DOE/MC/29257 -- 4005
(DE95000077)

Advanced Turbine Systems Program Conceptual Design and Product Development

Quarterly Report
February - April 1994

February 1995

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

DISCLAIMER

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QUARTERLY TECHNICAL REPORT-FEB THRU APRIL 1994

SUMMARY--GENERAL

This quarter of the ATS program saw progress occur in several areas;

An update (Revision A) of the Management Plan was submitted on May 15, 1994. This Plan was updated to reflect two basic changes to the program;

1. Task 8.5 was stopped and remaining funds transferred to the Task 8.1T, the test of the ATS 2600F prototype turbine.
2. Task 8.1B was added to the program. This task is the Build/Teardown of the prototype turbine. This task is fully funded by Allison and is in-kind cost share replacing cost share lost due to decreases on Allisons rates.

It is noted that these changes do not affect either the total value of the program or Allisons 25% cost share. We will be submitting justification for 2. above shortly.

Tasks 4 and 5 were kicked off in February. Task 4 will investigate conversion to a coal-fueled Advanced Turbine System (CFATS). Task 5 will perform a market study for the GFATS and its family Allison has selected. Tasks 4 & 5 are rather small tasks adding up to a combined funding level of ~$100K. Since Task 4 depends on the final GFATS configuration little progress will be made until we are significantly into Task 6. We have decided to seek an outside source for the market survey of Task 5. A statement of work has been issued and quotes are being obtained.

Task 6, System Definition and Analysis, was initiated in February. This task represents 20% of the total program. Its objective is the preliminary design of the selected GFATS which would be available for further development in future phases of the program. This task is defining the complete engine and skid systems from oil system to turbine configuration. Allison has decided to switch from Bechtel to US Turbine for definition of the skid equipment since US Turbine is a recognized packager of engines in this size range.

Task 8.1, Castcool technology development for industrial engines, now has an approved test plan. This plan will, however, be updated for inclusion of the Tasks 8.1T&B--prototype turbine Test and Build/Teardown. This plan contains the exact test matrices for the oxidation, corrosion and thermal effectiveness specimens to be tested right down to the Castcool pattern, materials-including doping levels of anti-oxidation elements in the CMSX-4 and coatings. Test sample manufacture is now 100% complete. A preliminary oxidation test run under other funding to help select materials, doping levels and coatings is complete. This test result established our final materials/coatings choices for the 5000hr oxidation test Intensive testing of these samples began in March and 500hrs has been accumulated. This puts us about 2 months behind the original test plan.

Task 8.4, Ultra low NOx combustion technology, has completed the code development and background gathering phase. Preliminary results indicate that the lean pre-mix system may be able to achieve very low emissions at the TRIT's required of ATS engines. Allison has submitted and received approval for the test plans. Allison has performed preliminary in-house testing within current funding to validate the codes making this prediction. This testing made use of existing hardware from the 9ppm NOx program. Promising results for NOx emissions were obtained at the ATS 2600F firing temperature. CFD analysis of the transition duct from combustor to HPT is complete. Space claim for this component will be critical in the engine design phase. A preliminary drawing of this component has been passed to the CMC vendor to investigate layup of this complicated part.

Task 8.5, Active Clearance Control, has been cancelled and replaced with a test of the 2600F prototype turbine. The Topical Report for this task will be submitted documenting work completed on this task. This new prototype 2600F HP turbine test task has been designated Task 8.1T. This test will be performed in August 1994. This turbine has the correct flowpath and similar configuration to the selected ATS unit and contains much of the same materials and the first Castcool hardware to be run in an engine.

Task 8.6, two-phase cooling of turbine vanes, is also proceeding well after initial schedule difficulties. The existing computer code, originally used for calculations involving fuel cooling, has been modified to make use of water vapor. Initial estimates indicate that nearly 2/3 of required cooling flow can be eliminated using this technology. Trade studies as to optimum configuration for such a system in an industrial engine have been completed. Test rig hardware has been defined and is being manufactured. The 3X size vanes and vapor cooling inserts have been fabricated. LASER drilling of the vane inserts has been initiated. Allison submitted and has received approval for the test plan. This task is approximately 1.5 months behind schedule but we have not impacted the completion date.

TECHNICAL SUMMARY

The ATS program is comprised of eight (8) separate tasks. The following is summary of the status of these tasks at the beginning of the seventh month of this contract. Figure 2 shows the program schedule by task. Please note that this shows a Task 9 which is used to collect costs of reporting, travel and program management and is not a SOW task.

ATS TASK 1---PROJECT PLAN

Objectives: The objective of this task is to develop and document a plan to perform all tasks of this contract.

Accomplishments: Task complete

Program Cost/Schedule; This task was completed on schedule but at a somewhat greater cost than anticipated. This overrun is small enough relative to the total program that it can be made up elsewhere.

Required Corrective Actions: None

ATS TASK 2--REQUIRED NEPA INFORMATION

Objectives: Provide information required by NEPA concerning Task 8 testing

Accomplishments: Task complete

Program Cost/Schedule; This task was accomplished within the cost estimates. Funds remaining in this task will be applied to Task 7, the Integrated Program Plan, to cover anticipated additional effort. Subcontractor funds from Task 2 will be moved to Task 6 to preserve the accounting procedures and subcontracts established at program begin.

Required Corrective Actions: None

ATS TASK 3-- SELECTION OF GFATS

Objectives: Perform initial trade-off studies in order to select one engine system(GFATS) that the contractor could demonstrate, at full scale, in the 1998-to-2000 time frame.

Accomplishments: This task is now complete. Allison has selected an engine family based on the core compressor currently in production in a family of flight engines. This selection was based on a number of parameters including ROI, 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.

Program Cost/Schedule: This task was completed essentially on cost. This task is complete on schedule with the exception of Allison internal management reviews which are ongoing.

Required Corrective Actions: None

ATS TASK 4---CONVERSION TO A COAL-FUELED ATS (CFATS)

Objectives: The objective of this task is to identify one CFATS that Allison feels would be the most marketable after yr 2005.

Accomplishments: Task initiated as of Feb. 1994.

Program Cost/Schedule; This Task was replanned and a detailed report is included in this section.

Required Corrective Actions: None

ATS TASK 5--MARKET STUDY

Objectives: The objective of this task is compare both the economic and siting constraints of the GFATS with competitive systems. The study will address the ability of the GFATS to compete in future industrial markets.

Accomplishments: Task initiated as of Feb. 1994.

Program Cost/Schedule; This task is in the planning review phase. Current intent is to select an outside contractor to provide an independent assessment of the market potential of the Allison GFATS.

Required Corrective Actions: None

ATS TASK 6--SYSTEM DEFINITION AND ANALYSIS

Objectives: The objective of this task is to develop a conceptual design for the Allison GFATS.

Accomplishments: Task initiated as of Feb. 1994. Significant progress has been made and a detail report is included in this section.

Program Cost/Schedule; This task is slightly behind schedule and expenditures.

Required Corrective Actions: None

ATS TASK 7--INTEGRATED PROGRAM PLAN

Objectives: The objective of this task is to prepare a plan which defines the Research and Development program that, when completed, would lead to commercialization of an ATS meeting program goals.

Accomplishments: Allison has submitted a Preliminary Integrated Program Plan. The final plan will be prepared as soon as practicable.

Program Cost/Schedule; nothing to report

Required Corrective Actions: None

TASK 4 QUARTERLY REPORT FOR FEBRUARY, MARCH, AND APRIL 1994,

Objectives for this tasks include:

- Define a coal-fueled advanced turbine system (CFATS) based on gas-fired advanced turbine system (GFATS)
- Estimate cost and performance for the CFATS
- Identify efforts, cost, and schedule for the development work to adapt GFATS to CFATS

As indicated above, the coal-fueled ATS is based on the gas-fired ATS. Since the gas-fired ATS is in the process of system definition, much of the work in this tasks to define and evaluate the coal-fueled ATS must await further specification of the gas-fired system. Consequently, work to date in this task has been directed to identifying potential systems modifications needed for operation with coal and defining an evaluation framework to analyze performance and economics of the coal-fueled ATS.

Potential GFATS system modifications were identified for operation with the compact and integrated coal combustor developed by Allison in the past DOE Advanced Coal-Fueled Gas Turbine Systems program. These modifications include cooling at least a portion of the compressor discharge air to transport powdered coal to the combustor, additional cooling of turbine vanes and blades to alleviate deposition and corrosion, erosion and corrosion resistant coatings, and accommodation of gas cleanup equipment after the combustor quench zone and possibly the turbine exhaust. Also, the flow areas of the turbine first stage vane passages likely need to be opened to accommodate the higher mass flows for coal fuel than for natural gas.

Operation of an ATS turbine with coal can result in numerous systems constraints to accommodate the modifications just mentioned. Tradeoff evaluations are needed to determine the effects of these constraints on the optimum compressor pressure ratio, turbine inlet temperature, airfoil cooling approach, etc., for the most economically attractive coal system. These considerations must be balanced by the extent and development cost for modifications of the gas fired ATS turbine to achieve a high level of performance with coal.

Efforts were started this quarter to develop the evaluation framework to define a highly economically attractive coal fired ATS system based on the Allison RQL coal combustion approach developed in the DOE/Allison Advanced Coal-Fueled Gas Turbine System Program. Existing performance analyses capabilities have not been configured to accommodate all of the possible turbine modifications for operation with coal, such an evaporative water cooling. The development of these evaluation capabilities is progressing, but is not of high current priority since the gas-fired ATS (GFATS) design is still evolving and the CFATS engine is a modification of the GFATS engine.

Task 6: GFATS System Definition and Analysis

Objectives: Task 6, System Definition and Analysis, was initiated in February. Its objective is the preliminary design of the selected Gas Fired ATS (GFATS), which would be available for further development in later phases of the program.

Accomplishments: The preliminary design of the GFATS system began during the subject quarter. Technical activities included clarification and refinement of engine cycles for the candidate GFATS and several possible configurations within the proposed Allison family of engines to cover Allison's current markets as well as ATS performance parameters. The performance model of the Intercooled and Recuperated (ICR) optional version of the ATS compressor was also refined during this time period. Updates were made to the applicable drawings to reflect resulting design changes. Work also continued defining the basic configurations of the family of products to cover Allison's current markets as well as ATS performance parameters, encompassing approximately 6000-15,000 shaft horsepower. Definition of the various members of this set of engines continued to evolve as the various LP and HP compressor and turbine sections are being optimized and evaluated to achieve maximum commonality between engines. Further evaluation of these components, particularly the turbines, has shown that a great deal of commonality of detailed blades and vanes is achievable in the various members of the engine family. The optional ICR engine performance has also been updated to reflect the refinements that have been made to the component definitions. Component efficiencies for both simple cycle and ICR were updated; additionally, the ICR engine cross-section drawing has been updated.

A general arrangement CADDS drawing of the selected GFATS engine was started in April. By the end of the reporting period, the compressor and turbine flow paths were laid out and the bearing sumps had been defined. The engine's internal flow system study was initiated, which will define the component cooling circuitry and the bearing thrust loads. The material selection process continued with emphasis on turbine component materials.

The ICR configuration was shortened to incorporate supercritical shafting given the limitations of the components involved and the rotor dynamics of the configuration. Definition of the ATS combustion system design is also progressing, including initial assessment of possible materials/processes to accomodate the thermal demands of the system.

The contributions of Bechtel in Task 3 have resulted in elimination of the need for their services in Task 6. Allison has instead requested the services of U. S. Turbine (UST), a longtime packager of Allison and other industrial engine class power generation skids, to quote to the statement of work outlined under WBS 6 in the new schedule. A proposal for the preliminary GFATS packaging design was received from UST in April. This proposal is currently being reviewed by Allison.Subcontractors including AlliedSignal Aerospace Systems and Equipment, AlliedSignal Ceramic Components, Babcock and Wilcox, the Basic Industrial Research Laboratory at Northwestern University (BIRL), and Du Pont Lanxide Composites were issued letter contracts covering engineering efforts required for this task. Subcontractor purchase orders are being put in place to replace the letter contracts issued in February covering engineering efforts required for this task.

Allison was not allowed to give purchase orders to two subcontractors (who had received prior approval during negotiations), Carborundum and Norton Advanced Ceramics, due to a pending ruling involving contractors/subcontractors with foreign ownership. As outlined in a letter to Diane Manilla of METC dated 28 February, this situation has impacted and will continue to affect Allison's ability to perform in Task 6 because it seriously limits access to their design and process expertise for preliminary design trade studies, which are the core of the conceptual design of the GFATS. A ruling that allows Allison to work with Carborundum and Norton Advanced Ceramics is needed to gain access to process and design expertise in support of the GFATS preliminary design study.

Required Corrective Actions: In order to minimize the effect on Task 6 design studies, the DOE must resolve the question of participation of subcontractors who have foreign corporate parentage.

ATS TASK 8.1 ADVANCED COOLING TECHNOLOGY

OBJECTIVE

The overall objective of this program is to achieve gains in turbine thermal effectiveness by the transition of Allison's Castcool® technology to industrial/utility applications. Improvements in thermal effectiveness will result in corresponding improvements in specific fuel consumption, output power and emissions through reduced use of turbine cooling flow. The Allison Lamilloy cooling system is currently under development for high performance aircraft applications in an effort to achieve significant improvements in SFC and thrust to weight over current propulsion capabilities. Although the design requirements for an industrial/utility engine may differ from that of a high performance aircraft engine application, Allisons Castcool® technology does offer the potential for significant improvements in turbine thermal effectiveness. Typical high performance aircraft applications have overall mission life requirements in the 3000 to 5000 hour range with only a fraction of the total mission time spent at maximum temperature conditions. For the ATS industrial application, it is expected that the life requirement will be in the neighborhood of 30000 to 50000 hours at a maximum temperature condition. To address the long life requirements, this task will evaluate thermal effectiveness of Allisons Castcool® system and issues related to long term dynamic oxidation, corrosion, and stress rupture since these are issues key to the design life of turbine airfoils in an industrial application.

APPROACH

Our test plan approach is to address the long life industrial requirements through long term oxidation, corrosion, and stress rupture testing. This will provide basic data required to design extended life Castcool® components in phase III of the ATS program. In addition thermal effectiveness testing will be conducted on a range of Castcool® configurations to provide a sensitivity of the heat transfer characteristics with changes in critical geometric parameters. Basic thermal effectiveness data is essential to fully understanding how the cooling effectiveness of a Castcool® system could be influenced by various operating conditions.
Dynamic oxidation, hot corrosion, and stress rupture testing will be conducted on materials and coating systems conducive to the design and fabrication of Castcool® components. Selection of materials and coatings for this testing was based upon Allisons current knowledge and design experience with turbine airfoils operating in an environment exceeding 2800°F. Potential cost implications were also considered in the selection process since cost per unit power output is an important factor in the competitiveness of future industrial engines.

PROGRESS

During this quarter of the program, progress for each of the subtasks are summarized below.

<u>Castcool® thermal effectiveness testing</u>

Definition of the test matrix as shown in figure 1 was completed during the last quarter. During this quarter all of the numerical control programs were generated for machining of the initial specimens. Machining of the various pattern types was initiated, but temporarily put on hold to address problems encountered during the machining process. The method of fixturing the specimen blanks was insuffecient to prevent deflection of the blanks during machining so a new fixture was designed and fabricated. Specific heat testing of the specimen material was also completed during this quarter. Specific heat data is essential in order to accuratly establish the thermal effectiveness of the test specimens. Continued fabrication of specimens during this quarter has been deleyed due to other program priorities within Alloson. These delays have been addressed and it is expected that work will resume in May. Remaining drawings will not be initiated until initial testing provides effectiveness differences between castcool® pattern types.

FIGURE 1. Internal Thermal Effectiveness Test Matrix

			DASH 1			DASH 2				
			COLD SIDE				CHANNEL	CHANNEL	SHEET	ASSEMBLY
NO.	PATTERN	P/N	PROJECT	HOLE DIA	THICKNESS	HOLE DIA	WIDTH	DEPTH	THICKNESS	THICKNESS
1	SNOWFLAKE	EX170458	P640-01	0.0260	0.0368	0.0130	0.0110	0.0110	0.0184	0.0662
2	GMA-1109	EX170806	P131-81	0.0260	0.0368	0.0130	0.0150	0.0150	0.0184	0.0702
3	SQUARE	EX170807	P131-81	0.0260	0.0368	0.0130	0.0130	0.0130	0.0184	0.0682
4	ROUND	EX170808	P131-81	0.0260	0.0368	0.0130	0.0130	0.0130	0.0184	0.0682
5	ROUND-COM	EX170809	P131-81	0.0260	0.0368	0.0130	0.0200	0.0130	0.0184	0.0682
6	NAVAJO	EX170810	P663-40	0.0260	0.0368	0.0185	---	0.0110	0.0258	0.0735
7	NAVAJO-DIA	EX170811	P663-40	0.0260	0.0368	0.0185	---	0.0110	0.0258	0.0735
8	TIRE TREAD	EX170812	P663-40	0.0185	0.0262	0.0130	---	0.0110	0.0184	0.0555
9	FROSTALLO	EX170813	P131-81	0.0185	0.0262	0.0130	---	0.0150	0.0184	0.0595
10	SNOWFLAKE	EX170459	P640-01	0.0531	0.0751	0.0260	---	0.0220	0.0368	0.1339
11	TBD	TBD	P131-81	0.0260	0.0368	0.0130	0.0130	0.0130	0.0184	0.0682
12	TBD	TBD	P131-81	0.0260	0.0368	0.0130	0.0130	0.0130	0.0184	0.0682
13	TBD	TBD	P131-81	0.0374	0.0529	0.0185	0.0130	0.0185	0.0262	0.0976
14	TBD	TBD	P131-81	0.0260	0.0368	0.0130	0.0130	0.0185	0.0183	0.0735
15	TBD	TBD	P131-81	0.0260	0.0368	0.0130	0.0130	0.0092	0.0184	0.0643
16	TBD	TBD	P131-81	0.0260	0.0368	0.0185	0.0130	0.0130	0.0262	0.0759
17	TBD	TBD	P131-81	0.0374	0.0368	0.0185	0.0130	0.0185	0.0183	0.0735
18	TBD	TBD	P131-81	0.0260	0.0368	0.0130	0.0130	0.0130	0.0184	0.0682
19	TBD	TBD	P131-81	0.0260	0.0368	0.0130	0.0130	0.0130	0.0184	0.0682
20	TBD	TBD	P131-81	0.0150	0.0368	0.0130	0.0130	0.0130	0.0184	0.0682
21	TBD	TBD	P131-81	0.0130	0.0184	0.0130	0.0130	0.0130	0.0184	0.0498

Long Term Dynamic Oxidation and Corrosion Testing

During the last quarter of this task, candidate materials and coating systems were identified for blade or vane applications as shown in table 1. Dynamic oxidation testing is targeted to be a 5000 hour duration test conducted at 1900°F with metallographic sectioning at 500, 1000, 2666, and 5000 hours. Dynamic oxidation testing was initiated during this quarter with an accumulation of approximatly 300 hours. At the present time all pins are showing positive wieght gains indicative of an aluminum oxide buildup on the surface of the specimens. Problems with thermocouples have been a key issue in this test since there have been significant delays associated with thermocouple failures. This problem is being addressed with the highest priority, and several backup thermocouples have been fabricated to minimize delays. Testing will continue during all shifts to accumulate as much testing time as possible.

TABLE 1. Dynamic Oxidation Test Specimens

Material	Coating Type	Coating Material
CMSX-4	None	None
CMSX-4	Diffusion	AEP-246
CMSX-4	Overlay	NiCoCrAlY
CMSX-4	Diffusion	AEP-32
CM-186	Diffusion	AEP-246
CM-186	Diffusion	AEP-32

Hot corrosion testing will be performed on the materials and coatings shown in table 2. This is an accelerated test that is targeted for a total of 1000 test hours, which represents about 10,000 hours of engine operation. Testing will be conducted at 1650°F with 10 ppm salt/airflow volume and 1% sulphur addition within the combustion zone. All specimens were cast and machined during this quarter, and are expected to be coated early in the next quarter. Testing should commence during the first part of June..

TABLE 2. Hot Corrosion Test Specimens

Material	Coating Type	Coating Material
CMSX-4	None	None
CMSX-4	Diffusion	AEP-246
CMSX-4	Overlay	NiCoCrAlY
CMSX-4	Diffusion	AEP-32
CM-186	Diffusion	AEP-246
CM-186	Diffusion	AEP-32
CM-186	None	None
CM-186	Overlay	NiCoCrAlY
IN-738	Diffusion	AEP-32

Static Oxidation and Creep Rupture Testing

Static oxidation testing will be conducted on specimens shown in table 3. Specimens will be placed in a ceramic holding fixture and three furnaces will be used to generate data at 1900°F, 2000°F, and 2150°F. This test is intended to try and establish a correlation with the results from the dynamic oxidation data.

TABLE 3. Static Oxidation Test Specimens

Material	Coating Type	Coating Material
CMSX-4	None	None
CMSX-4	Diffusion	AEP-246
CMSX-4	Overlay	NiCoCrAlY
CMSX-4	Diffusion	AEP-32
CM-186	Diffusion	AEP-246
CM-186	Diffusion	AEP-32
CM-186	None	None
CM-186	Overlay	NiCoCrAlY

During this quarter all specimens have been cast and delevered to Joliet Metallurgical Laboratories for testing. Additional specimens were also fabricated to obtain basic physical property data for CM-186. Results of this testing will be combined with existing material data from the material supplier and used to generate design data for phase 3 of the ATS program.

TASK 8.4

QUARTERLY PROGRESS REPORT FOR PERIOD FEBRUARY 94 TO APRIL 94

Objectives: The task 8.04, **development of ultra-low NOx emissions combustor** was initiated during September. The effort comprised the following specific subtasks.

> > Combustor can and case sizing/air flow distribution,
> > Variable Geometry/Compressor Bleed Requirements,
> > Wall Cooling Scheme/Heat Transfer Analysis,
> > Fuel Staging Design (parallel/Axial), and
> > Kinetic Analyses/Definition of performance requirements.

Accomplishments: A simultaneous effort on several of the above subtasks is continuing with significant progress made on each.

Combustor can and case sizing/air flow distribution: The major focus has been on defining the flow-field inside and at an exit of the intra-combustor-turbine transition piece. The objective of this CFD effort is to optimize the transition duct cavity volume such that the combustor effluents yield uniform turbine inlet temperature and pressure profiles. The primary results of the analysis to-date are as follows:

> > A splitter plate placed at 180 degree helps uniformize the temperature/mass profile entering the turbine,
> > The flow is not found to separate anywhere inside,
> > An optimized cavity geometry/volume, that provides near-uniform temperature profile at the turbine inlet has been selected and the efforts at refining it further are underway.

Kinetic Analyses/Definition of Performance Requirements: The testing effort aimed at studying ultra-lean premixed kinetics has been initiated. During this testing the Radial Swirler Plus Nozzle (RSPN) premixer (developed under the DOE 9 ppm program) is being investigated as a possible candidate for the ATS combustion system. A systematic series of tests is being conducted to evaluate emissions characteristics in a scaled model combustor rig that permits first order determination of emissions sensitivity to combustor inlet pressure, temperature and residence time at ATS specific conditions. Allison's initial tests have yielded some encouraging results. For example, at combustor inlet conditions: $T3=1060$ F, and $P3=10$ atm the measured NOx and CO levels are less than 10 ppm and 20 ppm, respectively as measured at the combustor exit centerline. We have also observed occasional upstream flame propagation into the premixer, when the pressure drop across the premixer was below 2.5%. These single point measurements, although encouraging, do not represent the full combustor emissions characteristics. However, this single module testing is a rapid and cost effective approach to screen and verify the potential of this and the other lean premixed module designs. Allison is planning to investigate the emissions characteristics of a family of RSPN modules in future combustor rig testing.

Combustion induced pressure oscillations (combustion instability) may possibly inhibit successful development of LPM combustors; a concern equally shared by DOE also. A program plan aimed at mapping the thermoacoustic characteristics of an LPM combustor sector has been developed and will be reviewed with DOE.

Some of the earlier test results in Allison's 4 by 4 rig demonstrate a copious amount of CO being produced at some of the test conditions. The high CO production is caused by wall cooling air that quenches the CO oxidation. Allison is planning to fabricate a new combustion liner that will significantly reduce detrimental cooling air influence on CO oxidation.

Fuel Staging Design: In addition to RSPN module (as described above), three other lean premixing modules are being fabricated and will be tested in Allison's combustion test facility. The first design features a Two Radial Swirlers Plus Nozzle (TRSPN) concept with the flow splits (air and fuel) determined to be 15% through the smaller secondary swirler and 85% through the larger primary swirler. The other two designs feature variations in the original RSPN design such that enhanced mixing levels are achieved at the premixer exit. The hardware components (e.g. swirlers, nozzle etc), all have been fabricated and are being assembled for testing. The plan is to test the TRSPN module, first at ERC for mixing. Following the testing at ERC, the TRSPN module and the other two RSPN modules will be tested at Allison.

Program/Cost Schedule: During this quarter of the program, the expectation is to complete the preliminary designs of the LPM module and the full combustor can. This planned work schedule with time now line is shown in Figure 1. To this date, sufficient progress has been made to conclude that this task in on schedule. In addition, as shown in Figure 2, the actual cost schedule is also found to follow closely the planned cost schedule.

TASK 8.6

QUARTERLY PROGRESS REPORT
MAY 1994

Objectives: The overall objective of Task 8.06, Water/Air Turbine Cooling, is to perform a conceptual design to identify the requirements for incorporating this cooling concept in an engine and to experimentally determine the increase in cooling effectiveness that can be achieved. The specific objectives for this Quarter were:

- o Perform detailed design of impingement tube and adaptive hardware required for experimental cascade study
- o Utilize analytical design code to study sensitivity of airfoil surface temperature to design variables and use results to formulate experimental test matrix
- o Prepare and publish Test Plan
- o Begin fabrication of the experimental hardware
- o Begin preparing facility for cascade tests

Accomplishments: Significant progress was made on all the stated objectives for this Quarter. Early in the Quarter design activity focused on detailed design of the impingement tube. A number of iterations were performed to establish the recommended hole patterns. This process involved using the analytical design code to determine hole patterns for selected operating conditions and then reviewing the desired hole patterns to determine what changes are required from a manufacturing standpoint. This process is expected to result in impingement tube designs that will provide the desired heat transfer characteristics without encountering any significant fabrication problems. Initial activities on defining the details of the method of casting the thin-walled (0.020 in.) impingement tubes were begun in February, with the first tube successfully cast in March. The programming of the laser drilling equipment required to drill the impingement tube holes was completed in April and trial pieces were successfully run. Laser drilling of the thin walled impingement tube will be completed in May. In addition, a thick walled impingement tube was successfully cast in April. Successful casting of these two impingement tubes has validated the manufacturing technique and provides assurance that tubes will be readily available for the cascade tests.

Following completion of the impingement tube design, attention was turned to the design of the adaptive hardware required to install the airfoils and impingement tubes in the cascade test section. The initial design was completed late in April and a design review was held on April 27th. As a result of this design review some changes in the design of cascade adaptive hardware are being made to simplify the fabrication and assembly process. These changes will be completed in May, which will provide time to complete fabrication of the adaptive hardware prior to the time the airfoils are ready to assemble in the cascade.

Good progress was also made during this Quarter on fabrication of the airfoils required for the cascade. In February a solid airfoil of the proper contour was machined to serve as the master for the casting process. Existing ceramic cores were then reworked to meet the specifications of the airfoil designed for this cascade study. This rework included design changes that were made to the trailing edge region to add fins in the trailing edge discharge passage to eliminate hot spots predicted by the design code. The casting tooling was completed and two trial airfoils were cast in March. These first two trial pieces were of sufficiently good quality that they will be used for the outer two slave vanes in the three vane cascade. During April a third airfoil was cast. It appeared that it was of excellent quality, however a check of the profile revealed it deviated slightly from the design due to warping of the casting die. A new die was fabricated with a built in stiffener to eliminate the warping. Additional airfoils will be cast in May until one is obtained that is satisfactory for use as the instrumented center airfoil in the cascade.

During this Quarter the analytical design code was used to study the sensitivity of the vane wall temperature to the cooling design variables. These results were then used to define a test matrix for the experimental cascade study. This activity culminated in the submission of the Test Plan in April. The Test Plan calls for a minimum of five different impingement tube designs to be tested in the cascade to verify the optimum impingement tube geometry. Prior to testing in the cascade, the impingement tubes will be flow tested to characterize the water droplet patterns and flow. The cascade tests will be run at simulated engine conditions. During the cascade studies the water and air flow will be varied to determine the optimum air and water flow necessary to support the water-air cooling technology. Consideration will be given to a water delivery system that can be incorporated into a typical industrial engine. Results of this experimental study will provide data to design the full-scale vanes for the ATS engine.

Work began in March on preparing the Allison Aerothermodynamic Cascade Facility for the experimental program. The inlet transition duct will be refurbished to insure the accuracy of the data describing the inlet conditions to the cascade. The inlet transition duct surface instrumentation was replaced in April and work has begun on replacing the pressure and temperature rakes. This work will continue in May.

Program Schedule: The original schedule indicated that the conceptual design for the engine should have been completed late last year. The major portion of that effort was completed. However, the decision has been made to postpone completion of this activity until late in the program so the conceptual design can be "fine tuned" based on the results from the experimental study that is being performed. Thus, while this effort appears to be behind schedule, it actually will await availability of the experimental data before it is completed.

The pacing item on the schedule is the hardware for the cascade tests. With the excellent progress made during this Quarter, it is currently anticipated that this task will be completed on schedule.

Program Costs: Program costs are still below the planned level, but are accelerating with the increase in activity that is currently taking place. With manpower loading increasing in the areas of hardware fabrication and facility preparation, it is expected that the overall expenditure will shortly return to the planned levels. The costs to date are in line with the technical progress.

Corrective Action: No corrective action is required at this time.

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(11-84)

U. S. DEPARTMENT OF ENERGY
MILESTONE SCHEDULE ☒ PLAN ☐ STATUS REPORT

FORM APPROVED
OMB NO. 1901-1400

1. TITLE	2. REPORTING PERIOD	3. IDENTIFICATION NUMBER
ADVANCED TURBINE SYSTEMS PROGRAM CONCEPTUAL DESIGN AND PRODUCT DEVELOPMENT	INITIAL PLAN	DE-AC21-93MC29257

4. PARTICIPANT NAME AND ADDRESS	5. START DATE / 6. COMPLETION DATE
Allison Gas Turbine Division, General Motors Corporation P. O. Box 420 Indianapolis, IN 46206 - 0420	5. START DATE: August 3, 1993 6. COMPLETION DATE: February 3, 1995

7. ELEMENT CODE	8. REPORTING ELEMENT	9. DURATION (1993: A S O N D; 1994: J F M A M J J A S O N D; 1995: J F; FY; FY)	10. PERCENT COMPLETE a. Plan	10. PERCENT COMPLETE b. Actual
P13101	Task 1	Plan; Present at DoE	100	100
P13102	Task 2	NEPA; Report	100	100
P13103	Task 3	Select GFATS; Report	100	100
P13104	Task 4	Conversion to coal fuel; Report	5	0
P13105	Task 5	GFATS market survey; Report	5	0
P13106	Task 6	GFATS system definition & analysis; Report	10	10
P13107	Task 7	Integrated Program Plan; Draft; Final	0	0
P13181	Task 8.1	Castcool®; Plan; Radiant test; Long Term Material property; Rig test; Analysis; Report	25	15
P1318T & P1318B		2600°F Turbine test	0	0
P13184	Task 8.4	Low emissions; Plan; LPM bench test; Catalytic test; LPM test; Downselect; Report	10	10
P13185	Task 8.5	Active turbine tip clearance; Plan; Design; TASK CANCELLED	0	0
P13186	Task 8.6	Liquid/air turbine cooling; Plan; Design; Fabricate; Test; Analysis; Report	30	20
P13109	Task 9.0	Program management; Final report	45	45

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Figure Allison ATS program schedule (Rev A).