Advanced Turbine Systems Program

Quarterly Report

November 1, 1995 - January 31, 1996

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

RECEIVED

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For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

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

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EXECUTIVE SUMMARY

This quarterly report covers activities on key tasks of the Allison Advanced Turbine Systems contract DE-AC21-93MC29257, from November 1995 to January 1996.

Allison Engine Company provided a progress report on this project to Mr. Leland Paulson, Project Manager, DOE/METC, on December 5, 1995. The all day presentation included an update on accomplishments, and proposed re-direction of certain sub-tasks to streamline Phase 2 extension activities with the goals and objectives of the Phase 3 cooperative agreement signed October 17, 1995. A request was submitted to DOE on December 6, 1995, for the approval of the seven (7) items presented during the meeting for re-direction. Allison received approval of the revision to six (6) of these items on January 16, 1996. On the last item, Allison was informed that for the time being, the ceramic vane design and evaluation task will continue as part of Phase 2 extension.

Allison also submitted a final quarterly report on January 16, 1996 for the period August - October, 1995. The submittal date of the final report was January 20, 1996. The draft report was submitted during November, 1995.

Allison continued progress on the following tasks during this quarter:

- * Task 5: Market Study
- * Task 6: GFATS System Definition and Analysis
- * Task 8.01: Castcool™ Technology Demonstration
- * Task 8.04: Low Emissions Combustion System
- * Task 8.07: Ceramic Vane Design and Evaluation
- * Task 9.0: Program Management

Task 5.0 -- Market Study statement of work was provided to the Electric Power Research Institute during this quarter.

SUMMARY -- SPECIFIC TASKS

Task 5.0: Market Study -- The market study will focus on distributed generation prospects for an industrial ATS, utilizing the Allison ATS family as the primary gas turbine systems. During this quarter, Allison generated a Statement of Work for review with DOE/METC Project Manager and the Electric Power Research Institute (EPRI) personnel. A meeting was subsequently held with EPRI to find out whether the cost and schedule of the study were consistent with the SOW. EPRI's preliminary comments were that the scope of the study was reasonable. However, it was indicated by EPRI that the study would require more funds than the available amount.

Task 6.0: GFATS Definition and Analysis -- The completion date for this task has been extended by DOE/METC to May 31, 1996 at no cost increase.

The combustion section flow path model was completed during this quarter. The resulting computational fluid dynamic analysis predicted mass flow and temperature distribution exiting the transition duct. The conversion of CADDs models of two candidate diffuser designs were completed. Solid grid generation will be initiated for subsequent application of the CFD code to their flowpaths.

The CADDs models of the two candidate combustor diffusers were completed. The design of the airflow rig adaptive hardware was completed, and the fabrication is in progress. Work on the study of carcass deflection from silo combustor is postponed until February 1996.

The work on revised estimates of cooling air flow requirements is behind schedule. However, it is planned to have this sub-task completed by the revised completion date of the task.

The objective of this sub-task is to evaluate the use of one piece continuous ceramic blade track for the first and second stages of HP turbine. Four designs have been completed. The ceramic material selected is silicon carbide fiber reinforced alumina. Heat transfer and stress analyses are expected to be completed by mid February.

Work on mixed flow compressor is continuing. The initial 3 D viscous flow analysis of the rotor was completed. Preliminary verification showed good correlation with available test data. Several iteration were completed on the exit vane definition based on 3D viscous analysis of the exit vane row. An economic assessment of the mixed flow compressor is being conducted to determine its viability based on the overall internal rate of return.

The work on increased LP rotor speed indicated that the LP turbine could be reduced from 4 to 3 stages. The results indicate significant cost saving with no penalty on performance. The HP turbine was modified to better match the new three stage LP turbine. This change resulted in overall engine efficiency increase. Optimization of the LP turbine design will continue.

The need for a surge protection valve has been established due to potential overspeed and infrequent compressor surges. The valve will be located on the combustor outer case and vent to the engine exhaust.

Extended oxidation testing of coated turbine material specimens continued through this quarter. The IN 738, NiCoCrAlY coated specimens, and CMSX-4 +La, bare and Pt-Al coated pins were tested. A total of approximately 2,000 hours have been accumulated on these specimens.

Other specimens to be tested will include CMSX-3, NiCoCrAlY coated pins; and CM186, Pt-Al and simple aluminide coated pins. The MAR M247 specimens were removed from further testing due to weight loss. Completion of testing will be done by the end of May, 1996, in accordance with the revised schedule for Task 6.0.

The current study of Lamilloy thermal effectiveness consisted of 10 different sample designs. Fabrication was completed for 7 samples, and thermal effectiveness evaluation has been completed for 5 of these 7 samples. Preliminary results indicate an increase in effectiveness with channel height within a certain range.

Work on TBC coated endwall continued. A cooling air reduction using small hole sizes and TBC in the Castcool™ configuration appears to be achievable. Although the use of the TBC reduces the wall temperature, it also produces some overcooling of the endwalls.

Task 8.01: Castcool^R Technology Demonstration -- The Castcool™ blade fabrication process was accelerated during this quarter. A significant number of good quality blades have been finished and fully inspected. Yield continues to improve. These blades will be tested in the ATS Phase 3 gas generator test.

Structural analysis of the HP turbine rotor to the ATS Phase 3 gas generator test conditions is complete. Modifications based on the 1994 test results have been incorporated in the design. Modifications to the preswirlers were defined.

Assets with baseline cooling flow data have been identified. Four Castcool™ vanes and 5 blades will be coated unmasked to evaluate any cooling flow reduction due to hole blockage.

Fabrication of seal hardware was completed in this period. Static and dynamic min/max and cyclic rig testing was successfully completed. The seal hardware was shipped to Allison for ATS Phase 3 gas generator test.

Blade tip bonding continued. A total of 17 tips with a bonded abrasive tip have been completed. These blades will be demonstrated in the Phase 3 gas generator test to evaluate durability of both configurations.

Task 8.04: Low Emission Combustion -- Fuel and air split calculations were completed for the ATS cycle using a first stage pilot. This information was used to size the cold flow rig for the test of the turbine inlet transition duct.

Work on the design of the premixer/preburner for the catalytic combustion system continued. Catalytica specified that a fuel/air mixture uniformity is required at the catalyst inlet. Further analyses were conducted on residence times to alleviate the possibilities of autoignition occurring upstream of the catalyst and incomplete CO burnout occurring downstream of the catalyst.

A survey of the types and levels of feedstream contaminants expected in commercial applications of catalytic combustion technology was completed at Catalytica. One contaminant of concern is salt from ingested seawater droplets. Catalytica will conduct tests, exposing the catalyst to the salt contaminant. This test would expose the catalyst to the same total amount of salt as would 8000 hours of operation on unfiltered air. Aluminum and silica are dominant particulate elements in ambient air. Tests simulating exposure of the catalyst to aluminum and silica particulates will be conducted to represent conditions of an 8000 hour exposure in actual operation.

The configuration RRSPN1.1 (Tapered Radial Swirler Plus Nozzle version 1.1) premixing module was tested at atmospheric conditions at Energy Research Consultants. Flashback was observed with the original location of the fuel delivery holes. Relocating the holes produced a relatively uniform mixing profile. Mixing tests on another configuration at ERC revealed a large tangential variation in mixing. The unsatisfactory results were due to problems in forming consistent fuel passages in the thin leading edges of the vanes. This configuration will not be pursued further. A different configuration with larger vane leading edge has been tested, and produced favorable results. Flashback tests were performed on various lean premix modules. The data is currently being analyzed.

Task 8.07: Ceramic Vane Design and Evaluation -- The design and drawings of the ceramic vanes and their metallic mounts are complete. Stress analysis indicated that the most significant stresses in the ceramic vanes are thermally induced. The effects of significantly different

coefficients of thermal expansion between the ceramic vanes and metal mounts, which result from cold engine startup to steady state operation are being analyzed. The analyses also include desired running clearances between adjacent vanes and between vanes and their mounts, considering flow leakages and loads transmitted to the vanes at various turbine operating conditions.

Stress analyses indicated that the highest steady state stresses result from the combustor temperature pattern. The highest transient stresses result from non-uniform cooling of the vanes during emergency shutdown conditions when fuel is shut off to the combustor. The maximum calculated emergency shutdown stress in the ceramic airfoil was a very acceptable value.

The thermal shock rig design is continuing. The purpose of thermal shock test will be to simulate the highest stress condition of the engine for the ceramic vanes and to verify that the mounts do not transmit undue loads or contact stresses to the ceramic vanes.

A computer file of the solid model of the vane has been sent to Allied Signal to prepare them for a quotation on Allison's request to supply ceramic vanes. DOE has given permission to utilize ceramic materials produced by NGK. NGK will also be contacted to seek their responses to providing ceramic vanes, and to obtain additional data on their SN88 silicon nitride material.

ORNL was also contacted during this quarter. Allison provided ORNL a matrix of test conditions and data requirements for the ceramic vane materials.

Task 9.0: Program Management -- The program management activity during this quarter was directed toward a project status update to the DOE/METC Project Manager. The presentation of the project was given to Mr. Leland Paulson on December 5, 1995 at Allison Engine Company. After the presentations, a tour of the test facility was provided to show the hardware being acquired for the program.

During the presentation, recommendations were provided to Mr. Paulson on how the Phase 2 extension tasks could be made even more effective to link better with the Phase 3 cooperative agreement program. A complete list consisting of re-direction of some of the subtasks was submitted to DOE/METC on December 6, 1995 for approval and concurrence. The approval was received in January, 1996.

The final quarterly report for the period August - October, 1995 was submitted to DOE/METC in January, 1996.

The Milestone Chart in Figure 1 contains the status of each program task.

MILESTONE SCHEDULE PLAN

U.S. DEPARTMENT OF ENERGY
MILESTONE SCHEDULE ☐ PLAN ☐ STATUS REPORTFORM APPROVED
OMB NO. 1901-1400

1. TITLE Fig.1-1 ATS Phase 2 Extension												2. REPORTING PERIOD May 1995 - March 1996								3. IDENTIFICATION NUMBER DE-AC-21-93MC29257 Mods 7,8										
4. PARTICIPANT NAME AND ADDRESS Allison Engine Company P. O. Box 420 Indianapolis, IN 46206-0420												5. START DATE May 1, 1995								6. COMPLETION DATE March 31, 1996										
7. ELEMENT CODE	8. REPORT-ING ELEMENT	9. DURATION										FY 1997								FY 1998								10. PER-CENT COMPLETE		
		1995										1996																		
		M	J	J	A	S	O	N	D	J	F	M															a. Plan	b. Actual		
P13105	Task 5.0	Market Study										Report																100		6
P13106	Task 6.0	GFATS System Definition and Analysis										Report																100		57
P13131	Task 8.01	Castcool										Report																100		82
P13184	Task 8.04	Low Emission Combustion System										Report																100		90
P131B	Task 8.07	Ceramic Vane Design and Evaluation										Report								3/98								100		42
P13109	Task 9.0	Program Management										Reports																100		60
11. SIGNATURE OF PARTICIPANT'S PROJECT MANAGER AND DATE																														

DETAILED REPORTS ON INDIVIDUAL TASKS

TASK 5.0 -- Market Study

Progress Report for November, 1995 - January 1996

A statement of work on distributed generation study of the Allison type ATS was generated during this quarter. The SOW was sent to DOE/METC Project Manager for review and concurrence. After obtaining concurrence from Mr. Paulson, EPRI was sent a copy of the SOW for their comments. Mr. Dan Rastler of EPRI met with Allison on January 29, 1996 to briefly discuss the statement. He agreed to provide his comments within the next 2 weeks.

A copy of the statement of work on distributed generation study is presented below:

Introduction:

Allison Engine Company (Allison) is currently under contract with the Department of Energy, Morgantown Energy Technology Center, to have a market study conducted on its Advanced Turbine Systems (ATS) configuration. The study should focus on potential applications of the Allison ATS in distributed generation.

The Electric Power Research Institute (EPRI) is conducting a comprehensive study on distributed generation for its members. This EPRI study appears to be broader in scope than the DOE funded Allison study work scope. The intent of the Allison requested study primarily is to utilize the work being done by the contractors for EPRI, and add the Allison Statement of Work to the EPRI contract as an additional task.

Statement of Work:

The objective of the distributed generation study for the Allison ATS is to determine potential markets for a 5 to 15 MW simple cycle gas turbine engine. The Allison ATS will be adaptable for installation at industrial customer sites and/or at select sub-stations owned by electric utilities.

The specific tasks to be performed by a contractor on this study are:

1. From a survey of end users determine the size range of power generation systems in terms of MW that defines "distributed generation."
2. Identify whether there is an optimum size range for gas turbines preferred by end users for distributed generation applications. This preference may vary geographically and by the type of end user.

3. Quantify the total distributed generation market niche and size (total MW) for gas turbines in the 5 to 15 MW range. Provide a market projection with time (years) for the distributed generation market. Any global projections would also be highly desirable.
4. Conduct a survey of representative end users to evaluate how well the Allison ATS gas turbines will meet their needs for their distributed generation markets. Also indicate the features these end users would like to emphasize, e.g., first cost, transportability, simple vs. combined or other cycle modes.
5. Determine whether there are demographic and geographic regions where the Allison ATS type gas turbines could best serve the distributed generation needs. The current EPRI distributed generation study might provide inputs and guidance for this task.
6. Provide a final presentation on the results of the distributed generation study on the Allison ATS engine at a mutually agreed upon site.
7. Generate a final report on the proposed study.
8. Submit recommendations for further evaluations which would enhance understanding of the distributed generation markets.

Schedule and Cost:

The study should be completed in approximately 3 months from the start of the contract. Allison will contract this study with EPRI, who in turn will select and authorize the contractor(s) currently conducting the EPRI distributed generation study.

The funding available for this study is limited.

TASK 6 QUARTERLY REPORT NOVEMBER 1995 THROUGH JANUARY 1996

6.01 Combustion Section Flow and Heat Transfer Analysis - The conversion of the CADDs model to a Patran surface model and then to a solid grid was completed for the transition duct inner flowpath this period. Using the generated solid grid, the computational fluid dynamics (CFD) code successfully yielded a converged solution for the transition duct inner flowpath. The resulting CFD analysis predicted mass flow and temperature distributions exiting the transition duct. The flow distribution will later be correlated with the rig test data from subtask 6.02. The analysis results will also point the way for subsequent design modifications.

The conversion of the CADDs models of two candidate diffuser designs, the combustor outer case, and the transition duct to Patran surface models was completed in January. They are now ready for solid grid generation to begin for subsequent application of the CFD code to their flowpaths.

6.02 Combustion Section Scale Model Rig Test - The CADDs models of the two candidate compressor diffusers (straight and turning flowpath) were completed. Conversion of all the CADDs modeled parts from subtask 6.01 to half size test part CADDs models was completed. Rapid prototype fabrication of the half size parts was delayed due to problems in converting the CADDs model data bases into the necessary STL files. A decision was made to pursue a parallel path by creating the models using a different software package. This and the subsequent conversion to the necessary STL files was successfully completed for the outer combustion case, the transition duct, the compressor "flowpath turning" diffuser, and the outer flowpath inner sleeve. Rapid prototype fabrication of these parts has begun. The creation of the half size CADDs model data base using the alternate software package is in progress for the compressor "straight flowpath" diffuser.

The design of the airflow rig adaptive hardware was completed, and fabrication is in progress.

6.03 Study of Carcass Deflection From Silo Combustor - Work on this subtask has been rescheduled to start mid to late February 1996, pending completion of subtask 6.01.

6.04 Reduced Turbine Cooling Flow Studies - Review of the chargeable cooling air used to run the ATS 5 performance shows that was used to achieve thermal efficiency. However, the secondary flow report issued has a total chargeable flow of This value was based on the use of slightly conservative clearances from Allison's experience base. The Secondary Flow group has reviewed the ATS HP and LP turbine cooling flows, and a number of clearances were reduced to achieve a reduction. Most of the reduction came from reducing the clearances on the lab seals in the HP and LP turbine. Work was planned to assess the practicality and risk involved in

reduction of the clearances. Although, this effort is somewhat behind the original schedule, it will be accomplished by program end.

6.05 Ceramic Blade Track Design - The objective of this subtask is to evaluate the use of a one piece continuous blade track for the first and second stages of the HP turbine. Four designs have been completed: a solid track with 4 pin locators; a solid track with tabbed ring locator; a pocketed track with 4 pin locators; and a pocketed track with tabbed ring locator. The ceramic material chosen for heat transfer analysis is Silicon Carbide Fiber Reinforced Alumina ($\text{SiCf}/\text{Al}_2\text{O}_3$).

The heat transfer analysis on the designs started mid-January, and is expected to be completed by mid-February. Boundary conditions chosen for analysis are based on the 501-K model used for ceramic vane analysis, scaled up to reflect ATS temperatures. Upon completion of the heat transfer analysis, a stress analysis request will be submitted for the designs.

6.06 Inlet Housing Loss Optimization - This task follows and benefits from the methodology recently developed and used on a similar inlet housing for another Allison industrial engine program. Due to the resulting significant reduction in workscope for this task, it has been redirected to optimize the inlet plenum flowpath upstream of the inlet housing.

A request has been issued to do this work. The goal is to reduce performance losses by reducing inlet distortion. Due to the nature of the problem (i.e., low Mach number) and available resources, it is felt that scale model testing in the research lab will be a more effective method for optimizing the design than CFD analysis. Effort to date has consisted of initial study of the background of another currently used radial inlet plenum and requesting estimates from the research lab for scale model work.

6.07 Study of Mixed-Flow LP Compressor - Work this quarter has consisted of the following items. The initial 3D viscous flow analysis of the rotor was completed and verification of the analysis progressed. This involved using the technique developed for the ATS rotor to model a similar rotor for which test data was available. The intent was to verify the 3D viscous analysis method by showing good correlation with the available data. Initial attempts with a non-Allison mixed-flow rotor were inconclusive due to insufficient blade geometry definition detail. Verification progressed using the Allison model 404 centrifugal rotor, for which the blade geometry was known and test data was available. Preliminary verification showed good correlation, which increases confidence in the analysis of the ATS rotor. Further verification and analysis were in progress at the end of the period.

Several iterations were completed on the exit vane definition based on 3D viscous analysis of the exit vane row, using ATS mixed-flow rotor exit conditions predicted by the 3D viscous rotor analysis. The analysis indicated that the rotor will have to be moved forward approximately 3 inches to obtain the required turning before entering the HP compressor inlet.

A customer's internal rate of return (IRR) cost analysis comparison was initiated toward the later part of this period to estimate how good the mixed-flow design's performance must be to make it attractive. This involves estimating the hoped for engine cost savings of the mixed-flow design versus the two stage axial design, and then factoring in the anticipated engine performance penalty predictions. Risk of achieving the predicted performance must also be considered.

No work has been started on IGV definition, airfoil stress and dynamics, or off design performance.

6.08 Increased LP Rotor Speed - The scope of this subtask was redirected, with COR approval, to analyze reducing the LP turbine from four to three stages as a means of lowering engine cost. Work accomplished this quarter consisted of a preliminary study by Turbine Aero to show the feasibility of the three stage turbine, and a cost effectiveness study to verify that the slight LP turbine efficiency loss does not negate the hardware cost savings.

As part of the preliminary study, the HP turbine was modified to better match the new three stage LP turbine. This resulted in net increases in overall engine efficiency and horsepower respectively. Combining these increases with the hardware cost reduction yields an increase in IRR from 22.8% to 23.12% (+ 0.315%). The modified turbine has a flowpath that matches Allison's AE3012 engine's turbine. The AE3012 is another model being developed in the AE2100 family of engines.

Future work on this subtask will consist of further optimizing the LP turbine design as the final design configuration is established.

6.09 Surge Protection Valve Study - Compressor surges, while infrequent, may occur in industrial gas turbine engines. In the event of a violent surge, severe damage to the compressor flowpath hardware can occur. The need for a surge protection valve to protect the compressor has been established. There is also concern for potential overspeed from the large amount of stored pressure energy in the event of electrical generator load loss. It has been recognized that one valve can provide protection from either event. The valve will be located on the combustor outer case and vent to the engine exhaust. An initial study of the control requirements has been performed this quarter.

6.10 Update Design Sketches - This subtask covers revisions to the general arrangement drawing of the ATS engine which was created in Phase 2. The add-on contract effort has not yet identified any configuration modifications requiring incorporation in the drawing. However, at the present time it appears that a 3 stage power turbine will replace the previously considered 4 stage unit (ref.: subtask 6.08). The decision on this turbine should be made in February. If the decision favors the 3 stage unit, the engine general arrangement sketch will be changed accordingly.

6.11 Effect of Thin Wall and Coating on SX Mechanical Properties - The objective of this subtask is to generate creep rupture properties for coated CMSX-4 single crystal alloy for thin wall applications. Fifty-five samples were shipped to Joliet, IL for — machining at the end of January. The balance of the 100 castings is scheduled to be received by Feb. 23. Twenty-five of these castings will be coated at Allison, and 25 left uncoated. Also, 25 are scheduled to be delivered to Chromalloy by Feb. 9, and 25 are scheduled to be delivered to TCC by Feb. 16 for application of their proprietary coatings.

It is expected to take 3 weeks for the coating processes to be completed, and 1 week for heat treating at Allison, which puts the projected completion date for the 1000 hour test in May.

6.12 Extended Oxidation Testing - Oxidation testing of coated turbine material specimens continued through this quarter. The following specimens, added as part of the Phase 2 Add-on program, have accumulated 1,957 total hours of testing and include:

IN738: NiCoCrAlY and Pt-Al coated pins;

CMSX-4 + La: bare, Pt-Al, and simple aluminide coated pins.

The next specimen started testing in November and has accumulated 1,358 hours of testing during this quarter:

CMSX-3: NiCoCrAlY electroplated pins.

The following specimens, which accumulated 5,000 hours of testing in Phase 2 of the program, have now accumulated a total of 6,957 hours of testing:

CMSX-4: Pt-Al, simple aluminide, and NiCoCrAlY coated pins;

CM186: Pt-Al and simple aluminide coated pins.

The bare MAR M247 specimen, added to the test in November, was removed in January due to weight loss, indicating no oxide growth, and replaced with simple aluminide coated IN738. This specimen has accumulated 167 hours of testing to date. Completion of the test is expected by the end of the add-on extension ending date of 31 May 1996.

6.13 Castcool Heat Transfer Effectiveness Testing - The discussion below uses both the terms Castcool and Lamilloy. Since these terms have slightly different connotations, a short definition follows to address this point. Castcool is a process that permits single-step casting of complex shapes including, but not limited to, thin multi-wall transpiration-cooled structures similar to Lamilloy. In the context of thermal effectiveness discussions, the terms Castcool and Lamilloy may be used interchangeably. The term Lamilloy is used below simply because the test specimens are not cast but use sheet type construction.

The current study of Lamilloy thermal effectiveness involves 10 different sample designs that incorporate variations in internal geometry parameters such as pedestal spacing, hole patterns, and channel depth, all using a square pedestal shape. Three specimens of each design were to be fabricated, both to assess the effects of variability in the fabrication process and to ensure at least one good specimen in the event of fabrication problems.

During this quarter, fabrication has been successfully completed for 7 of the 10 sample designs. The 3 remaining sample designs are awaiting rework due to machining problems that affected all three specimens of each sample design, and should be completed by late

February. Thermal effectiveness testing has been completed for 5 of the 7 samples fabricated to date. Testing of the remaining five samples should be completed by mid-March; analysis and reporting of the results, by the end of March.

Specifically, ATS thermal effectiveness characterization was started with the re-running of specimens 807 A, B, and C using an improved steady state temperature calibration. The 807 samples have been designated as the baseline specimens for the study. More recently five thermal effectiveness samples, EX172358 A-C and EX172355 B-C, were tested in January. Also, the baseline Lamilloy samples (EX170807 A, B, and C) for this study were re-run with the rig cooling water temperature held steady at 72 °F to assess the effect of rig cooling water temperature on effectiveness data. No discernible effect was observed.

Preliminary effectiveness results from test samples EX170807, and EX172357, 358, and 359 are plotted in Figure 1 to show the effect of channel height on cooling performance over a range of cooling air flow rates. The graph indicates that effectiveness increases with channel height. Increasing channel height yields no additional increase in effectiveness. Further analysis is required to relate these results to other pertinent Lamilloy design parameters.

6.14 Thermal Barrier Coating of Turbine Vane Platforms - Work on the TBC coated endwall continued in November with work on the affects of film cooling on metal temperature. As reported previously, Allison was able to realize a cooling air reduction using smaller hole sizes and TBC in the Castcool configuration. In addition, it was desirable to determine whether any economy could be achieved using a film cooled approach combined with TBC. Recall that a maximum metal temperature of 1750°F was established for the analysis. Given the constraints of a minimum hole size on the cast cool, the film cooling approach showed that comparable metal temperatures can be achieved when run with the ATS 5 performance cycle. This demonstrates that an alternative cost effective approach is available as a backup plan for the Castcool design.

The heat transfer group completed a technical analysis report on the study of the 1st stage vane endwall. Although there are a number of important items, the primary conclusion is that the use of thermal barrier coating (TBC) can reduce the wall temperature and thus provide the potential to reduce cooling flow. As noted above, a physical limitation of gas side hole size was imposed to minimize clogging during service. Although the use of the TBC does reduce the wall temperature, this limitation results in some overcooling of the endwalls, i.e., wall temperature less than 1750°F.

Tasks which remain to be completed under this subtask will be to rerun the performance model to determine how much power and SFC will be changed with the reduction in cooling. Another task will be the investigation of any possible cost reduction which might be derived from the use of film cooling coupled with TBC. Progress on this activity will be reported in the next quarterly report.

6.15 Design Validation - The first step in Allison's design validation process is the establishment of the design requirements document, which, according to Allison procedures, is the responsibility of the Chief Project Engineer. The engineer identified to fill this position for Phase 3 of the program was not available to work on the ATS—program until January which, in turn, resulted in a delay in the creation of the design requirements. It is now planned that the requirements document will be written in February. The design criteria will then be developed in March. According to Allison procedures the conceptual design review is to be conducted after the requirements, criteria, and general arrangement drawing are completed. This review will now be accomplished in Phase 3 of the program since the revised 3 stage power turbine configuration (ref.: subtask 6.08) will not be incorporated in the general arrangement until the end of this add-on program.

INTER-ORGANIZATION

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

To : S. Ali

Address :

From : J. Skinner

Date : February 8, 1996

Subject ATS Phase 2 Quarterly Progress Report for November-January, 1996 - Task 8.01

Significant progress was made during the reporting period of November 1, 1995 to January 31, 1996 on Task 8.01, Castcool™ Technology Demonstration. To date, 82% of the technical activities of this task have been completed. The progress made during this reporting period is summarized in the following paragraphs.

8.01.01 - Castcool™ Blade Fabrication (80% complete)**Objective:**

Castcool™ turbine technology is a critical technology needed for the DoE's ATS program. Castcool™ is a manufacturing process that enables the casting of holes and intricate patterns in high temperature capable single crystal materials. Allison is using the Castcool™ process to manufacture turbine airfoils that utilize highly effective cooling schemes, such as Lamilloy®, in a cost effective manner to improve engine thermal efficiency.

Allison has been developing a Castcool™ blade that is directly applicable to the ATS turbine. Under an ATS Phase 2 task, Allison continued to refine the fabrication process initially developed under IR&D and cast a limited number of blades (56) and improved yield from the start of the effort. However, the fabrication process cannot be validated by making a small quantity of airfoils. A large enough sample needs to be made to verify the yield and overall quality of parts. This subtask was established to build upon the previous efforts and cast an additional number of engine quality blades and complete all detailed inspections of these castings. This includes visual inspections, ultrasound (for wall thickness), borescopes, x-ray (to examine internal features and deviations), chemistry analysis, metallography, water flow, and air flow tests. This data will be compared with the design intent and previous castings to validate the current process and identify potential process refinements that would be required to assure production readiness for ATS applications. As a side benefit, this task will fabricate blades that can be used for other subtasks and for engine testing.

Progress:

Significant activity on this effort continued during this reporting period. To date, a total of quality blades have been finished and fully inspected. Yield continues to show improvement from earlier molds and has surpassed the levels demonstrated in the Phase 2 effort. Continued progress in the area of wax assembly quality has been the result of continued effort by Allison's Single Crystal Operations working in conjunction with the assembly vendor. These blades will be demonstrated in the ATS Phase 3 gas generator test, including coated blades from Task 8.01.03.

8.01.02 - Castcool™ HP Turbine Design Analysis (100% complete)Objective:

In 1994, Allison completed testing of an ATS prototype turbine in the AE 301X turbofan engine under a Phase 2 task. This turbine, which featured Castcool™ technology first stage vanes, was successfully tested above the ATS turbine rotor inlet temperature goal of 2600°F. As reported in Phase 2 Annual Report, a significant amount of information and experience was gathered on this turbine from the test program. Future plans call for upgrading the turbine to incorporate Castcool™ first stage blades and running a durability test at even higher temperatures in a gas generator. This subtask has been established to evaluate the results of the previous test and analyze the design modifications to the turbine in relation to this future testing.

Progress:

Structural analysis of the HP turbine rotor to the ATS Phase 3 prototype turbine gas generator test conditions is complete. All of the components met the design criteria for this test, with the exception of the 2nd stage blade. Additional cooling holes were added to the pressure surface tip region and trailing edge to attain acceptable average section metal temperatures. Cold flow data demonstrated that the required cooling flow levels had been achieved with the blade reworks. A shaker test to demonstrate that blade life had not been compromised by the additional cooling holes was successfully conducted.

Modifications to the static structure based on lessons learned from the 1994 test and new hardware and design requirements have been evaluated and incorporated into the design. Modifications to the first and second stage preswirlers were defined from the results of the blade structural analyses.

8.01.03 - Demonstration of Coating Castcool™ Airfoils with Pt-Al (40% complete)Objective:

Under a previous ATS Phase 2 task, Allison evaluated several types of coatings for long term oxidation resistance. These results indicate that a platinum-aluminide AEP coating is the best solution for the first stage Castcool™ CMSX-4 airfoils. Allison has performed some demonstrations of applying this coating on Lamilloy® and Castcool™ disk samples, but not on actual Castcool™ airfoils. Under this subtask, Allison is developing and demonstrating the application of the platinum-aluminide AEP coatings on Castcool™ vanes and blades using existing assets.

Progress:

Coating fixtures and material are available. Assets with baseline cooling flow data have been identified and will be coated following final machining. Castcool™ vanes and Castcool™ blades will be coated unmasked to evaluate any cooling flow reduction due to hole blockage. Following successful cold flow testing, these assets will be demonstrated in ATS Phase 3 gas generator testing.

8.01.04 - Development of a Film-riding Face Seal (98% complete)Objective:

Film riding seal technology has the potential to reduce seal leakage below levels demonstrated on brush seals with higher ΔP capability and longer durability due to the non-contacting design, making it an attractive technology for ATS applications. Allison has been developing this technology and has demonstrated these potential benefits on a seal rig. This task will take the "next step" and design, fabricate, and rig test an engine configuration film riding seal. This seal will replace the current three-stage brush seal at the compressor discharge location on the T406/AE engine compressor. After successful rig testing, this seal will be available for gas generator/engine testing. Allison is subcontracting John Crane Co. To fabricate and rig test the seal.

Progress:

Fabrication of the seal hardware was completed in this period. A rig test was conducted at the subcontractor, John Crane Co., prior to shipping. Static and dynamic min/max and cyclic rig testing was successfully completed and engine speed and pressure. Demonstrated flow rates were an order of magnitude lower than the existing three-stage brush seal. The seal hardware was shipped to Allison and will be incorporated into the ATS Phase 3 gas generator test in 1996.

8.01.05 - Castcool™ Blade Abrasive Tip Development (78% complete)Objective:

The Castcool™ blade design incorporates Lamilloy® cooling technology to cool an abrasive tip (for clearance control) with a minimal amount of cooling air. Two fabrication approaches are being evaluated for the blade tip:

- (1) a Castcool™ tip with a bonded abrasive tip, and
- (2) a machined Lamilloy® tip with a double-braze, single crystal plate/abrasive tip.

Under our completed ATS Phase 2 Castcool™ blade fabrication development effort, we successfully cast the Castcool™ tip on several development pieces. The data taken to date clearly shows a negative impact on casting yield with this approach. The need exists, therefore, to develop an alternative approach. This task will develop the process to put abrasive tips on both configurations, demonstrate these processes on a set of blades, and compare the finished part yield of both approaches and provide a recommendation for the ATS program.

Progress:

Blade tip bonding continued during this period. A total of Castcool™ tips with a bonded abrasive tip have been completed. A total of machined Lamilloy® tips with a double-braze, single crystal plate/abrasive tip have been completed. machined Lamilloy® tip blades remain to be completed in the next reporting period. These blades will be demonstrated in the ATS Phase 3 gas generator test to evaluate the durability of both configurations.

TASK 8.04

Progress Report for November 1995 - January 1996

Status

Task 8.04 is approximately 90% complete.

Task 8.04.01: Catalytic System Pilot/Preburner Design and Test

An actual 501-KB7 start was analyzed in preparation for the upcoming subscale test of the pilot/preburner/premixer module and to better understand the start schedule implications on module design. The actual start data was also compared to data from performance predictions. The results of this comparison will be used in modifying the thermodynamic cycle analysis to support future design of the combustion system. A similar exercise will be performed on a T406/AE2100/AE3007 engine to ensure commonality between actual start data and data from performance predictions for the ATS engine.

Fuel and air split calculations were completed for the ATS-5 cycle using a first stage pilot. The resulting airflow split is: to the pilot/preburner and to the premixer (0% dilution air). This information was used to size the half-scale cold flow rig for the upcoming test of the turbine inlet transition duct.

Continuing work on the design of the premixer/preburner for the catalytic combustion system was performed. The overall system design was discussed at length with Catalytica during a meeting that was held at Allison. Catalytica specified that a fuel/air mixture uniformity is required at the catalyst inlet. Further analyses were conducted regarding residence times to alleviate the possibilities of autoignition occurring upstream of the catalyst and incomplete CO burnout occurring downstream of the catalyst. Pressure losses and wall cooling with its effects upon flow splits were also evaluated.

Task 8.04.02: Catalytic Element Evaluation

A survey of the types and levels of feedstream contaminants that are expected to be present in commercial applications of catalytic combustion technology was completed at Catalytica. Three sources were surveyed: turbine manufacturers, published literature, and ambient air monitoring data that was obtained from the California Air Resources Board.

One contaminant of concern is salt from ingested seawater droplets. The vapor pressures of various salt compounds were estimated for the conditions in the catalytic reactor since their volatility is likely to be an important factor in determining the extent to which the compounds may deposit on the catalyst surfaces.

Catalytica modified a reactor system that is currently being used for the contaminant studies. The system is capable of operating at pressures up to ten atmospheres. The desired contaminant can be dissolved or suspended in water and injected through a high pressure spray nozzle into the fuel/air mixture upstream of the catalyst. The initial tests will confirm the spatial uniformity of the contaminant concentration entering the catalyst. These involve injecting an alcohol/water solution into the air stream and measuring the resulting alcohol concentration at the reactor inlet face. Static mixers can be installed to improve the uniformity of the contaminant distribution.

A detailed test plan was finalized and approved by the Catalytica Process Safety Review Team. The test plan calls for 1) generating baseline catalyst performance data in the absence of contaminants, 2) verifying the performance of the contaminant injection system, and 3) measuring catalyst performance over time while injecting various potential contaminants. Catalyst performance will be monitored continually by measuring catalyst substrate and outlet gas temperatures and emissions. The test conditions will be established to generate catalyst wall temperatures similar to those observed in prior evaluations of prototype reactors for the 501-KB7 and ATS applications. Catalytica has produced enough catalyzed foils to make about fifty catalyst replicates for the contaminant experiments.

For the salt contamination test, an initial salt feed rate was chosen so that a 50-hour test would expose the catalyst to the same total amount of salt as would 8000 hours of operation on unfiltered air at a non-coastal location. A second fifty-hour test was conducted at a time-weighted average salt concentration that was suggested by Allison.

Aluminum and silicon are dominant particulate elements in ambient air. As a result, silica and alumina particles were chosen for contaminant testing involving these two elements. One feed rate represents unfiltered air at an engine site that is on the lower end of the range of reported ambient air particulate loadings. Another test simulates exposure at an engine site that is on the higher end of reported ambient particulate concentrations but assumes that the inlet air is filtered. In both tests, the total mass of silica and alumina that will be fed to the catalyst in 50 hours will be equivalent to the amount that would pass through the reactor in 8000 hours of field operation.

Catalytica has developed several catalyst module designs. One design uses a bonded metal honeycomb as a support. The structural integrity of this design has been verified by both finite element modeling and testing of full scale hardware in another Catalytica development program.

The Configuration TRSPN1.1 (Tapered Radial Swirler Plus Nozzle version 1.1) premixing module was tested at atmospheric conditions at Energy Research Consultants (ERC). Flashback was observed with the original location of the fuel delivery holes. However, relocating the holes produced a relatively uniform mixing profile with a slightly lean core that was flashback resistant at low pressure drops using either natural gas or a mixture of . . . natural gas and ethane. The AC_d of TRSPN1.1 was measured to be much higher than that of TRSPN1.2 and the flame position is consistent with all other RSPN designs. ERC attempted to make velocity measurements at the throat of the module using back scatter from seed particles. However, the existing instrumentation was incapable of making these measurements reliably.

Flashback tests were performed on various individual lean premix modules from the Ultra-Low Emissions Gas Turbine Combustion System (9 ppm NO_x) program. The data from these tests is currently being analyzed.

TASK 8.7

ENGINE COMPONENT DESIGN AND EVALUATION

Quarterly Report for November-December, 1995 and January, 1996

Objective: Since ceramics have not been used commercially for airfoils in industrial gas turbines, it would be beneficial to prove this technology first for current turbine inlet temperatures (approximately 1100 C (2000 F)) as a stepping stone to introduction at the very high ATS inlet temperatures in excess of 1427 C (2600 F). Accordingly, the objective of this task is to design, evaluate and demonstrate ceramic first stage vanes in an industrial turbine.

This task was established in June of 1995 through contract Mod A008 of the program.

Accomplishments: Activities for this task were in the following areas:

- * design and drafting for the ceramic vanes and their mounts
- * thermal and stress analyses of the vane and mount designs
- * design of thermal shock rig for ceramic vanes
- * preparation for ceramic vane procurement
- * presentation and publication

Vane/mount design. The design and drawings of the ceramic vanes and their metallic mounts are complete except for checking and fine tuning the specification of a few dimensions and tolerances using results from thermal and stress analyses. The final detailed dimension specification is in progress and considers:

- significantly different coefficients of thermal expansion between the ceramics vanes and metal mounts that result in differential thermal growths from cold engine startup to steady state operating conditions
- desired running clearances between adjacent vanes and between vanes and their mounts considering flow leakages and loads transmitted to the vanes for the range of turbine operating conditions

Vane/mount analyses. The most significant stresses in the ceramic vanes are thermally induced. The highest steady state stresses result from the combustor temperature pattern. The highest transient stresses result from non uniform cooling of the vanes during emergency shutdown conditions when fuel is shut off to the combustors.

Data from six past combustor tests were previously used to generate three bounding radial combustor temperature contours for the vane stress analyses. Data from previous engine runs were used to represent the thermal shock environment for the vanes under emergency shutdown conditions. Ceramic vane 3-D stress analyses are to be conducted for both steady state full power turbine conditions and emergency shutdown conditions using the three bounding combustor temperature patterns. All three emergency shutdown cases were completed and the steady state condition corresponding to the maximum temperature combustor pattern was completed. The maximum calculated emergency shutdown stress in the ceramic airfoil for all the analyses was a very acceptable value.

The maximum calculated steady state vane stress was also acceptable. Although stress analyses have not been completed for the remaining two steady state conditions and perhaps normal startup and shutdown conditions, the conditions evaluated to date are believed to produce the highest vane stresses.

Thermal shock rig design. Thermal shock test equipment is being designed for proof tests of every ceramic vane expected to operate in later engine tests. The proof tests will simulate temperatures corresponding to at least one engine startup from ambient temperature to full load (vicinity of 2000 F), a period of exposure at full load temperature, and an abrupt drop in temperature to represent an emergency shutdown in service which results in an immediate shutdown of fuel to the turbine. The purpose of this test is to simulate the highest stress condition of the engine for the ceramic vanes and to verify that the mounts do not transmit undue loads or contact stresses to the ceramic vanes. The design of the thermal shock rig is nearly complete and is awaiting the results of the analyses described above to determine refined vane and mount dimensions. This dimensioning is needed for proper clearances throughout the operating temperature range considering differential thermal expansion coefficients of the metallic mounts and the ceramic vanes.

Preparation for vane procurement. Because of the promising stress analyses to date, ceramic suppliers have been alerted that Allison is approaching the time for a request for quote. To facilitate the schedule, a computer file of the solid model of the vane has been sent to Allied-Signal Ceramic Components in anticipation of the request for quote. DOE gave permission this quarter to utilize ceramic materials produced by NGK Insulators Ltd of Japan, subject to providing NGK only information necessary for fabrication. Initial contacts were made with NGK in January to obtain additional data on their SN 88 silicon nitride material.

Publications. A paper titled "Ceramics for ATS Industrial Turbines" has been accepted for presentation at the 1996 ASME Turbo Expo. This paper discusses technical issues for use of ceramics in ATS turbines and describes this project to retrofit ceramic vanes into an Allison 501 turbine for a long term field demonstration.

TASK 9.0 -- Program Management

Progress Report for November, 1995 - January 1996

Allison continued program management of the ATS during this quarter. The final quarterly report for the period August - October, 1995 was submitted during this quarter.

Allison personnel made presentations on the progress of the project to Mr. Leland Paulson on December 5, 1995 pertaining to all six (6) tasks of the Phase 2 extension program. Copies of the presentation material were submitted to Mr. Paulson after the meeting.

During the meeting, Allison provided recommendations on re-directing some of the subtasks to better meet the requirements of the ATS Phase 3 project. A request was submitted to DOE/METC for concurrence and approval. The approval to streamline these subtasks was given in January, 1996. A listing of the recommendations is given below:

1. Task 9.0 - Program Management: Allison recommends reallocation of total dollars within the various tasks of ATS Phase 2, without increasing the total cost, or modifying the scope of the program. When the Management Plan was generated, the intent was to have each task cover its respective charges for project engineering and reporting. Later on, it was found easier to charge all project reporting activities to Task 9.0. As a result, we need to move some funds from other tasks into Task 9.0. A recommended re-allocation of funds by tasks is presented in the attached figure for METC's concurrence.
2. Task 6.0 - GFATS System Definition and Analysis: Allison recommends a redirect of sub-task 6.06 'inlet housing loss optimization' to the design of upstream intake system. This redirect will provide useful design data for Phase 3, and not add any new cost.
3. Task 6.0 - GFATS System Definition and Analysis: Allison recommends the evaluation of whether the power turbine stages can be reduced by one, under sub-task 6.08. Completion of this sub-task is important to Phase 3 design, and for overall cost reduction of the ATS production engine.
4. Task 6.0 - GFATS System Definition and Analysis: Allison requests a time extension for sub-tasks 6.11 and 6.12 (to May 31, 1996 from March 31, 1996) to complete these sub-tasks at no additional cost to the program.

5. Task 8.01 - Castcool™ Technology Demonstration: Allison requests a no additional cost time extension for sub-task 8.01.01 to May 31, 1996.
6. Task 8.04 - Low Emissions Combustion System: Allison recommends a redirect of sub-task 8.04.03 funds to sub-task 8.04.01. Preliminary design of catalytic combustion system (8.04.01) is vital to Phase 3. Additional testing of this concept, using task 8.04.03 funds, will be more important for Phase 3 than evaluating ATS engine family performance (8.04.03).
7. Task 8.07 - Ceramic Vane Design and Evaluation: This task will extend through March 1998, whereas all other tasks under Phase 2 will be completed by the middle of 1996. Allison would like to know whether DOE will retain this task under ATS Phase 2, or combine it into Phase 3.

Two papers submitted by Allison personnel were accepted for presentation at the IGTI ASME Turbo Expo, 1996 in Birmingham, England in June. The titles of these papers and authors are:

1. Ceramics for ATS Industrial Turbines -- Richard Wenglarz, Sy Ali
2. Government/Industry Partnership: A Revolutionary Approach in Global Leadership of Advanced Gas Turbines -- Sy Ali, Charles Zeh

The program is within budget and on revised schedule approved by DOE/METC.