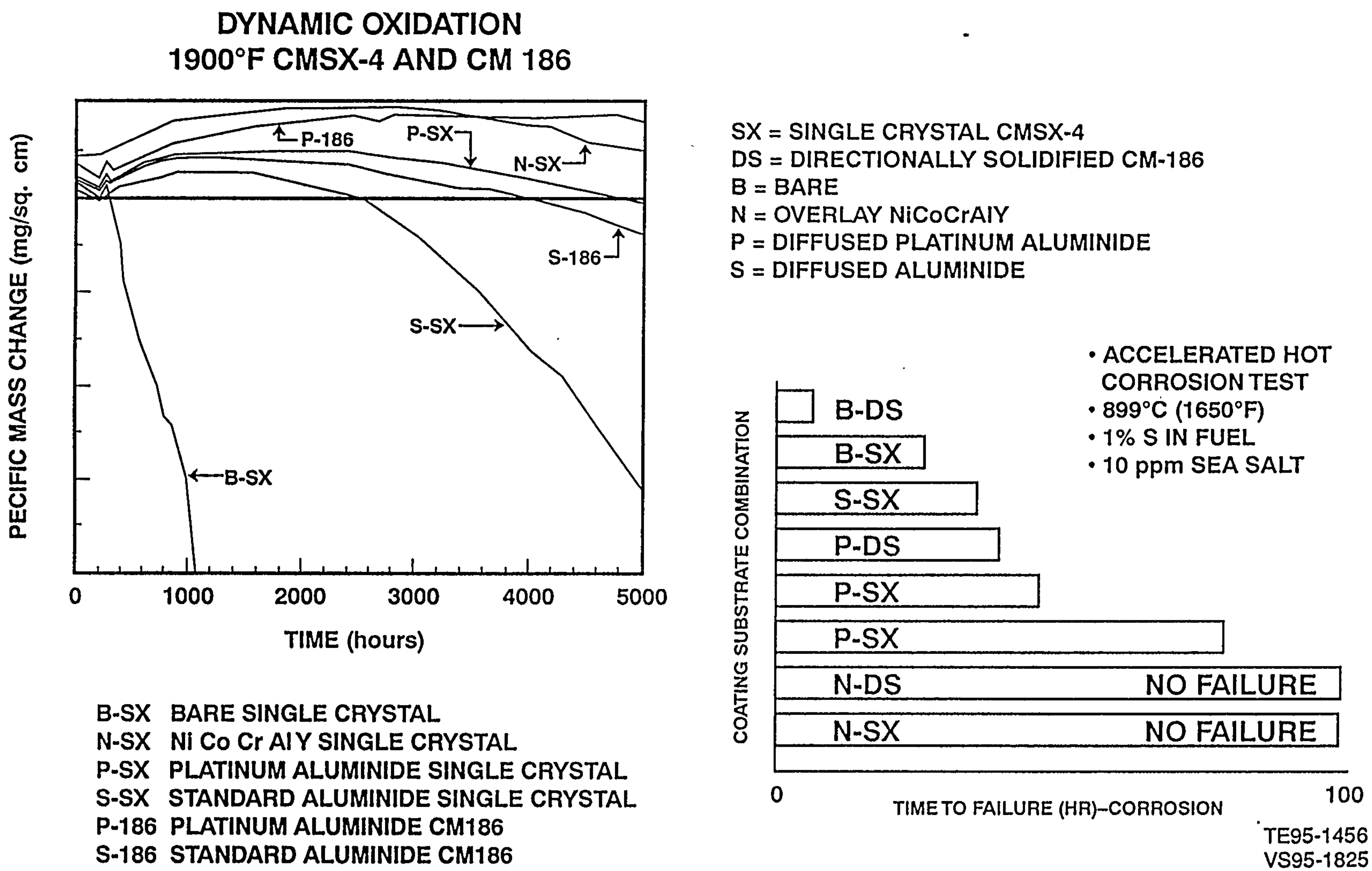


Figure 8. ATS Oxidation/Corrosion Test Results

Laboratory Test Of Two-Phase Cooled Turbine Vane

The phase change (evaporation) of certain liquids, including water, is a very strong endothermic process. Allison had developed a concept for use of this process to cool turbine vanes. ATS Phase 2 allowed Allison to design, fabricate, and laboratory test a 3X scale version of this vane cooling system in a cascade. Figure 9 shows detail of this concept as applied to an airfoil. Figure 10 shows this concept can achieve the same cooling effectiveness as even the most advanced air-cooled vanes with 1/3 to 1/4 the cooling air usage. Detail temperature and pressure data are available on this concept both chord and spanwise.

Definition of a "Ruggedized" Version of ATS Turbine for a Coal-Fired Configuration

The following defines the objectives, assumptions made and results of this study (Ref 5).

- objective
  - define ATS with coal/biomass fuel capability
- assumptions
  - cogeneration plant with rich-quench-lean combustor
  - cooling of metallic high pressure turbine gas path components to 1000°F for deposition/corrosion protection
  - two-phase cooling system on blades and vanes
- results
  - 22% efficiency loss for a coal-fired ATS plant
    - 9% associated with coal combustion
    - 13% associated with high pressure turbine cooling
  - hot section endwall cooling penalty may be conservative

The conclusion of this study is that deposition/corrosion protection is a primary driver in coal-fired systems. As indicated by past tests of alternate fuels at high gas tempertures, the very large airflows of gas turbine engines combined with the very good but imperfect cleanup systems likely to be available in the near future results in the requirement to cool metal surfaces

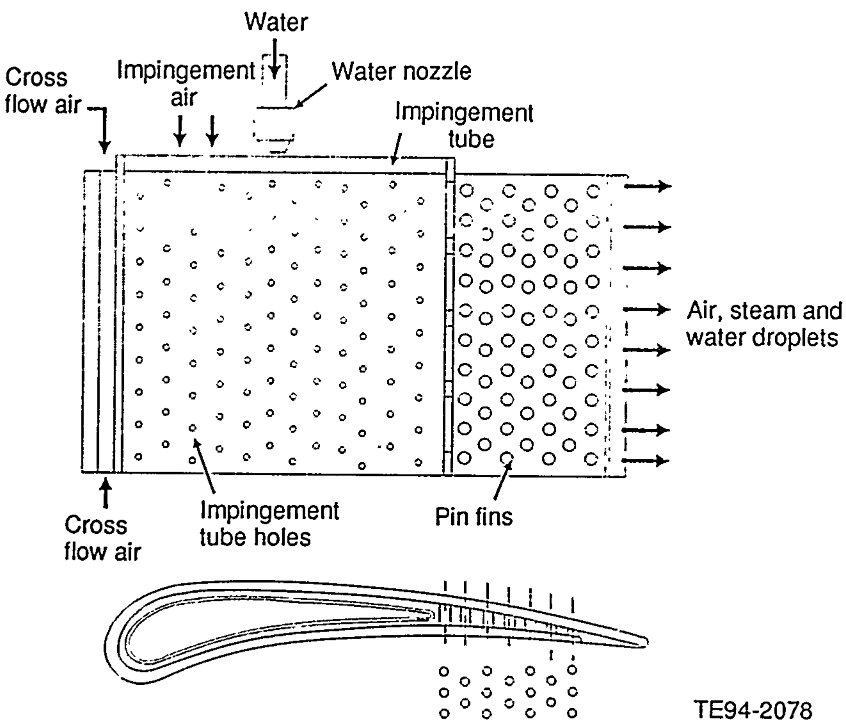
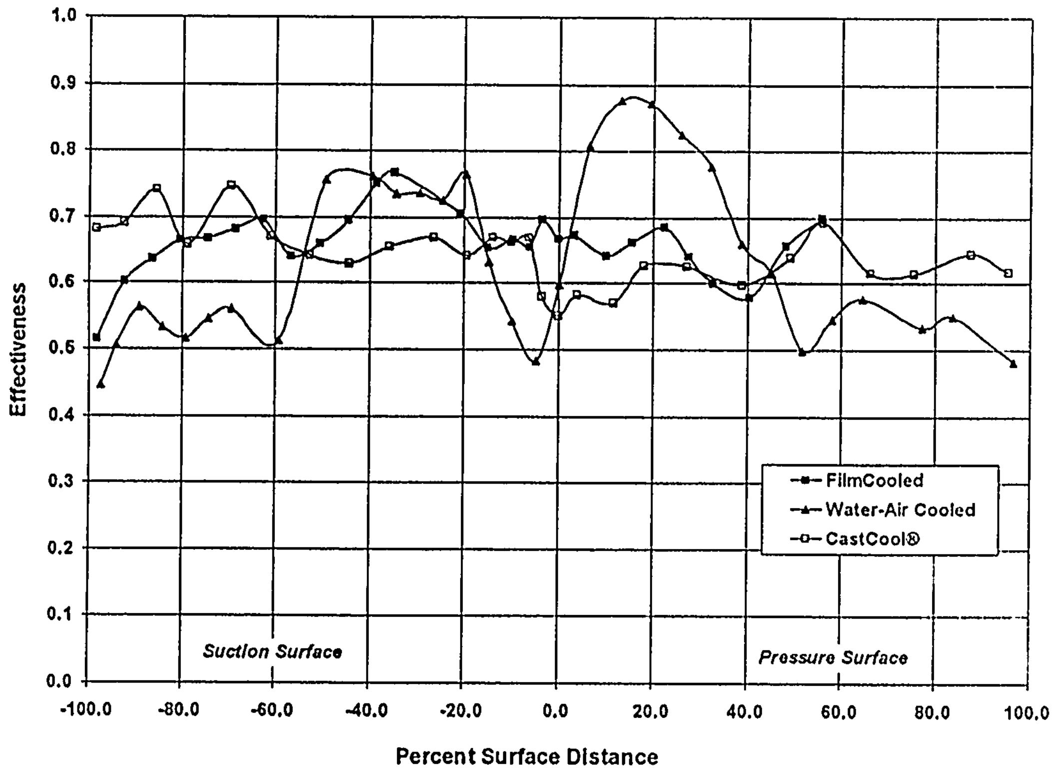


Figure 9. Concept of Two-Phase Cooling as Applied to an Airfoil



Water-Air Cooled	
Air:	2%
Water:	0.4%
Avg Eff:	0.6323

CastCool®	
Air:	5.83%
Avg Eff:	0.6487

Film Cooled	
Air:	7.30%
Avg Eff:	0.6654

TE95-1457
VS95-1830

Figure 10. Comparison of Two-Phase Cooling Effectiveness with Air-Cooled Airfoils

far below levels currently used in gas or liquid fueled machines.

Benefits

Development of the selected ATS system provides benefits to Allison, the Allison customer base, and the general public.

Allison can move several important turbine engine technologies from prototype phase into full-scale development and into the product base. In many cases these technologies represent conversion of defense developments to commercial use. This results in more competitive technology being offered to customers and a resulting increase in sales.

Our customer base benefits from a more efficient system operating at lower pollution levels. Customer IRR is improved dramatically.

The public benefits from cheaper products produced by more efficient manufacturers at reduced levels of pollution

Acknowledgments

The performance period for this contract (Modification 8) is 3 August 1993 through 31 March 1998. I wish to thank the Contracting Officer Representatives who have ably supported and guided this effort: Diane Hooie, Abbie Layne, and Leland Paulson (current).

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