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

**Quarterly Report
October 1 - December 31, 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 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.

2.2 Overall Assessment of Performance

As of the end of the reporting period work on the program is 24.7% complete (22.8% last quarter). Work on the Mercury 50 development and ATS technology development portions of the program (WBS 10000 *et seq*) is 41.6% complete. Although a great amount of work occurred in the quarter, a significant amount of this work entailed the revision and rerelease of several Mercury 50 drawings. Estimates of percent complete are based upon milestones completed. In order to maintain objectivity in assessing schedule progress, Solar uses a 0/100 percent complete assumption for milestones rather than subjectively estimating progress toward completion of milestones. Cost and schedule variance information is provided in Section 4.0 Program Management.

Mercury 50: The detail design of the Mercury 50 engine continues. Critical design reviews held during the quarter included the recuperator and the second stage turbine blade. Preliminary design reviews were held on the enclosure/ancillary and controls.

Production and development parts are being received, and some machining is being done. Solar accepted the nozzle support forgings and sent them to the machining supplier. The housing and end cover for the combustion rig were received, and the end cover was machined. Testing of the development gear boxes was completed, with all design criteria being met. Design Engineering received sample castings of Compressor blade stages 3, 4, and 5 for review and acceptance. The first stage turbine blade tooling was completed and delivered to Howmet Whitehall Casting Division who has started pouring the development hardware for engineering evaluation and test on the first stage turbine blade. Second stage turbine blade tooling is nearing completion. Casting tools for the IGV and the two VGV (vanes) were completed and the first set of parts cast.

The total drawing effort for the engine is estimated to be 60% complete. An increasing number of drawings are being released at levels allowing the fabrication or procurement of hardware. Some 250 controlled preliminary drawings were issued this quarter at a level authorizing the fabrication/procurement of parts. The latter include components for which lower level CPDs had previously been issued. It also includes the rerelease of CPDs in which design changes were incorporated. (Solar design engineers, manufacturing engineers and suppliers work concurrently based upon progressive levels of CPDs rather than working in serial manner based on the formal release of final drawings.)

The Mercury Design Team is still pushing for a June first engine test date, but this major milestone is under considerable pressure from unreleased long lead items such as compressor stators (latter stages), nozzle support case forging, first stage diaphragm assembly and the turbine sliding ring assembly.

Rigs and Technology Development: Work on the test rigs and in the enabling technology is also progressing well.

- Work has been completed on several technology development tasks, and topical reports are under preparation.
- First stage nozzle flow tests on the turbine test rig were completed.
- Fabrication of components for the ultra-lean premix combustor test rig was completed with testing to start in January 1998.

ATS-L: Concept design work continues.

Commercialization: An order was placed by Rochelle Municipal Utilities for the first Mercury 50 gas turbine and package. The host site for the 8,000 hour demonstration will be located in the Utility's service district.

3.0 TECHNICAL PROGRESS BY TASK

3.1 Mercury 50 Engine and Package

WBS 10100: Technical Coordination

A team has been formed consisting of package production personnel to drive the initial Mercury 50 package (the development test cell unit). Assembly of package subsystems will start in February. The CSGT test has finished and the remodel of the test cell for the Mercury 50 has begun.

The recuperator top level assemblies were loaded into the MRP system and are being driven in the master schedule. The delivery date for the development skid core assembly is in March. A recuperator rig test has been completed at Cat and the data is being analyzed. Preliminary results are equal to or better than predicted.

The engine installation drawing has been released.

An update of the Product Requirement Specification is in process. A draft of the field evaluation test specification is being reviewed.

WBS 10300: Package Definition

Basic package definition has been completed. Much of the detail package design effort (WBS 12000 *et seq*) was completed in the fourth quarter of 1997. Detail design of some components was in still process. Package Product Engineering accelerated activity to order parts and complete remaining detail drawings in preparation for the first build in the 1st quarter of 1998.

WBS 11100: Air Inlet System

The design of the air inlet muff was completed in October and the drawing released for fabrication of the part.

The air inlet casting first article inspection report was accepted in December for dimensional features. The bolt pattern on the inlet and #3 bearing housing machine drawings must be changed to match up with revisions to the centerframe design.

WBS 11200: Compressor Assembly

Compressor Static Structure: The #1 bearing housing machining drawing was released in October. Two housings were cast and inspection reports were accepted with some minor changes being required to the drawings.

The inner diffuser support casting first article inspection report was accepted for dimensional features. However, X-rays of this part show some shrinkage. This casting will be machined to determine if the shrinkage is detrimental to the final part. The first article inspection report was accepted for the compressor discharge casting. The datum system and bolt pattern have been changed on the discharge machine drawing to match the bolt pattern on the compressor case.

It was determined early in the quarter that a redesign of several stators would be necessary due to modifications to the analytical model predicting modal frequencies. All stator designs have now been finalized including the outlet guide vane (OGV). Drawings for stages 3,4,6,9,10 and OGV are released. Drawings for stages 5,7 and 8 will be released shortly.

VGW Actuation System: All drawings for the vane actuation rings, support brackets, actuation shaft, shaft bearings, production graphic plates, roller axles, graphic plates and turnbuckles have been completed during this last reporting period and have been issued for fabricating parts.

The clearance between the IGV inner ring and the rotor 1st stage disk has been redefined and drawings changed as a result. The inner ring definition is now complete.

Machining definition for the 1st stage and 2nd stage compressor vanes has been completed and forwarded for drawing completion. Negotiations have been in process with the machining supplier to finalize machining definition for the IGV small button.

Compressor Rotor: The first article inspection reports have been accepted for stages 3 through 5 compressor blade castings during this reporting period. Three to five engine sets of cast parts have been received by the supplier for machining.

Casting drawings for compressor blades 3 through 10 were modified and reviewed for completeness and commonality and shipped to the casting supplier. Wax patterns for all stages have been completed.

Drawings for stages 2 through 5 disk assemblies have been placed in the review and sign off cycles.

Designs and machining drawings for the forward cone, 1st stage disk assembly, and the aft hub were placed on hold while sealing and turbine shaft issues were addressed. The hold has since been lifted and drawings are in the review cycle.

WBS 11300: Combustor Assembly

Combustor Case: Two end cover castings were received from the casting supplier in October. One casting was found to be excessively out of tolerance to machine a finished part. The rig end cover has now been completely machined by Wisconsin Centrifugal. Initial checks for assembly have been completed.

Semi-machining drawings were issued for the combustor housing in October for tool fabrication. Thermocouple flanges and probe lengths have now been defined.

An alternate design has been started to replace the 1st turbine stage piston rings. This design utilizes metallic seals. Extensive coordination has been started between Solar and EG&G.

WBS 11400: PSR Section

Manufacture of air cells has begun at Solar's new recuperator manufacturing facility near Houston for the first core for a scheduled March delivery to San Diego. Source control drawings for all expansion joints are being revised for the first engine.

Steady-state structural analysis of the recuperator has been completed. The analysis results for the air out duct indicated that stainless steel 321 lacked the required creep strength for the required component life. The material has been changed to stainless type 347. Also, additional analyses were performed to investigate design changes to facilitate fabrication of the recuperator.

WBS 11500: Fuel System - Mercury 50

Ultra Lean Premix (ULP) Combustion System: The definition of the combustion liner hole pattern was completed early in the quarter. Sub assemblies for liner #1 were recently tested on the cold air flow bench to determine their flow characteristics. The measured flows satisfied the design intent. The liner has been fully assembled and brazed. The liner is now complete apart from final machining of the internal diameters of the mounting pin supports and the welding the torch igniter grommet assembly in position.

Several manufacturing problems relating to the first set of fabricated swirlers for the first full injector set resulted in two of eight being unusable. Several samples from Howmet of alternate (cast) swirlers were recently received. These were adequate to base a decision to make a cast set of swirlers for the second set of injectors.

Manufacture of the first air diverter valve (for combustion rig use) was completed in December and is being assembled. Structural analysis of the recently redesigned valve was completed with no major issues resulting. The revised design will be installed into the first engine.

WBS 11600: Turbine Assembly

Turbine Static Structure: Due to concerns regarding the availability of waspalloy, the material for the forward turbine nozzle case for the first engine was changed early in the quarter from waspalloy to Haynes 242. Material properties and nozzle case temperatures were reviewed, confirming that Haynes 242 can be used for turbine nozzle case. The resulting change in coefficient of thermal expansion (from waspalloy) will require a redesign of the nozzle case to aft nozzle support pilot.

The flange area responsible for the connection of the centerframe, aft nozzle case and combustor case underwent significant conceptual redesign early in the quarter due to manufacturing concerns.

A 3D quarter model of the centerframe was created due to the inability of a 2D model to capture complex thermal behavior and its direct effect on tip clearance. Both the thermal and mechanical tip clearance prediction finite element models are running accurately and efficiently.

Turbine Rotor: The casting drawing for the stage 1 turbine blade was issued in October. Work on the core and airfoil dies has proceeded. The rim seal and snap ring drawing was also released. First stage disk and rimseal drawings were also released. Extensive coordination has taken place over the past month between Howmet Whitehall Casting, Howmet Winsted Machining, Canon Muskegon (single crystal material supplier), Liburdi Engineering (abrasive tip) and Solar to discuss post-casting processing of the 1st stage turbine blade. Plans were also completed for development of CMSX-10 single material process.

Drawings were released for stage 2 turbine rotor components. Casting and machining definition for the blade was released to support tool build. Minor changes in the blade root geometry have required revision of the disk broach tool design and the disk forging envelope.

Wyman-Gordon successfully forged several full scale PM U-720 disk pancakes early in the quarter supporting the first two engines. The forgings passed pre- and post-heat treatment ultrasonic inspection.

A preliminary design review for the rotating instrumentation test was held with Agilis in December.

Turbine shaft stiffness was modified to raise critical speeds. A revised finite element model of the turbine shaft was constructed and stress runs made. The revised design is adequate.

Rotor Dynamics: Drawings were released for the main shaft rolling element bearings in October. Changes have been incorporated into these drawings based upon comments received from the manufacturers. The trim balance wheel, key phasor bracket and proximity probe bracket drawings were also completed. The proximity probe brackets were redesigned in December to accommodate revisions to the shaft.

WBS 11800: Exhaust Assembly/Center Frame

Center Frame: The center frame assembly drawing was fully reviewed in October by the supplier/Solar team with most tolerances being found acceptable. Mechanical loads on the center frame have been determined and final analyses have been performed for the upcoming critical design review. Updated load calculations have revealed a significant load reduction that will improve stage 1 blade tip clearance control due to the smaller nozzle case axial displacement at full load conditions.

Disposition requests for discrepant aft plate castings and forward plate castings were offered by the supplier, Texas Steel. After fully reviewing nature of the discrepancies, it was decided that only minor drawing changes are required with respect to the aft plates. However, the forward plate casting requires significant correction before an acceptable casting can be used in the engine. This activity has delayed the arrival of the first engine center frame.

Exhaust Collector: Recent input from the manufacturer has resulted in changes to the inner and outer collector design. The drawing issued earlier this quarter will therefore be modified.

WBS 12110: Generator

The generator for the first build was selected and placed on order with delivery scheduled for March 1998.

WBS 12120: Reduction Gearbox

The gearbox for the first unit has finished testing and is available.

WBS 12140: Package/Generator Frame

The base design and detail drawings were completed. Drawings were sent the supplier to facilitate procurement. The trunnion mount design, 'soft foot' mount and lifting device designs were completed. All detail drawings were in process.

The recuperator support frame design was completed and was scrutinized at a mini 'design review' prior to creation of detail drawings. Detail drawings were in process.

WBS 12150: Enclosure Assembly and
WBS 12160: Ancillary Equipment

A 'drop over' enclosure concept was presented at a design review. Alternate concepts were discussed, and cost comparisons were made.

A multi piece (steel) air inlet duct design was completed and detail drawings were in process. A silencer was selected for the relief valve system. Drawings were in process.

WBS 12210: Control Console

Control boxes were identified, and the control box/frame assembly design and drawings were completed. The control box assembly design was completed.

Wiring diagram/electrical schematics were in process.

WBS 12220: Lube Oil System

The lube oil system design was completed. Motor and other system component drawings were completed and parts were placed on order.

WBS 12230: Fuel System

The fuel system design was completed. The design and drawings for the fuel system support bracket were completed.

3.2 Technology Development

WBS 19100: Advanced Turbine Cooling and Sealing

Blade Screw Cooling: All fundamental studies including: MIT work on the rotating rig, University of Utah work on flow and heat transfer in the large swirl chamber, and Solar in-house work on the entry slot to leading edge diameter ratio optimization have been completed. Results obtained from these studies suggest that this technique, when optimized, might allow sufficient internal cooling of the leading edge for turbine rotor inlet temperatures up to 2300°F, for cooling temperatures up to 900°F. A topical report on this technology is being prepared.

Nozzle Film Cooling: A calibration rig for the technique to map film cooling effectiveness was fabricated. The University of Minnesota completed validation of the cascade rig to perform the endwall cooling optimization task.

Disk Cooling: The disk cooling optimization rig was modified to obtain heat transfer data via the liquid crystal technique. A report on the first phase of the disk cooling optimization study has been prepared, providing a sufficient data base to establish disk buffer air requirements.

Semi-active Tip Clearance Control: This control technique was successfully demonstrated on a Saturn engine. The technology will be considered for application on the Mercury 50 as well as potential early application on existing Solar engines. A topical report on this technology is being prepared.

WBS 19200: Advanced Combustion

Ultra-lean Premixed Combustor Development: Combustion tests in the high pressure and atmospheric single injector combustion rigs have been conducted with the prototype Mercury 50 injector. Although the injector was shown to be capable of producing less 10 ppm NO_x and less than 15 ppm CO (the program targets) strong combustion induced pressure oscillations at 300 Hz were encountered. Unlike existing Solar low emission injectors, the oscillations were not suppressed by increasing the pilot fuel flow. CFD modeling and further testing with a modified fuel injector have not yet demonstrated an improvement in emissions or oscillation performance.

Advanced Combustor Controls: Servomex tested its CO sensor to determine interference effects of CO₂ and H₂O on the sensor's ability to accurately measure CO concentration. There was no effect due to H₂O, but 2% CO₂ did affect the sensor by 5 ppm CO. However, because the concentration of CO₂ in the exhaust gas remains fairly constant this effect can be compensated for during the calibration of the sensor. A sensor from Servomex will be received early in the new year and will be placed on-line with one of our low emission endurance test engines to monitor its long term accuracy and durability.

Advanced Liner Cooling: Rig tests were done with dimpled surfaces to test for enhanced heat transfer from the combustor liner wall. Heat transfer enhancement factors of 1.6 to 1.7 have been measured, compared to factors of over 2.0 claimed in published literature. Two 8 ins diameter test liners, incorporating dimples, are being built to measure actual wall temperatures on the combustion rig. The electrochemically milled liner cylinders with chevron trip strips have been received for testing. One liner will have thermal barrier coating applied to the gas side wall to determine the benefit of this insulating layer.

Catalytic Combustion: The interface of the catalyst/catalyst container with the combustor can was defined. Detailed manufacturing drawings are nearing completion. The catalyst/container will be manufactured at Catalytica. The geometry of the combustor air flow path has been defined. This includes the flow of air from the plenum into the combustor can, cooling of the combustor, and the flow into the premixer and catalyst. The details of the fuel delivery system during part-load and catalyst operation, and details of the premixer upstream of the catalyst have been completed. Design of an actuation system using bellows to shut off air flow into the part-load injector during catalyst operation has been completed. This part will be supplied by EG&G. The design of the can-to-annular transition piece (from the combustor to the turbine) has been completed.

An atmospheric pressure rig has been designed and built to test the ignition system concept for the Mercury 50. A prototype ignitor has been procured from Unison for the tests.

The steady state and transient thermal stress analysis of the combustor end-cover continued. Texas Steel is working on a solidification analysis of the end-cover casting.

WBS 19300: Ceramic and Composite Materials

Ceramic Blade Development: The rub disk has been prepared for testing of the ceramic blades. Two ceramic blades with the old 55 degree dovetail configuration will rub against tipshoe coatings, both ceramic and metallic. A monolithic tipshoe made of porous ceramic will also be tested. The tipshoe configurations will be graded from the quality of the rub, and the ceramic blades will be evaluated for damage.

Ceramic Nozzle Development: A patent application for the long term conditioning of silicon nitride has been formalized.

Ceramic (composite) Interstage Seal Ring: The feasibility of using CFCCs in interstage seal rings has substantially improved with the successful rub testing of a specimen made of Dow Corning's ceramic composite. The knife edges used in this testing had an abrasive top coat that showed very little deterioration after two severe rubs. Deeper cuts are planned in the forthcoming tests. The supplier has expressed concern about making a component larger than 14 inches in diameter. The tipshoe support ring needs to be much larger in size (30 inches) and also has a thicker cross section than the suppliers have experience with.

Continuous Fiber Ceramic Composites: An order was placed for a subscale combustor liner fabricated from Nextel 720 reinforced alumina-silicate manufactured by Composite Optics, Inc. Coupons of this material were delivered to ORNL for materials testing. A meeting on commercialization was held at BFG, which has the only CMC parts in production. Melt infiltration technology for combustor liners looks very promising. Life prediction codes for CFCCs and their application to the combustor liner were discussed at ORNL. Solar will resurrect a previous FEM on the CSGT combustor to assist VPI with analysis. Several teleconferences were held between Solar, DOE, ORNL and GE to discuss the possibilities for testing CFCCs at ORNL and GE's Corporate R&D Center.

WBS 19400: Advanced Turbine Materials Development

Forged Disk Development: Development of Udimet 720 for the Mercury 50 second stage disk continued in parallel with forging suppliers Wyman-Gordon and Ladish Company. Due to funding constraints, down selecting to one supplier (Ladish) was accelerated. An analysis of available mechanical properties data from both companies was completed in order to measure level of success in reaching the program targets. The Ladish development results were clearly closest to reaching the specification requirements.

Mechanical testing of two isothermally forged U-720 disks from Ladish continued. Results showed an excellent balance of improved creep strength relative to Waspaloy and acceptable low cycle fatigue (LCF) properties. Fatigue crack growth testing was initiated during December, with results expected by the end of January 1998. Studies of the effect of heat treat cooling rate on gamma prime morphology and grain boundary shape are also underway, and will continue into the first quarter of 1998.

Advanced Casting Techniques: Work continued toward developing a low-cost vacuum die cast third stage Mercury 50 compressor blade made of 17-4 PH stainless steel. The blade tool was delivered and a series of casting trials performed. Initial dimensional and surface finish measurements were satisfactory except for the blade trailing edge radius. Examination of the

die revealed a discrepancy, which required a new die. Additional trials were run with the new die and experiments were conducted on several casting variables to establish an acceptable process window for alloy 17-4PH. A set of 15 blades will be produced in January, followed by a set of experiments to evaluate die life. Tensile testing of VDC test bars was completed during this quarter and the results are very promising. Three bids for the high cycle fatigue (HCF) testing contract for VDC were received and evaluated. The Howmet Technology Center was selected for the HCF program. HCF specimen grinding/polishing were completed in December, with testing to be completed in January and February.

Spray casting was selected to produce the Mercury 50 sliding ring component produced in Waspaloy. (This will not, however, be available to support the first engine build schedule.) A significant cost savings is expected relative to forged rings. Additionally there will potentially be lower residual stresses compared to forged products and therefore less tendency for component distortion during high temperature service. The Waspaloy sliding ring was spraycast, HIPed and heat treated, then delivered to Solar. First article evaluation of mechanical properties will be completed in early January.

Low Coefficient of Expansion Material: A report on the process development of 12" diameter Haynes 242 billet for the Mercury 50 nozzle case was delivered by Doncasters. The development was very successful, with forgeability improved relative to Waspaloy and a low tendency for cracking during the forge and heat treat processes. Doncasters also reported that the machinability of the rough forging was significantly improved compared to Waspaloy. The rough machined parts were subsequently delivered to Solar on schedule for prototype evaluation. The parallel effort on the higher risk 10" diameter billet development for the Mercury nozzle case began during this quarter. Two forging temperatures were evaluated as variables in the process. The nozzle cases were completed on schedule and delivered in December. Mechanical property tests of the development rings will begin in the first quarter 1998.

Single Crystal Blade Material - CMSX-10: The team formed between Solar, Howmet, and Cannon-Muskegon continued experiments evaluating a shortened solution heat treat cycle for third generation single crystal CMSX-10 for the Mercury first stage blade. The goal is to reduce time and cost of the post-cast cycle without compromising strength or stability of the alloy. The influence of cooling rate from the solution treat temperature on gamma prime size and alignment is also being studied. Four cooling rates spanning the anticipated production furnace capability have been completed. Metallographic analysis of the specimens is ongoing.

WBS 19500: Recuperator Material Development

The CRADA with ORNL continues to provide excellent progress toward the extended life program goal (1200°F/10ksi/100,000hr life). Several long-term creep tests of experimental version 347 SS now exceed 3000 hours with selected tests surpassing 4500 hours. Cyclic and static oxidation tests indicate that the life goal can be achieved from an oxidation standpoint. A second iteration of the invention disclosure has been processed, potentially leading to a patent centered around the modified Thermomechanical Processing (TMP) method developed by the Team. Team member Allegheny-Ludlum completed an outline of steps to produce the modified 347 using full-size mill equipment at the Pittsburgh facility. Scale-up of the new process from the laboratory to a high production mill environment will be one of the important milestones of the program.

Planning for 1998 research efforts relative to the second goal of increased temperature (1300°F) proceeded early in the quarter. Several ongoing preliminary creep and oxidation tests of a commercially available heater tube alloy have shown promise in meeting this second goal. Due to funding constraints this goal will no longer be pursued under the ATS program. Any further efforts will go forward with Solar's internal funding.

WBS 19700: Advanced Coating Systems

Thermal Barrier Coatings: Laboratory screening tests for plasma sprayed and EB-PVD thermal barrier coatings were completed. A Solar developed air plasma TBC system outperformed state-of-the-art systems available from outside suppliers by 2.0x life. The EB-PVD TBC with Pt-Al bond coating outperformed a TBC system with low pressure plasma sprayed MCrAlY bond coating by 10.0x life.

A rig test of a thermal barrier coated combustor liner was completed, showing a 75-150°F temperature surface reduction. Thermal barrier coating was applied to a Mercury 50 combustor liner for rig testing. TBC life assessment for combustor applications was completed, and predicted to be 73,527 hours at 1700°F surface temperature. To date, the Cat York Mars field engine test of turbine blades with TBCs had accumulated over 8000 hours without any noticeable engine performance degradation.

Rub rig testing of untipped and abrasive tipped systems provided by Liburdi and Praxair were completed against metallic and ceramic shroud coatings. Best rig results were for a system with the abrasive blade tip rubbing against a ceramic shroud coating. A concurrent engineering meeting was held between Solar, Howmet (casting, machining, and coating), and Liburdi (abrasive blade tips) to review the entire manufacturing routing and schedule for the stage 1 Mercury 50 turbine blade.

Internal Coatings: Optimization of the gas phase diffusion process to produce clean, thin and uniform internal aluminide coatings was completed, as were the process assessment on Centaur 50 stage 1 blades and the oxidation and hot corrosion testing of thin aluminide coatings. Coatings provided 5 to 10x life improvement to the base alloy.

Alloy Coatings: Oxidation testing of uncoated CMSX-4 and CMSX-10 alloys was completed. The CMSX-10 alloy exhibited severe oxidation attack and weight loss as compared to the CMSX-4 alloy. An oxidation resistant coating is required for CMSX-10 alloy. The "as-coated" and "thermal exposed" samples of CUK Pt-Al on CMSX-10 alloy were evaluated. In the "as-coated" condition, no Topologically-Closed-Pack (TCP) phases in the alloy were found. After thermal exposure, some TCP phases were found at the coating/substrate interface. The amount of TCP formation was considered acceptable considering the thermal exposure temperature. A technical paper on the performance of Pt-Al coated CMSX-4 and CMSX-10 alloys was submitted for presentation at the ASME IGTI meeting in Stockholm.

WBS 19800: Advanced Diffusers

No further testing was done on the test rig. The next tests will be on the half scale turbine rig and will be conducted in the spring of 1998.

WBS 19900: Human-Machine Interface

Testing continued on each of the HMI setup programs and controls. Integrated testing was started and will continue through January. Development effort will focus on bug fixes and missed functionality found during the testing phase.

3.3 ATS-L Engine and Package

WBS 20100: Technical Coordination and **WBS 20200: Engine Design**

Following the conceptual design review in July of 1997 efforts have focused on detailing the individual engine sections.

The airflow of the ACE compressor has been reexamined in order to maximize market potential. Two and three-bearing designs were evaluated, and a selection made to address rotor dynamics issues. The new compressor design is being detailed. Agilis has been subcontracted to perform mechanical analysis support work for the compressor design. A preliminary compressor design review is scheduled for late January.

The compressor design change required a redesign of the hot section. An analysis was performed on a substantial number of candidate engine configurations. For each of these configurations cycle performance data was generated including shaft thermal efficiency, output power, exhaust temperature, TRIT, and air cooling flow. Cost data have been generated along with the performance data. An overall engine product cost estimate and cost/hp have been calculated. Rough development costs are also being prepared.

The performance study will continue into the first quarter of 1998. A definitive engine configuration will be selected which will form the basis for a preliminary design review scheduled for the end of March 1998. Full detailing of the hot section will be delayed pending final selection of the engine configuration. Aerothermal studies are being performed to support the cycle evaluations.

Cost data are being generated to support the cycle studies and the development plan. The data uses existing data from the Taurus, Mars, and Titan engine families as well as new data obtained from supplier quotes.

Development plan cost estimates are being generated along with engine product cost data. The basis for the cost estimate are the current ATS-L time line and management plan and the engine configuration reviewed at the conceptual design review in July. The estimates are being updated with bottoms up cost estimates for components and assemblies. Development cost, resource and schedule estimates are being developed using the Open Plan software.

3.4 Test Rigs

WBS 42100: Compressor Rig Testing

The test summary report was completed on the aerodynamic performance of the advanced component efficiency (ACE) axial compressor. The test article inspection and discrepancy disposition was completed. This activity is complete. The topical report is under preparation.

WBS 42210: Ultra Lean Premixed Combustor Test Rig

Test Rig components fabrication has been completed, and the test article is being assembled into the atmospheric test cell for testing in January 1998.

WBS 42400 - Turbine Test Rig

After completing the first stage nozzle flow tests in October 1997, baseline testing with the full two and one half stage test article is scheduled for March-98 due to airfoil design and fabrication reiterations. The rig thrust collar has been a critical path item from the supplier due to critical production volumes.

WBS 42500: Squeeze Film Damper Test Rig

A squeeze film damper from Waukesha completed its characterization testing early in the quarter. Efforts through most of the current quarter focused on the fabrication for testing of the Solar squeeze film damper design configuration.

WBS 42600: In-House Engine Test - Mercury 50

Full engine test of the compressor to map high speed surge margins is being planned for test cell operation in late 1998. Test cell ducting requires recuperator bypass with throttle valving for simple cycle compressor mapping. This is being defined in conjunction with the new development test cell modifications now in progress.

WBS 65000: Reliability, Availability, Maintainability and Durability (RAMD)

The efforts to improve tracking of durability aspects and proactive maintenance enhancements of the ATS power plant is continuing with the integration of the HMI/Expert System controls developments. With the concept /methodology defined, the system specification completed, and the basic control functions incorporated into the engine control system, the remaining software is being assembled for demonstration of the RAMD system using prefabricated data. Continuation of the RAMD system development for the factory test package is planned for mid 1998 with further integration for host site application in 1999.

3.5 COMMERCIALIZATION

WBS 61000: Market Readiness and WBS 71000: Host Site - Mercury 50

Rochelle Municipal Utilities has placed an order for the first Mercury 50 generator set. The unit will be used in an intermediate duty, economic dispatch mode to reduce Rochelle's electric costs and improve reliability to its industrial and commercial customers.

The Mercury 50 was formally launched at the December PowerGen International Conference and Exhibition in Dallas. Activities included a very well attended editors' breakfast for key members of the trade press and a direct mail campaign that provided additional incentive to visit Solar's exhibit and learn about the Mercury 50. A sales brochure and two separate technical data sheets are now available.

As part of Solar's in-kind contribution, Solar has commissioned the construction of a one-third scale model of the Mercury 50 using actual drawings of the product with ProE/CADS. The model is being built by DCI, Inc. in Kansas and should be completed in the first quarter of 1998. The model will be shown at various trade meetings and exhibitions to further market interest and knowledge.

WBS 62000: Manufacturing Readiness

Significant momentum was gained during this reporting period. The Harbor Drive facility (TMO) has been working on long range planning with the Mercury 50 program as a cornerstone of that planning. MRI has been folded into the long range strategy sessions, and the data which they have generated on load analysis has become the baseline for the decision making process. The strategy sessions are close to reaching consensus as to what is expected to be the high water mark for the number of engines which TMO can support. Once that decision is reached, back-scheduling can begin on alternatives for increased capacity.

The Cold CAM and Rotor CAM have agreed on new shop layouts to support the increased loads. The layouts are being fine tuned with an in-depth facility and load analysis. The plan includes a phased relocation of equipment. A five year plan is also being prepared for the purchase of new equipment.

Work in the Hot CAM is gaining momentum. Load analysis reports have been created using the long range forecast in the nozzle/tip shoe, and fuel injector areas. This data is presently being reviewed with management. Two producibility projects are also in work.

Manufacturing readiness at the Kearny Mesa site is still in the fact finding stage.

4.0 PROGRAM MANAGEMENT

4.1 Program Management Activities

The Continuation Application for Budget Period 2 was prepared and submitted. The application included an inception to date progress report, a written proposal of work to be performed, a cost proposal, and environmental checklist and all required certifications.

The California Energy Commission (CEC) notified Solar that funding issues had been resolved paving the way for a grant to Solar under the Defense Conversion Matching Funds Program. The grant stems from the same 1995 application that resulted in a \$250,000 grant from California Trade & Commerce Agency, Office of Strategic Technologies described in earlier reports. The CEC grant of just over \$300,000 is expected to be approved in early January. It will be used to support a demonstration of catalytic combustion on an existing (Saturn) Solar gas turbine.

The ATS-L engine program has been a pilot project for the Open Plan software over the past four months. "What if" scenarios are being generated for different engine configurations and development plan schedules. Cost estimates developed with Open Plan have been used as inputs into the ATS Continuation Proposal for Budget Period 2.

4.2 Program Status

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

As of the end of December there was an unfavorable 55.0% schedule variance against the 6 year baseline for the overall ATS program (53.6% last quarter). This is principally attributable to funding constraints resulting in a planned delay to the large engine program. A 0/100 percent complete assumption for program milestones in assessing progress on tasks also conservatively impacts the variance assessment. The retraction of previously issued CPDs during this quarter for revision and rerelease has had a minor negative impact on the schedule variance.

Solar also shows an unfavorable cost variance of 13.0% (15.1% last quarter) that is due in large part to the high degree of outsourcing and expediting to maintain project schedule on the Mercury 50 program.

The Mercury 50 Team is holding to the key target of a June 1, 1998 commencement of the first in-house engine test. However, this date is considered to be 8-10 weeks at risk. The principal items currently pacing the Mercury 50 schedule are:

- Stage 1 and 2 Turbine Blades
- Stage 1 Turbine Nozzle Segment
- Turbine Sliding Ring
- Stage 2 Tipshoe
- Compressor Aft Hub
- Compressor Stators (Stages 5, 7, 9 and 10)
- Center Frame Structure