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**Industrial Advanced Turbube Systems:
Development & Demonstration**

**Quarterly Report
July 1 - September 30, 1997**

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE) has initiated a program for advanced turbine systems (ATS) that will serve industrial power generation markets. The objective of the cooperative agreements granted under the program is to join the DOE with industry in research and development that will lead to commercial offerings in the private sector. The ATS will provide ultra-high efficiency, environmental superiority, and cost competitiveness. The ATS will foster (1) early market penetration that enhances the global competitiveness of U.S. industry, (2) public health benefits resulting from reduced exhaust gas emissions of target pollutants, (3) reduced cost of power used in the energy-intensive industrial marketplace and (4) the retention and expansion of the skilled U.S. technology base required for the design, development and maintenance of state-of-the-art advanced turbine products.

The Industrial ATS Development and Demonstration program is a multi-phased effort. Solar Turbines Incorporated (Solar) has participated in Phases 1 and 2 of the program. On September 14, 1995 Solar was awarded a Cooperative Agreement for Phases 3 and 4 of the program (DE-FC21-95MC31173) by the DOE's Office of Energy Efficiency and Renewable Energy (EE). Technical administration of the Cooperative Agreement will be provided from EE's Chicago Operations Office. Contract administration of the Cooperative Agreement will be provided from DOE's Office of Fossil Energy, Federal Energy Technology Center (FETC).

Phase 3 of the work is separated into two subphases: Phase 3A entails Component Design and Development; Phase 3B will involve Integrated Subsystem Testing. Phase 4 will cover Host Site Testing. The cooperative agreement funding is separated into three budget periods. Budget Period 1 expires March 14, 1998.

2.0 SUMMARY PROGRAM ASSESSMENT

2.1 Estimate at Completion

Forecasts call for completion of the program within budget as originally estimated. Scheduled completion is forecasted to be approximately 3 years late to original plan. This delay has been intentionally planned in order to better match program tasks to the anticipated availability of DOE funds. To ensure the timely realization of DOE/Solar program goals, the development schedule for the smaller system (Mercury 50) and enabling technologies has been maintained, and commissioning of the field test unit is scheduled for May of 2000. The development schedule for the larger system (ATS-L) has been delayed to accommodate the funding shortfall without undue impact to near-term program goals, with commissioning of the field test unit planned for March of 2002.

Significant efforts were spent this quarter to reforecast and control expenditures due to Solar's and DOE's current funding and resource constraints. Selective reductions and delays in program activities were identified and implemented. Although these actions will increase technical risk and the attainment of stretch goals, it is not anticipated that the schedule for initial test units or the attainment of basic program performance requirements will be impacted.

2.2 Overall Assessment of Performance

As of the end of the reporting period work on the program is 22.80% complete based upon

milestones completed (16.04% last quarter). This measurement is considered quite conservative as numerous drawings on the Mercury 50 are near release. (In order to main objectivity in assessing schedule progress, Solar uses a 0/100 percent complete assumption for milestones rather than subjectively estimating progress toward completion of milestones.) Variance information is provided in Section 4.0- Program Management.

Mercury 50: Work this reporting period has focused on the release of long-lead, critical part drawings. As is usually the case with programs involving any major turbine design, stages 1 and 2 blades and nozzles are pacing items and are consuming a large portion of the design resource.

Design reviews held during the quarter are listed in Table 1. Each of the reviews resulted in positive suggestions for design improvements (mechanical integrity or cost); none were sufficient to impact the engine schedule.

Good progress has been made on the release of compressor parts during this reporting period, there being only two remaining stages of blades and disks left to release to the suppliers. The aft hub is the only remaining critical compressor part of significance.

The latest estimate of engine drawing completion is 45-50%.

Subassembly / Component	Date
Stage 1 Blade and Disk	15 August
Stage 1 Nozzle	27 August
Catalytic Combustor	05 Sept

Table 1. Mercury 50 Design Reviews

The status of preliminary drawing issuance is summarized in Table 2. In order to maintain an aggressive schedule, Solar design engineers, manufacturing engineers and suppliers work concurrently based upon various levels of controlled preliminary drawings (CPDs) rather than working in serial manner based on the formal release of final drawings. The table includes only CPDs at purpose codes sufficient to allow tooling to be built or hardware to be procured.

CPD's Issued in Prior Quarters	103
CPD's Issued this Quarter	113
Total CPD's Issued to Date	216

Table 2. Mercury 50 Controlled Preliminary Drawings

Tooling orders are also accelerating in order to support engine and rig build dates, as summarized in Table 3.

Tools Ordered in Prior Qtr	47
Tools Ordered in This Qtr	113
Total Tools Ordered to Date	160

Table 3. Mercury 50 Tooling Orders

Solar received three development gear box housings this quarter, which were machined and delivered to assembly at Kearny Mesa. Kearny Mesa Assembly has completed the assembly of one gear box and delivered it to Superior Gear for test.

Twelve compressor case casting halves have been received and are awaiting the machining design release. The first development nozzle support forging was received, which will be used for machining development at the supplier. This first part is a Haynes 242 alloy and will be reserved for future testing.

Howmet is building casting tools for the first stage nozzle, second stage nozzle, first stage blade and second stage blade. Texas Steel built the patterns for the combustor end cover and the forward and aft end plates on the center frame. Many castings and forgings are scheduled to arrive during the next quarter.

Rigs and Technology Development: Work on the test rigs and in the enabling technology development programs is also progressing well. Highlights in this area include:

- Completion of validation testing on upscaled nozzle film cooling rig.
- Construction of housing and end cover for combustor test rig.
- Assembly of first injector for combustor test rig.
- Completion of stage 1 nozzle flow tests on turbine test rig.
- Construction of Vortex cooling heat transfer rig at University of Utah
- Mechanical testing and inspection of Vdimet 720 disks for first two engines. Test Results exceeded creep and rupture life targets.
- Completion of vacuum die cast process and receipt of test bars.

ATS-L: An engine concept design review was held on 10 July. Preliminary design proceeded with considerable effort spent on investigating alternative combustor designs. A preliminary design review is anticipated by year end.

Commercialization: Meetings were held in Rochelle, Illinois and at Solar's San Diego

facilities to pursue locating the Mercury 50 field demonstration unit within the Rochelle Municipal Utilities' service district. An announcement of the host site is anticipated in the upcoming reporting period.

3.0 TECHNICAL PROGRESS BY TASK

3.1 Mercury 50 Engine and Package

WBS 10200: Engine Design

Task complete.

WBS 10300: Package Definition

A design review was held in early September to status the package design effort and to ensure that the overall system schedule will be supported. As of that meeting the following subjective estimates of completion were made: frame design - 60%; recuperator support structure - 25%; lube oil system - 75%; gas fuel system - 50%; air assist system - 50%; and electrical packaging - 25%.

This quarter saw comprehensive development of detail design for the package with a focus on engine assembly removal from the forward end. The air inlet duct and the relief valve system design were completed.

WBS 11100: Air Inlet System

The inlet muff drawing has been fully reviewed with the supplier (Ketema) during this reporting period. Several minor changes have been requested to simplify the fabrication of this part. After a number of aerodynamic CFD (computational fluid dynamics) iterations based on preferences from Package Design, the air inlet duct configuration was accepted by all parties concerned, with minimal pressure loss compared with original designs.

WBS 11200: Compressor Assembly-Mercury 50

Compressor Static Structure: Detail design of static hardware has progressed well during this reporting period.

Preliminary machining drawings for the air inlet housing, compressor case and compressor discharge were issued for hardware procurement. #1, #2, and #3 bearing housing casting drawings were also issued and parts were ordered. Some changes to the datum system have been requested by Manufacturing relating to the compressor discharge machining drawing. These changes will be made, and the drawing will be reissued.

The inner diffuser assembly has been issued to allow fabrication of this part. The outer diffuser assembly is also being detailed. Oil seals for the #1 bearing housing have been issued.

The outlet guide vane (OGV) went through a couple of major iterations during this reporting period. Product cost considerations played an important role in the final design selection. The inner diffuser casting and the semi-machined stator ring were redesigned accordingly. Changed castings will support the first few engines with extra machine time required.

Casting drawings for the IGV, VGV1, and VGV2 have been issued for part procurement. The stator vane 6 drawing has been issued for tooling. Stator vane design is complete for stages 7 and 8, and drawings are in the process of being created at Agilis.

Variable Guide Vane Actuation System: During this reporting period the layout of the vane actuation system has been completed. Drawings for the IGV, 1st stage and 2nd stage vane actuation rings were issued to initiate tooling. Two of the three rings have been designed similar to existing Solar engines, and the 2nd stage will be manufactured using tooling common with the IGV and 1st stage rings. No new tooling will be required for any of the rings. The supplier has reviewed the design and given feedback, which facilitated manufacturing processes.

Prototype components for the new variable vane shaft design were fabricated by the current vane supplier and are in transit to Solar. Availability of prototype test pieces will speed up the release of machined vane drawings.

Casting drawings for the IGV inner guide vane ring have been issued. The interface with the air inlet housing, the 1st stage compressor disk, and the inlet guide vane have been worked sufficiently to allow the supplier to proceed with the machining of the inner ring. Sufficient latitude has been incorporated in the design to allow for future potential changes without having to delay component delivery.

Compressor Rotor: Issuance of blade drawings progressed well during this reporting period. Drawings and electronic data for compressor blades 1 and 2 have been issued to the new forging supplier. Blades 3, 4, and 5 castings were received, and the first article inspections were completed for these blades. Some minor issues were evident relating to the chord width and platform contour profile; however the airfoils themselves were excellent in quality. The first metal samples of blade 6 castings were completed. Casting drawings of blades 7 and 8 were recently issued to the supplier. The machining supplier was recently chosen for blades 3 through 10.

Disk and spacer drawings were also worked vigorously during the last reporting period. Disk assembly drawings for tooling purposes were issued for stages 1 through 9. The forward and aft hub semi-machined drawings were completed and issued.

WBS 11300: Combustor Assembly

Combustor Case: The endcover castings were received from Texas-Steel. These two castings will be used for the combustor rig testing. Also, the combustor housing casting drawing was released to Wisconsin Centrifugal enabling tooling fabrication.

A visit was made to the machining supplier, Major Machining, to review the endcover and housing machining drawings in detail. Many suggestions were made based on Major's experience with Solar parts. Most of these suggestions have been incorporated into the drawings.

A material test plan has also been conceptualized. This will involve testing 347 stainless steel keel bars for creep and fatigue properties. Test samples will then be removed from an endcover casting. These will be correlated to the keel bars. These tests will be used to verify design margins.

A 3D elastic/plastic analysis of transient thermal and static loads was completed for engine startup to shutdown. These results have been compared to the original 2D analyses and to standard ASME Boiler Code. Several areas of high stress concentration were identified which necessitated the introduction of an additional heat shield to buffer the thermal gradients during the engine transients.

WBS 11400: PSR Section

A design review was held with recuperator manufacturing in July. The core, air inlet and outlet ducts, gas inlet and outlet ducts, mounts, thermally balanced restraint system (TBRS), end beam and mount drawings were reviewed by manufacturing.

Final assembly drawings completed and are undergoing final check.

Factory assembly of a Solar prototype core is in progress. All air cells have been manufactured for that core, and core assembly is in progress.

Transient structural analyses during start up of the recuperator are being performed. Preliminary results have shown that the air'out duct tee is excessively stressed. The high stresses are due to thermal gradients that occur during start up. Structural supports are being redesigned to alleviate the thermal stresses that develop.

Sample welds of the tee to core weld were fabricated and analyzed. The analysis revealed poor penetration due to the difference in thickness of components. Modification to the weld preparation of the tee and the resulting impact on the structural integrity is being analyzed.

TBRS stud stress analysis was performed to validate change in thread. Gas ducting deflection analysis was performed to verify the clearance of stiffener tube during operation.

WBS 11500: Fuel System -Mercury 50

Ultra lean premix (ULP) combustion system: The majority of the drawings for the ULP combustion system assembly and the annular combustion test rig were released during this last reporting period for the manufacture of combustion development hardware. The combustion liner hole patterns have still not been fully defined but liner drawings were released to the allow design and manufacture of the required tooling.

A decision was made to modify and use Centaur 40 fuel manifolds for the Mercury 50 engine. CFD and flow modeling work has been continuing to support definition of the injector plenum air deflector baffle. Other sheet metal parts which go into the injector plenum, i.e., the air flow baffle and end plate heat shield are still being worked.

The injector design was released, but certain key dimensions will not be fully defined until test results from the prototype injector are obtained.

Concerns relating to the ability of the electro-chemical milling supplier to meet target dates for the turbulated liner cylinders forced a decision to go with wire turbulators for the first engine build. The ECM liners will now be used for the 2nd development liner.

The first prototype Mercury 50 ULP gas only fuel injector was assembled and underwent cold flow testing to measure its flow effective areas for comparison with the design intent. The injector also was tested in a cold air flow combustor rig to visually observe the flame from the main and pilot systems. Thus far all testing has met expectations, but the design will not be fully qualified until testing at representative inlet air temperatures and pressures is completed. Manufacturing of components to make a full engine set for the annular combustion rig tests has been ongoing during this reporting period.

WBS 11600: Turbine Assembly

Stage 1 Blade: Mercury Machine Tool Company is in the process of developing the airfoil wax die and the electrodes for the ceramic core die. They have completed 40% of the wax die and approximately 80 % of the ceramic core electrodes during this reporting period. They have also completed 20 % of the machining fixtures. A drawing/tooling design review was held in July. Attendees included Solar personnel from design, heat transfer and layout as well as representatives from Howmet and Mercury Machine Company. An electrode review was held in September.

A critical design review (CDR) was held in late August for the stage 1 blade and disk. A few minor issues were raised, but the design team sanctioned the blade design. The design team has been evaluating three different suppliers for the abrasive tip coating deemed necessary for optimal engine efficiency. Solar and Howmet are in process of evaluating a Pt-Al coating/CMSX-10 material combination. Solar and Howmet are also of consolidating the thermal cycles for the CMSX-10 blade.

Drawings for the stage 1 disk and rim seals have been released for tooling purposes, with the disk rough machining drawing released to order actual parts. Rough machining disks have been received in house. Blade damper drawings have also been issued.

Stage 2 Blade: The second stage turbine blade drawing was issued this reporting period for tooling purposes. Release of the turbine blade casting definition has allowed for investment casting tooling procurement. Details of the blade firtree attachment have been thoroughly analyzed for adverse tolerance conditions and the design definition incorporated into the blade configuration. Similarly, rough machined disk definition release has stimulated progress on the Udimet 720 intermediate grain size development program. Ladish Corporation has developed forging die and ultrasonic inspection shapes and completed preliminary cooling rate studies. Wyman-Gordon Corporation completed the first four pancake forgings for Udimet 720 and has developed ultrasonic and heat-treat shapes from the released disk design definition.

Detail design of the turbine shaft and center-shaft has progressed over the last reporting period. Seal stress calculations for the threaded labyrinth seal were completed using ANSYS finite element modeling. The shape was optimized to fit in the available space with due regard to thermal and centrifugal deflections matched with acceptable stress. Curvic coupling separation forces and required assembly interference for pressing the seal disk on the turbine shaft were calculated and found acceptable. Both shafts modeled using finite element techniques and acceptable

stresses/deflections were demonstrated as a result. Appropriate spline dimensions and pilot dimensions were assessed and incorporated into the design.

Stage 1 Blade Cooling Design: The cooling design of the first stage turbine blade was completed during the last reporting period. Design options were identified in an effort to reduce risk and to be rainbow-tested. A 15.4X scaled leading edge model with the screw-shaped swirl cooling configuration was tested for heat transfer coefficients using a transient liquid crystal technique. The measured values matched within 5% of the predicted values. A 7X polyurethane model of the overall cooling core is being constructed that will be used for a flow visualization and pressure drop and heat transfer measurements.

The aft nozzle support was redesigned during this reporting period in order to minimize thermal distortion.

A finite element thermal model is being constructed to provide transient response data for turbine tip clearance predictions. This model will include a 3D centerframe along with 2D combustor, turbine and compressor sections. The complete engine thermal model is 50% defined, pending completion of nozzle support/centerframe interface redesign. The thermal FE model will make use of a recently completed engine dynamic simulation database which predicts dynamic transient behavior characteristics for the recuperated Mercury 50 engine for all operating conditions.

WBS 11800: Exhaust Assembly/Center Frame

Center Frame: A design review of the center frame design was held in July. The review confirmed the acceptability the center frame under steady-state, and full load conditions. A simplified 3D finite element transient thermal and stress model for the center frame (based solely on the axial deflections) was completed in August.

Drawings for the forward and aft end plates have been issued for tooling purposes and have been sent to the supplier for procurement. The full center frame assembly supplier has been selected and is awaiting the full assembly drawing release.

The preliminary relief valve piping system were defined. Engine design is working closely with Packaging to assure that the system performs as required.

Exhaust Collector: A Critical Design Review for the exhaust collector was held in July. Agilis representatives presented the current design and analysis to the Mercury design team. The design was approved, pending action items documented in the review. During this visit, Agilis and Solar's engineers visited Solar's collector supplier, Ketema. A few modifications to the design were incorporated based on this visit.

Drawings have been released to the supplier for tool fabrication. These drawings include the flange forging, the flange machining and the outer flowpath.

A stress analysis of the collector without heat shields resulted in a design modification to exclude the heat shield. This will reduce cost and the complexity of the assembly.

A CFD analysis was undertaken during this reporting period which demonstrated an increase in

pressure recovery with the addition of a simple baffle plate. As a result of this analysis, a baffle plate will be added during engine development testing to verify predicted efficiency increases. If the test is successful, the plate will be introduced into the collector design.

A detailed conceptual study was undertaken by Agilis during this reporting period to investigate the feasibility of incorporating a hot strut design in place of the current EGV and nozzle case support system. The hot strut would mitigate the sensitivity of the stage 1 blade tip clearance from centerframe thermal effects. The conceptual design has been completed. A preliminary hot strut drawing will be prepared in order to send to potential suppliers for cost assessment.

WBS 12110: Generator

The generator specification was issued and Request for Quotes were issued to several suppliers. Only one supplier had responded as of the end of the quarter.

WBS 12140: Package/Generator Frame

The basic skid was designed, and a CAD model was completed. The base design includes the generator support, oil tank (inclusive to frame/not removable), pivoting trunnion mount, 'soft foot' mount, tie down pads and lifting devices.

The recuperator support is still in the concept stage - no detail design was done this quarter.

WBS 12150: Enclosure Assembly and WBS 12160: Ancillary Equipment

Package heat rejection for ventilation requirements and package noise signature were established after technical interfaces between package and engine design engineers. Ancillary engineering finalized the air inlet duct configuration with a comprehensive interface with engine design engineering. The 'relief valve system' silencer design was modified to allow for updated design conditions. The associated control scheme was revised. The air inlet filtration system and the ventilation system for the enclosure were initially sized, thus allowing an assessment of the feasibility of innovative package design concepts. The 'drop-over' enclosure concept was presented at the package design review. Work was initiated on the design of an overhead engine removal system that will be integral with the package support structure.

WBS 12210: Control Console

Conceptual control concepts were developed and sketches reviewed sketches within the Controls Group. An input/outlet list was completed based on available current information relating to the engine and package equipment. A CO analyzer was selected on an interim basis.

WBS 12220: Lube Oil System

The lube oil system was 80% complete. Work was done towards selection of suppliers of oil

pump/motor/valve assembly. A further iteration of the on-going update of lube oil schematic was completed. The thermo control valve was defined.

WBS 12230: Fuel System

Another iteration of the gas fuel schematic was completed. The design of the system is approximately 80% complete.

WBS 12240: Start System

Design of the start system is complete.

3.2 TECHNOLOGY DEVELOPMENT PROGRAMS

WBS 19100: Advanced Turbine Cooling and Sealing

Blade Screw Cooling: A test rig to evaluate the heat transfer coefficients in a screw-shaped vortex cooling chamber was completed at the University of Utah. The engineering report on the flow phenomena for this cooling technique was submitted to Solar. A test report on the effects of rotation on screw-shaped cooling effectiveness was completed at MIT and submitted to Solar.

Nozzle Film Cooling: Validation testing on the upscaled turbine nozzle film cooling test rig was completed. Testing included steady state and transient testing, as well as the secondary (coolant entry) flow systems.

Disk Cooling: The gas ingress test on the unsealed disk cavity was completed on the rig as a baseline for evaluating optimized turbine disk sealing and cooling. Comparison tests on the sealed disk cavity have been started.

Semi-active Tip Clearance Control: A Saturn engine demonstration test with semi-active tip clearance control was successfully completed, and results are under evaluation.

Other: A feasibility study was performed for application of dimples for heat transfer augmentation without and increase in pressure loss penalties. Results are promising for both turbine hot section and combustor liner cooling.

WBS 19200: Advanced Combustion

Ultra-lean Premixed (ULP) Combustor Development: CFD runs on the initial design of the Mercury 50 lean premixed injector indicate flow detaches from the downstream portion of the centerbody due to the flow expanding into the liner. This can be prevented by recessing the centerbody.

The first Mercury 50 prototype fuel injector was assembled and cold flow tested. A single injector test section was initially commissioned with a standard SoLoNOx injector. Testing of the Mercury 50 injector will begin next period.

Advanced Combustor Controls: Attempts to operate the CEMCAT carbon monoxide (CO) sensor on a wet (undried) gas sample failed. The need to dry the gas sample and control flow rate over the sensor requires nearly as much flow conditioning as a conventional CEMS system. On the other hand, testing at Servomex has shown that its CO sensor has the sensitivity necessary to measure concentrations of less than 50 ppm, without the complexity of the CEMCAT system.

Advanced Liner Cooling: Dimpled plates were prepared and tested in the heat transfer rig. This surface has demonstrated the required high heat transfer coefficients with very low pressure losses. This offers potential for significant improvement in the combustor cooling approach, and manufacturing methods are being evaluated.

Catalytic Combustion: Atmospheric rig tests of a subscale catalyst bed was completed at PCI. Local overheating of the catalyst was evident, and a redesign is in progress. At Catalytica, the subscale tests for durability and the effects of contamination continued. At Solar, the layout of the Mercury 50 combustion system was completed, and a very successful preliminary design review was held.

WBS 19300: Ceramic and Composite Materials

Ceramic Blade Development: The rub rig is being prepared to test ceramic blades (from CSGT) rubbing against an abradable tip shoe. Effort on the design of a ceramic blade for the Mercury has been delayed indefinitely due to funding limitations.

Ceramic Nozzle Development: A patent application for the long term conditioning of silicon nitride was finalized. No further effort will be spent on the ceramic nozzle at this time.

Ceramic (Composite) Interstage Seal Ring: The rub test disk knife edges were coated with chrome carbide, and the disk and CFCC seal ring are ready for rub testing.

WBS 19400: Advanced Turbine Materials Development

Forged Disk Development: Results of initial creep and rupture tests of course-grained Udimet 720 at Ladish Company meet the minimum life targets established for the Mercury 50 second stage disk design. At the design operating temperature, the Udimet 720 disk is expected to have 20 times the life of a Waspaloy disk. Notch ductile behavior has been observed on all creep rupture specimens to date. Promising results were also obtained from the first low cycle fatigue tests at 1325° F.

At Wyman Gordon, mechanical tests of the course grain material are 60% completed. Tensile tests at 1000° F and 1200° F exceed program targets and creep rupture tests are in progress. On this material notch brittle behavior was observed, which is a critical issue being investigated further. Pancake forgings for the first two Mercury 50 engines have been forged, heat treated, and ultrasonically inspected. Machining at the supplier will be completed next period, following release of the drawing.

Dual Property Disk: Hub materials and rim castings have been received, and samples are being

tested for material properties. No further effort will be spent on this program at this time due to funding limitations.

Advanced Casting Techniques: The vacuum die cast mold for test bars was modified to provide straight test bars, and bars were received for materials property testing. A mold for the compressor blades was fabricated. Test blades will be cast during the next reporting period. A sliding ring for the Mercury 50 engine has been spraycast and HIPed, reducing manufacturing cost. Test data shows properties similar to wrought ring-rolled Waspaloy.

Low Coefficient of Expansion Material: The first Mercury 50 nozzle support rings produced in Haynes 242 from 12" diameter billet were delivered. They are being used for mechanical testing and machining trials, and one ring will be made available for engine testing. Mechanical properties have met the specified requirements. The prime path material for this part is Waspaloy due to its superior high temperature properties.

Single Crystal Blade Material -CMSX-10: Experiments have led to a 33% reduction of solution heat treating cycle time, which is a cost saving factor. Mechanical tests are being made to determine the effects of the reduced solution time.

WBS 19500: Recuperator Material Development

Initial testing of the modified 347 SS has shown excellent results in both creep and oxidation tests. The modification is achieved via new thermomechanical processing techniques, and the material has an estimated creep life of two to four times that of standard 347 SS. A patent disclosure on the process has been initiated. This material is expected to increase recuperator life at 1200°F from 30,000 hours to 100,000 hours.

Other materials were reviewed as candidates to increase operating temperature capability to 1300°F. Three candidates are being tested, and one shows good potential based on early creep tests, and another may actually be capable of 1400°F for low pressure applications.

WBS 19700: Advanced Coating Systems

Thermal Barrier Coatings: An instrumented test on a thermal barrier coated (TBC) combustor liner demonstrated metal temperature reductions up to 150°F. A longer term test is being prepared. Engineering Design Memos (EDM) were issued on material property data measurements of plasma sprayed TBCs and on a life prediction method for plasma sprayed TBCs.

Thermal cycling tests to 2000°F were completed on four different TBC systems. The tests showed that TBC life is shorter for 10-hour thermal cycles than it is for 100-hour cycles. EB-PVD TBCs were applied on Taurus turbine blades for evaluation.

Rub rig tests of un-tipped blades against functionally graded material and thick ceramic abradable tipseals were completed at temperatures of 1100°F, 1650°F and 1800°F. Some blade tip loss was observed, and evaluation is ongoing.

Internal Coatings: 1000 hours of oxidation tests at 1500°F and hot corrosion tests at 1200° F were completed on thin aluminide coatings on single crystal alloys CMSX-4, CMSX-10, and CMSX-11. In the hot corrosion tests, the coated samples had one tenth the weight change of the uncoated samples, indicating that the aluminide coating provides ten times the stability of the base alloy. They may help provide a component life of 5 to 10 times that of one of uncoated alloy. Chemical Vapor Deposition and Above the Pack processes were performed on sample blades. Uniform coating distribution and clean coating/substrate interface were accomplished. A successful cleaning process for internal coatings was established.

Alloy Coatings: The evaluation of as-coated Chromalloy UK Platinum-Aluminide on CMSX-10 single crystal alloy was completed. Results showed no topologically close packed (TCP) phase formation on the machined surfaces. In comparison, state-of-the-art coatings such as MDC-150 exhibited up to 1 mil in TCP phase formation. After oxidation at 2100°F for 100 hours, the CUK coating exhibited 2.5 to 3 mils in TCP phases, whereas the MDC-150 coating exhibited 5-6 mils TCP phases. Oxidation testing at lower temperature is in progress.

WBS 19800: Advanced Diffusers

Diffuser tests with vortex generators installed demonstrated greater improvement on diffusers without collectors than those with collectors. Preparations are now in work for the half scale diffuser for the turbine test rig.

WBS 19900: Man-Machine Interface

All of the run-time services for the MMI have been demonstrated, as has the multi-language and historical data playback capability. The graphical editor toolkit has been integrated. Testing is continuing on the Integrated Development Environment and the View Editor. Development is also continuing on the integration of Visual Basic for Application to perform the math calculations and on the MMI setup programs for alarms and data.

3.3 ATS L-ENGINE

WBS 202000: Engine Definition

The ATS-L engine concept design was reviewed at a Concept Review meeting on July 10. All aspects of the engine and some of the package features were presented by the design engineering staff responsible for the various sections and/or overall engine configuration. Following this major review the efforts of the Design Team are focused on the preliminary design. The Preliminary Design Review is planned before the of 1997.

The engine design must meet the criteria specified in the ATS-L Business Plan and the Product Requirement Specification (PRS) incorporate in the plan. The document specifying the "L" engine design criteria were completed in early August. This document is a supplement to the PRS and provides specific technical criteria relating to the design of the engine.

Accessibility will be a major factor in the "L" package design. Specific operations carried out during a standard overhaul of Solar's current products will be conducted in the field. Thus, the engine and package design will maximize the ability to change out components and parts in the field. Space requirements are also critical for the "L" package. Package footprint, volume, and height are to be kept as small as practical.

Preliminary design work has proceeded including a preliminary selection of materials for most components. A major focus of the effort was on the examination of alternative combustion schemes. Considerations include the ability to operate under part load conditions without performance penalties, and the ability to retrofit an ultra-lean premix combustion system to a catalytic design, rotor dynamics issues and product cost.

A detailed product cost analysis was undertaken using a bottoms-up approach involving a careful estimate of cost for the individual components and assemblies. The initial estimate indicates that the L will be able to achieve the 10% cost of power reduction goal as well as more aggressive internal cost goals. The cost estimate will change further as the design becomes more detailed.

The "L" Development Plan is being refined along with the conceptual and preliminary design efforts. The basis for the plan are schedule, effort and cost estimates from the current ATS-L time line and Management Plan and data from the Solar ATS-L Business Plan. The estimates are being updated with bottoms-up cost estimates for the components and assemblies.

The schedule, effort, and cost estimates will be incorporated in a project plan being loaded into the Open Plan software. This software is currently the subject of a conference room pilot project at Solar; use of the software may ultimately be extended to encompass all of Solar's development projects. The plan enables rapid estimates of effort and cost and "what if" scenarios. A new program plan for the ATS-L should be in place before the end of November.

3.4 TEST RIGS

WBS 42100: Compressor Rig Testing

The Advanced Component Efficiency (ACE) compressor rig testing was completed at the end of July. The Phase V testing completed the optimum mapping with various vane positions. Exit traverse surveys determined that exit flow profiles per the NASA code over-predict blade row interactions. The code will be refined accordingly. Inlet duct straightener additions demonstrated no measurable differences compared to the original inlet configuration. A test summary report draft has been completed by Wright Patterson AFB with the final report expected by November.

The rig and test compressor were disassembled, and high cycle fatigue (HCF) cracking was found on the compressor stators of stages 5,6 and 7. An investigation was undertaken to find out the cause of the deficiencies, and the extent to which the current Mercury 50 stator design would need to be modified to ensure hardware longevity. Following an analysis of the modal characteristics of the stators, the team and concluded that stator 4 needed minor redesign to avoid a sixth engine order interference. This redesign has been successfully accomplished without negative impact to schedule or to downstream aerodynamics.

In addition to the stator cracking, the ACE rig exhibited stage 9 disk cracking. Investigation into the possible causes was ongoing at the close of the reporting period.

WBS 42210: Ultra Lean Premixed (ULP) Combustor Test Rig

The combustor housing end cover has been cast and delivered to Solar for machining. The combustor housing itself is currently being cast. The first prototype fuel injector has been assembled. The test facility is being modified to accept the combustor rig, and testing is scheduled to begin in December.

WBS 42400: Turbine Test Rig

Airfoil designs were completed, and procurement of test hardware is in process. First stage nozzle flow tests were completed, and the flow capacity agrees with design calculations although the nozzle configuration used does not account for the effect of cooling flow on the overall turbine. Baseline testing with the full two-stage rig is scheduled to start in December.

WBS 42500: Squeeze Film Damper Test Rig

A squeeze film damper from Waukesha has completed its characterization testing, and the Solar damper is being fabricated for comparison testing.

WBS 65000: RAMD

The specification for the RAMD Interface/Display System has been completed identifying inputs, data processing requirements, workstation and presentation program requirements, system operation and maintenance manuals and other documentation.

3.5 COMMERCIALIZATION

WBS 52500: Product Cost Management

The current estimate of the engine cost is comfortably below the program goal of 10% reduced cost of power although the estimated product cost increased slightly during the past quarter as current quoting is showing higher than expected costs on some components. Of the drawings released, 32% have current quotes. Costs under scrutiny and receiving significant attention include the Stage1 nozzle, center frame, combustor end cover, compressor rotor spacers, air divertor valve, and package controls. In all cases, cross-functional groups are looking at cost reduction options to get cost and target to align.

WBS 62000: Manufacturing Readiness Plan

Work continues on the Readiness Plan in the Cold CAM, Hot CAM, Rotor CAM and Controls. All areas are at different phases of the project, and work is progressing smoothly. Recently, a

new shop layout was selected by the Cold CAM. This layout includes a significant amount of floor space for a stand-alone Mercury Cell. This cell will manufacture many parts including the air inlet, diffuser, compressor case, and gear box housing and will also have an assembly area. The cell will be designed so that at some point it could be relocated as a part of a Mercury specific factory, if required.

The Rotor CAM is evaluating long range strategies in concert with shop layouts. Significant work will have to take place to accommodate the equipment required to manufacture the hardware forecasted for five years out and beyond.

Hot CAM and Controls are in the load analysis and assessment stage. The bottlenecks and problem areas are not yet clearly defined. Studies are ongoing. At some point both areas will progress to the current stage of the Cold CAM.

WBS 71100: Host Site Research and Selection

Solar and Rochelle Municipal Utilities (RMU) moved closer to locating a host site for the 8,000 hour demonstration of the Mercury 50. Solar's ATS Commercialization Manager made a presentation in late July with RMU and members of local industry in Rochelle, IL regarding the ATS program, Solar's ATS product, and the selection of the host site. Following continued strong interest, an August meeting was held in Rochelle with the GM of RMU and representatives of Hormel Foods. In September, RMU's General Manager and Solar's Commercialization Manager made a joint presentation to DOE's Steve Waslo, Pat Hoffman and Lisa Barnett, as well as to Solar's ATS and Sales & Marketing personnel. They proposed that RMU locate the demonstration unit in its service area. The presentation was favorably received by all parties. A proposal was later sent to RMU. Communications are ongoing to finalize an arrangement.

4.0 PROGRAM MANAGEMENT

Program Activities: Considerable efforts were initiated in August, as part of the company's annual budget planning process, to reforecast and control '97 and '98 ATS labor and material expenditures. The continuing shortfall of DOE funding from levels identified in the cooperative agreement together with heavy demands on Solar resources for product development and support, as well as the constant need to meet investors' financial performance expectations, has forced Solar to commence selective reductions or delays in program activities. These reductions also are reflective of the progress made to date on engine design and analysis and technology development activities. As with any relatively high risk R&D, parallel pathways were required to be pursued until sufficient knowledge and data was available to make design decisions and technology down selections. Solar has reached a stage where it may commence such selective reductions consistent with its RD&T plan.

A detailed investigation and analysis of technology development and test rig planned activities identified potential cost savings as described further below. The ground rules were to identify those activities that are not deemed absolutely critical to (i) preserve Mercury 50 the schedule for the initial test units and (ii) meet ATS performance requirements.

Ceramic blade and nozzle design and development programs have been placed on hold. Efforts related to basic material characterization will continue at a minimal level, but the plan to test ceramic components in the field demonstration (and the development engine) has been canceled.

Continuous Fiber Ceramic Composite (CFCC) programs have similarly been reduced to basic material characterization. The CFCC transition duct will continue to be considered for a back-up for the L engine.

An effort to establish a life prediction model for the TBC turbine blades has been canceled at the Southwest Research Institute. TBCs may be applied to blades on either the S or L engines, but the insulating benefit is not being considered in the design life due to the uncertainty in TBC adherence life.

Effort planned to establish a life prediction model for superalloy turbine disks has been eliminated from the ATS technology program.

Down selection to a single supplier for the Udimet 720 turbine disk material will occur at the beginning of 1998 rather than later in the year. At this time the material from one supplier is meeting all the material test goals, and the early down selection will add minimal risk to the success of the material development program.

Development of the dual alloy turbine disk will be discontinued, except for continuation of material creep testing already underway. The primary need for the dual alloy disk was for supporting the ceramic blades, which would typically operate with a higher disk rim temperature.

Development of alternate recuperator foil materials to extend the service life and operating temperature capability have been reduced. Initial test results of the 1200° F material are encouraging and indicate a substantial life increase over standard 347 stainless steel is possible. Efforts to develop a higher temperature material capable of 1300° F have been eliminated from the program.

ATS funding of the vacuum die casting and spray casting process development efforts for product cost reduction has been stopped. This activity will be continued by Howmet as a part of their internally-funded technology development activities.

A portion of the combustion research testing not considered vital for the ATS program has been terminated. Similarly, portion of the tests planned for the half scale turbine test rig have been eliminated from the test program because they are not vital to support the initial development of the Mercury 50. Tests of the turbine diffuser and collector have also been reduced to the minimum considered necessary. A plan to test a scale model of the compressor inlet has been canceled because of high confidence in the analytical model, and the low risk of an adverse consequence on performance.

Although the above program revisions add some risk to the attainment of low cost and long life goals, they are considered low risk as far as engine schedule and performance are concerned. Some of the eliminated or reduced activities may resume later as deemed necessary for the achievement of program objectives.

ATS Program Status: The Financial Status Report (SF 269) and Federal Assistance management Summary Report (DOE Form F4600.5) for the month of September are attached.

As of the end of September there was an unfavorable 53.6% schedule variance against the 6 year baseline for the overall ATS program (59.5% last quarter). This is attributable to (i) continuing funding constraints and (ii) a 0/100 percent complete assumption for program milestones. Solar also shows an unfavorable cost variance of 15.1% (16.21% last quarter) that is due in large part to the high degree of outsourcing. The unfavorable variances are expected to continue to diminish somewhat over the next few months as preliminary drawings are issued.

The Mercury 50 Team is holding to the key target of a March 1998 commencement of assembly on the first engine build. The principal items currently pacing the Mercury 50 schedule are:

- Stage 1 and 2 Turbine Blades
- Stage 1 Turbine Nozzle Segment
- Stage 1 and 2 Turbine Disks
- Stage 10 Compressor Aft Hub
- Stage 10 Compressor Outlet Guide Vane
- Stage 9 and 10 Compressor Blades
- Center Frame Structure
- Rotor Bearings

Based upon the components that are currently most critical to schedule, it is estimated that the Mercury program is some four months behind schedule.