DOE/MC/29257 -- 4018
(DE95000088)

Advanced Turbine Systems Program Conceptual Design and Product Development

Quarterly Report
November 1993 - January 1994

January 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

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, 175 Oak Ridge Turnpike, Oak Ridge, TN 37831; prices available at (615) 576-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161; phone orders accepted at (703) 487-4650.

DISCLAIMER

DOE/MC/29257 -- 4018
(DE95000088)
Distribution Category UC-111

Advanced Turbine Systems Program Conceptual Design and Product Development

Quarterly Report
November 1993 - January 1994

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

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

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

January 1995

QUARTERLY TECHNICAL REPORT-NOV 1993 TO JAN 1994

SUMMARY--GENERAL

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

Task 3, selection of the Allison GFATS, is complete. A summary of the results of this task was presented to DoE representatives on Feb. 3, 1994 at Morgantown. Allison has selected an aeroderivative configuration which can meet all ATS requirements and be a significant factor in a large segment of the industrial engine market. Allison has developed preliminary designs for a family of engines based on this ATS candidate which cover the 4-10 MW power class market. An engine family concept with minimal hardware changes between family members is required in order to maximize market penetration. This engine, when developed as a family of engines, provides an excellent return on the Allison and DoE investment. The selected ATS engine also provides the customer with an internal rate of return on investment (IRR) improvement of +5 points (+17%) in cogeneration and +7 points (+37%) in electric power generation over Allisons current 571 state-of-the-art engine. These improvements will boost the competitiveness of American industry and provide jobs in both the using industry as well as in the industrial turbine manufacturing segment.

Task 8.1, Castcool technology development for industrial engines, now has a detail test plan. 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 approximately 50% complete. A preliminary oxidation test run under other funding to help select materials, doping levels and coatings is nearly complete. This test result will establish our final materials choices. Intensive testing of these samples will begin in March. This puts us about 1 month 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 added an additional in-house test within current funding to validate the codes making this prediction. This test will make use of existing hardware from the 9ppm NOx program. CFD analysis of the transition duct from combustor to HPT has been initiated. Space claim for this component will be critical in the engine design phase.

Task 8.5, active turbine clearance, is now proceeding well after initial schedule difficulties. Trade studies have been completed which resulted in definition of a configuration for test. The two keys to success of such a system are the ability to move a shroud <u>concentric</u> to the turbine rotor and to be able to seal the required shroud activation hardware from the flowpath without leaks or use of significant amounts of cooling air. The test rig chosen will allow proof of the concepts chosen to accomplish these key items. This task is approximately 1.5 months behind schedule but we have not impacted the completion date.

Task 8.6, water vapor/air mixture 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. This task is approximately 1.5 months behind schedule but we have not impacted the completion date.

DoE requested and Allison delivered Preliminary Integrated Program Plan data on Jan. 28, 1994. This document included cost, schedule and a narrative program plan. This was a precursor effort to Task 7 of this contract--Integrated Program Plan.

General Motors, former owner of Allison, has sold this division to a management-led group of investors. The sale was completed as of Dec. 1, 1993. We are now known as the Allison Engine Company or simply Allison.

The only program difficulties to arise during this 3-month period occurred with tasks 8.5 & 8.6. These two tasks required significant up-front design effort and the required manpower was not immediately made available to these two projects. The Monthly Reports for this time period document both the problems which arose and the steps taken to solve the problem. Adequate manpower has now been assigned but a behind-schedule position exists which will have to be made up.

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 with the exception of Allison internal management reviews of the selected system. 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. The airflow size of the selected compression system provides the basis for achieving a family of engines between 4 and 10 MW power class; the industrial market with the highest potential sales volume. The following is a description of this family of flight engines from which Allisons ATS family will be derived;

-**T406/AE 2100/AE 3007 FAMILY:**

Allison has developed an engine core which has broad application in various markets including military systems such as the Bell-Boeing tiltrotor and C-130 cargo aircraft and commercial applications such as the Saab 2000 50-Passenger regional turboprop aircraft and a Cessna business jet. This core engine has been in development for nearly 10 years and has reached a very high level of maturity. Modifications to this basic compression system will be required to adapt it to the industrial marketplace but the aerodynamics are fully characterized.

A high temperature turbine with 2800 F TRIT capability at flight rated takeoff is currently under development for this basic core compressor. Turbine technology is key to success of the ATS system and this ongoing Allison IR&D work will blend in smoothly with ATS requirements. Again, modifications to this basic flight engine HP turbine design for the industrial marketplace will be required but since the basic design fits the compression system chosen for ATS these modifications will be of a mechanical design/process development nature and not basic redesign.

This choice of compression system and engine family provides an excellent basis from which Allison can proceed directly to an 8000 hour demonstration of a product beginning in 1998 and ending in the year 2000

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 TASKS 4, 5, 6, 7

Tasks 4,5, & 6, the Coal Conversion task, the Market Survey and the GFATS Engine Design are scheduled to begin immediately at completion of Task 3. These tasks have been kicked off as of Feb. 1, 1994. Task 7, the Program Planning task is scheduled for begin late in the program.

ATS TASK 8

The four subtasks under Task 8 are kicked off as desired. Very good progress is now being made on all four subtasks. Design engineering and drafting are now supporting all tasks fully after initial start-up problems. Good progress is being made in all areas although we still have a slight behind schedule position in several areas. The following are summaries of progress made in each of the four subtasks.

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.

Castcool® thermal effectiveness testing

Definition of the test matrix as shown in figure 1 was completed during this quarter. This matrix focuses upon the critical variables used within our castcool® design optimization system. Five of these twenty one specimens will be fabricated using other Allison IR+D funds since the matrix is still somewhat large for funds available within this program. The five specimens that are most pertinent to other castcool® development efforts will be fabricated and tested under other IR+D programs, but included within the ATS matrix. This will assure that sufficient data is available to fully characterize castcool® internal thermal effectiveness. Drawings for the first nine of these specimens were completed and released for fabrication. 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 this quarter of this task, candidate materials and coating systems were identified for blade or vane applications. Materials and coatings shown in table 1 were selected based upon expected operating temperatures, expected required design lives for an industrial application, and potential cost implications. Both materials selected offer excellent stress rupture capabilities, and CM-186 provides a lower cost alternative to the single crystal CMSX-4. Although it would have been desirable to evaluate several other coatings and materials, additional specimens can not be evaluated due to rig limitations. Dynamic oxidation testing is targeted to be a 5000 hour duration test at 1900°F with metallographic sectioning at 500, 1000, 2666, and 5000 hours. The dynamic oxidation rig has successfully demonstrated continuous 24 hour (unattended) operation, which is a key element in achieving the 5000 hour test duration. In the past, the lack of failsafes within the test facilities required attended operation up to a maximum of about 15 hours per day. All CM-186 specimens have been cast, and enough CMSX-4 specimens have been cast to initiate testing. CMSX-4 specimens under another Allison program are currently undergoing dynamic oxidation testing for various compositions. As the results become available, the most desirable composition (design, manufacturability, and cost considered) will be selected for test.

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 CM-186 specimens for this test have been cast, and CMSX-4 specimens will be cast as soon as dynamic oxidation results are available for various CMSX-4 compositions currently in test. Like the dynamic oxidation testing, the number of specimens for corrosion testing is limited by rig capabilities.

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

Limited material property data on both CMSX-4 and CM-186 is available from the supplier of the basic materials (Cannon Muskegan). Allison and the supplier have agreed to share the cost of this testing to provide us with as much test data as possible without duplication of testing currently in progress by the material supplier. It is planned to test both CMSX-4 and CM-186 to generate .5%, 1.0%, and 2.0% creep, and stress rupture curves. CMSX-4 will be tested at 2000°F at stresses ranging from 7.3 to 11.5 ksi, and CM-186 will be tested at 1900°F at stresses ranging from 9.0 to 21.5 ksi. Testing will be conducted at Joliet Metallurgical Laboratories in Joliet, Illinois. 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.

QUARTERLY PROGRESS REPORT FOR PERIOD NOVEMBER 93 TO JANUARY 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: Initial combustor can for the preliminary ATS cycle has been sized. The computed combustor volume is of the order of 1 ft^3, with the combustor loading parameter being 0.011 pps/ft^3 , at full power conditions. The corresponding combustor reference velocity is 130 fps resulting in combustor residence time of 10 msec. For the assumed combustor dome pressure drop of 3%, the combustor flow factor is computed to be 4.86757. This results in 0.1776 ft^2 , for the combustor effective flow area.

Two parallel and one series fuel staging schemes are being investigated for the ATS combustor. The parallel staging scheme would require a total of 28 premixing modules. A fuel staging scheme for these modules has also been developed. The scheme identifies a cluster of premixing modules, in five stages, which will be successively fueled as the engine transits from idle to full power. The series fuel staging would require three axial stages. They will be fueled successively as the engine transits from idle to full power.

The efforts at integrating the combustion system with rest of the engine components are continuing. The preliminary ATS engine/combustor integrated system design has been developed, flow fields defined and pressure drops evaluated. A new revised version of the ATS cycle has also been developed. The efforts at re-sizing some of the combustor parameters at the new revised cycle are continuing.

The overall airflow distribution budget has also been determined. A salient outcome of the analysis is that the combustor airflow ($W_{3.1}$) of 46.173 pps may not be adequate both for the desired lean combustion, and for transition piece cooling.

A detailed geometrical definition of the transition piece has been completed and the efforts are underway to define the aerodynamic flow field inside.

Kinetic Analyses/Definition of Performance Requirements: The Sandia laboratory developed chemical kinetic code (CHEMKIN) has been made operational on Allison's computing system, and has been validated against published lean premixed combustor data. In order to establish its full potential at defining kinetic performance of a practical combustor; a need to verify the code against practical lean premixed combustor data is indicated. Test plans are underway to test one of the Ultra Low NOx (nine ppm) combustor modules at Allison. The objective of these tests will be to parametrically vary combustor operating pressure and combustor residence time (ΔP across the dome), and acquire benchmark quality emissions data for the code validation.

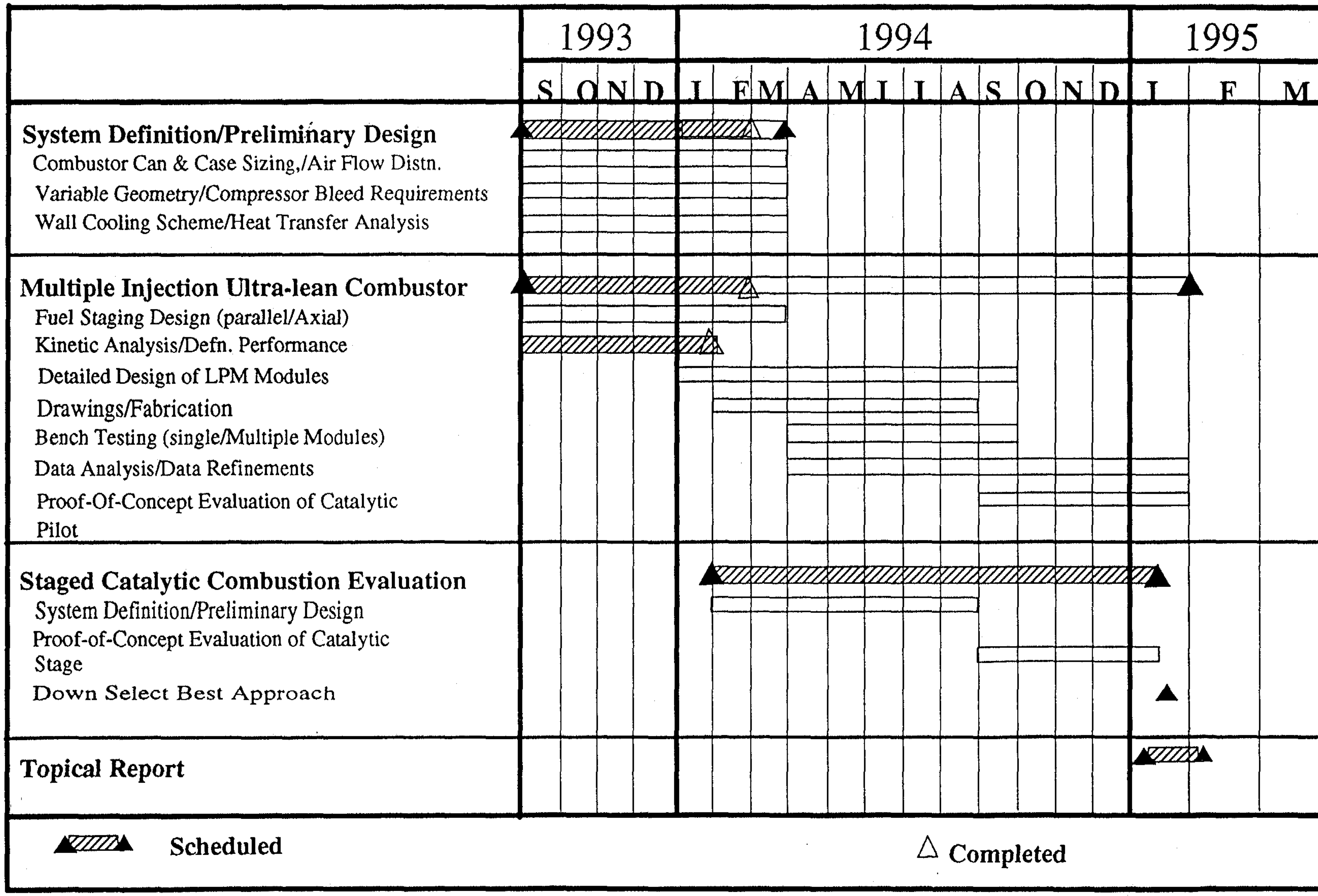
Combustion induced pressure oscillations (combustion instability) has been identified as a possible concern for LPM combustion systems by DOE. A program plan aimed at mapping the thermo-acoustic characteristics of an LPM combustor sector has been developed and will be reviewed with DOE.

Fuel Staging Design: Preliminary layouts for the two parallel premixing modules have been developed. In addition, CAD2B (A 2D Viscous Code) models of these modules have been developed with the objective of evaluating their mixing potential at full power conditions. The plan is to develop an optimized premixer design, and then fabricate these modules using Allison's Rapid Prototype Fabrication technology prior to sending them out to Energy Research Consultants (ERC) for testing.

Wall Cooling Scheme/Heat Transfer Design: The transition piece, quasi-1D heat transfer analysis has been completed. Four wall cooling schemes were analyzed. These include: Backside impingement cooling, TBC coating with and without effusion cooling, CMC (Compliant Metal Composites) with and without cooling, and SiC/SiC composites without cooling. The analysis led to the conclusion that CMC with 1.5% cooling (at CDP temperature), or SiC/SiC wall, without cooling, could be the viable options for the transition piece liner.

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.

ATS Task 8.04: Ultra Low NOx Emissions Technology
1993-1995



10

Quarterly Report for November, December and January 1994

Active Turbine Blade Tip Clearance Control System

Objectives: Task 8.05 is to develop an active turbine blade tip clearance control system where the case is moved in the axial direction relative to tapered turbine blades. By controlling to reduced blade tip clearances the turbine performance will be enhanced and tip rubs that normally degrade performance will be eliminated. The specific objective for this three month period was to design the hardware for the 4X4 combustor rig and begin fabrication of hardware. Several changes were made in the original plan to directly address issues of accommodating the Active Turbine Tip Clearance in industrial engine designs. First of all, several alternate approaches for the ATCS were drawn for engine application. This directed the rig design towards a more general approach that could accommodate for changes without a complete redesign. This should remove a great deal of risk from the program. The plan was also changed to include a magnetic actuation system that Allison has experience with for magnetic bearings and for compressor active tip clearance control. This also removes risk from the test program. The original plan to test on a bench with temperatures of 1200 deg F was changed to testing in an existing combustor rig at 2600 deg F to reduce risk for the engine design.

The program changes while improving program value and reducing risk has resulted in a two month delay in this 18 month program.

Accomplishments: Several design approaches were investigated including using guide pins for the shroud and air to actuate the blade shroud in the axial direction. It was finally decided that a double shim pack arrangement would be used to support the blade shroud and allow the axial freedom. A model was fabricated to further verify the design approach. Shim packs are commonly used for high speed couplings where precise positioning of the center spool is required.

Magnetic pan style actuators were selected over linear magnetic actuators and air pistons. Air pistons may be suitable for an on-off system but air compressibility is a problem for precise axial control. Linear actuators are precise controllers but are more practical for larger displacements. For this application a pan style magnetic actuator was selected because it was smaller, easier to control for precise axial control, and was within Allison's experience for designing magnetic bearings.

Another change was to separate the ATCS module into three cooling zones. The upstream and downstream chambers are pressurized separately so that temperatures can be better controlled and flow can be minimized. In addition, the magnetic actuator will have a third separate cooling chamber.

These changes, although resulting in the current 2 month delay in the program reduce risk which will allow Allison to catch up during the test phase and still finish on schedule.

The design layout of the ATCS module is now complete and the design layout of the adaptive 4X4 combustor rig hardware is expected to be completed in February.

Some preliminary estimates were made to determine a performance benefit for control of the 570 1st stage turbine clearance. It was estimated this feature would be worth $60,000 for this engine in terms of higher power output. Reduced SFC are an additional long term benefit.

Program/ Cost Schedule: The program is two months behind the original schedule with some additional unplanned cost to address some initial design concerns. Current updated cost based on the present design layout show that the program can still be completed on schedule and within budget. The initial risk reduction effort should therefore benefit the program without effecting the ultimate program completion on time and within budget.

Required Corrective Actions: Now that the design has become solidified the program effort can be intensified to regain lost time. Several parts will be made in the research machine shop to further expedite the program. The test program is also expected to be shorter than originally planned because less risk is present in the final design.

QUARTERLY PROGRESS REPORT
FEBRUARY 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 Complete a conceptual design of a water/air cooled first stage turbine vane, including provisions within the engine for supplying water to the airfoil
- o Select the airfoil profile to be tested and identify the relevant variables for the experimental program
- o Design the hardware required for the experimental program
- o Begin fabrication of the experimental hardware

Accomplishments: With respect to the conceptual design, the major portion of the activity was completed this quarter with only one detail remaining to be completed. Initial efforts on the conceptual design focused on selecting an airfoil shape that would be typical for the engines under consideration in this program. After reviewing the available candidates, the "1109" airfoil was selected for both the conceptual design and the experimental studies. This airfoil is typical of the designs that are being considered under this program. In addition, Allison has considerable experimental data on a film cooled version of the airfoil and is currently performing experimental studies of a Castcool[R] version of the airfoil. This extensive data base will provide an excellent basis for evaluating the cooling performance improvements that can be achieved with the water/air turbine cooling technique. Efforts completed on the conceptual design include selecting the size and hole patterns for the impingement tube and the design of the pin fin arrangement in the trailing edge of the airfoil. In addition, the water delivery system has been designed. The concept utilizes a manifold system external to the engine case with supply lines to each vane. A nozzle will be located at the inlet to each impingement tube to provide the atomized water spray to each airfoil. Selection of appropriate nozzles is the only item in the preliminary design that has not been completed. Discussions are currently underway with a nozzle vendor to select a nozzle to provide the desired spray pattern to provide uniform water distribution within the airfoil. This conceptual design study has demonstrated the feasibility of incorporating this cooling technique in an engine.

Relative to the experimental program, progress this Quarter included conversion of an analytical model to define the relevant experimental variables and the test matrix. This model was originally configured for the design of fuel/air cooled turbine blades, where the mixture was exhausted out the blade tip. During November, the code was rewritten to handle turbine vanes with trailing edge discharge of the type being studied in this program. The airfoil profile selected in the conceptual design was then programmed into the code. During December the code was used to design the hole patterns on the impingement tubes and to identify the expected effects of the experimental variables, thereby providing information to assist in defining the test matrix for the experimental studies. Figure 1 shows the significant improvement in surface temperature gradients that can be achieved by changing the impingement tube design from a uniform hole pattern to one with a pattern matched to the local heat flux. This case was run for a 2600 ^{o}F RIT with 3% cooling air and 0.10 water/cooling-air mass flow ratio.

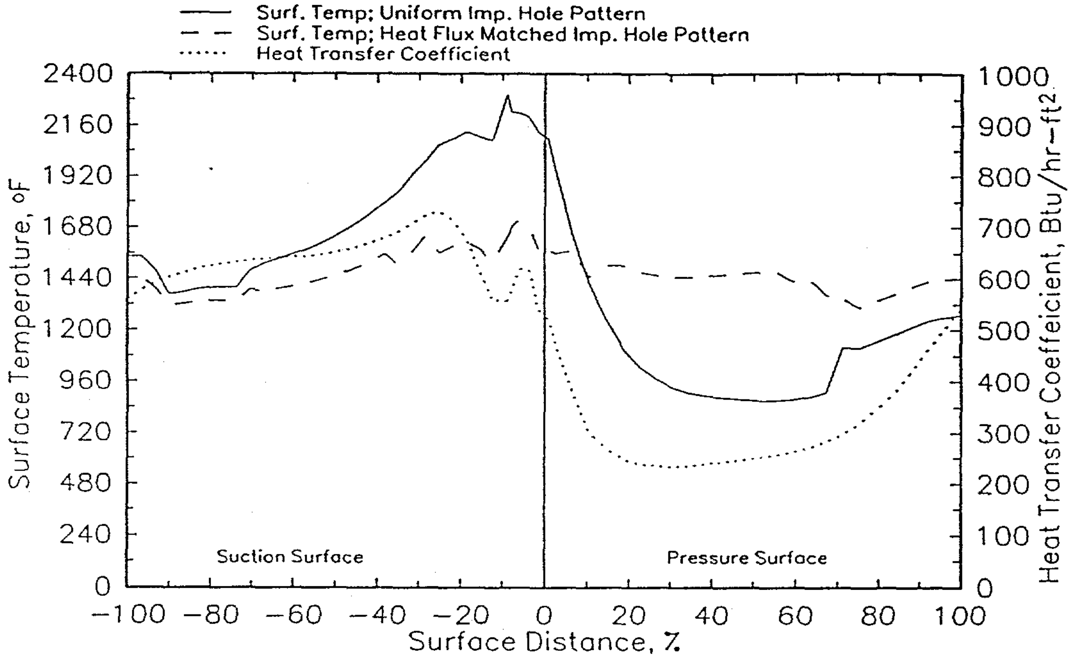


Figure 1. Early predictions of the first order model applied to the water/air cooled vane.

During January the analytical design code was used to estimate the water and air flow rates that will be required in both the engine and in the experimental cascade test. These results were then used to size the nozzles, tubes and manifolds for both applications. These analytical results also provided initial data to begin developing the test matrix that will be studied experimentally.

Activities began in January on design and fabrication of the hardware required for the experimental effort. With the airfoil contour having been firmly established, selection of the method for fabricating the airfoil was reviewed this month. It appears that modifications can be made to existing tooling that will permit the basic airfoil to be cast in a reasonable period of time. Fabrication of the hardware will be the pacing item relative to maintaining the overall schedule for this task. Work began on the tooling late in the month, and will continue into February.

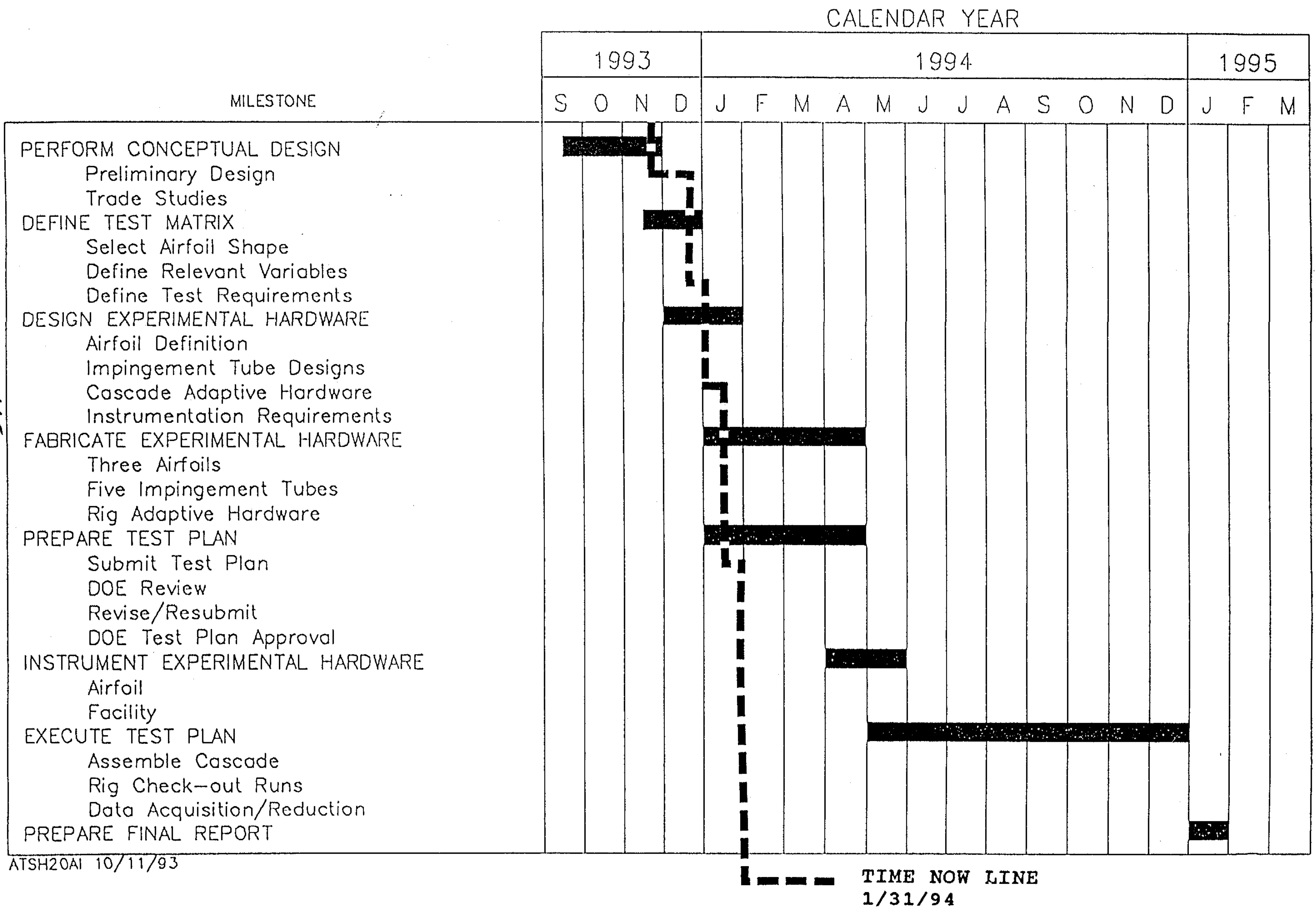
Program Schedule: The conceptual design study was scheduled to have been completed by this time, but still is not quite complete. This schedule slippage is partially due to a significant interaction between the conceptual design activity and the experimental rig design activity. This combined effort will provide better overall program results. Since the conceptual design is not a pacing item, this slippage will not impact the overall program schedule. The balance of the efforts on this task are progressing satisfactorily.

Program Costs: Expenditures on this task are less than planned due to schedule slippage in the conceptual design effort. As stated previously, this is not a pacing item, and expenditures will align with the plan as this task is completed. Thus no effect on overall program costs is expected.

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

ADVANCED TURBINE SYSTEMS (ATS) PROGRAM

TASK 8.06 -- WATER/AIR TURBINE COOLING



DOE F 1332.3
(11-84)

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

FORM APPROVED
OMB NO. 1901-1400

1. TITLE ADVANCED TURBINE SYSTEMS PROGRAM CONCEPTUAL DESIGN AND PRODUCT DEVELOPMENT	2. REPORTING PERIOD INITIAL PLAN	3. IDENTIFICATION NUMBER DE-AC21-93MC29257
4. PARTICIPANT NAME AND ADDRESS 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)	10. PERCENT COMPLETE a. Plan	b. Actual
P13101	Task 1	Plan; Present at DoE	80	80
P13102	Task 2	NEPA; Report	0	0
P13103	Task 3	Select GFATS; Report	0	0
P13104	Task 4	Conversion to coal fuel; Report	0	0
P13105	Task 5	GFATS market survey; Report	0	0
P13106	Task 6	GFATS system definition & analysis; Report	0	0
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	0	0
P13184	Task 8.4	Low emissions; Plan; LPM bench test; Catalytic test; LPM test; Downselect; Report	0	0
P13185	Task 8.5	Active turbine tip clearance; Plan; Design; Fabricate; Install; Test; Report	0	0
P13186	Task 8.6	Liquid/air turbine cooling; Plan; Design; Fabricate; Test; Analysis; Report	0	0
P13109	Task 9.0	Program management; Final report	5	5

TE93-1716-4

Figure 2. Allison ATS program schedule.