Advanced Turbine Systems Program Conceptual Design and Product Development

**Quarterly Report
November 1994 - January 1995**

Work Performed Under Contract No.: DE-AC21-93MC30246

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

By
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February 1995

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CONTENTS

<u>Paragraph</u>		<u>Page</u>
	EXECUTIVE SUMMARY	1
1.0	WORK STATUS	1
1.1	Task 4 - Conversion to Coal	2
1.2	Task 8 - Design and Test of Critical Components	2
	1.2.1 Subtask 8.1 - Low Pressure Drop Recuperator	2
	1.2.2 Subtask 8.2 - Subscale Catalytic Combustion Rig	3
	1.2.3 Subtask 8.3 - Autothermal Fuel Reformer (ATR)	5
	1.2.4 Subtask 8.4 - Dual Property Turbine Disc	6
	1.2.5 Subtask 8.5 - Full-Scale, Single-Can Catalytic Combustor Rig	7
	1.2.6 Subtask 8.6 - Total Plant Controls	7
	1.2.7 Subtask 8.7 - Recuperator Materials	8
	1.2.8 Subtask 8.8 - Low Cost Combustor Materials (Ceramics)	8
	1.2.9 Subtask 8.9 - Advanced Ceramic Material	10
2.0	PROGRAM SCHEDULE AND BUDGET	11
2.1	Schedule	11
2.2	Budget	11
3.0	FUTURE INVESTIGATIONS	11
	APPENDIX 1 - GLOSSARY	12

FIGURES

<u>Figure</u>		<u>Page</u>
1	Transient Response Curve of Recuperator	4
2	Standard f&j Core Tests	4
3	Flattened Tubes Tests and FEM Strain Comparison at Room Temperature	5
4	Tube Reactor for Reforming Catalyst Screening Tests	6
5	Autothermal Fuel Reforming Test Rig	6
6	Subscale Catalytic Combustor Catalyst Inlet Velocity Profiles	8

TABLES

<u>Table</u>		<u>Page</u>
1	Thin Foil Creep Test Results	9

EXECUTIVE SUMMARY

This Quarterly Technical Progress Report covers the period November 1, 1994, through January 31, 1995, for Phase II of the Advance Turbine Systems (ATS) Program by Solar Turbines Incorporated Under DOE contract No. DE-AC21-93MC30246. The objective of Phase II of the ATS Program is to provide the conceptual design and product development plan for an ultra high efficiency, environmentally superior and cost competitive industrial gas turbine system to be commercialized by the year 2000. A secondary objective is to begin early development of technologies critical to the success of ATS.

Tasks 1, 2, 3, 5, 6 and 7 of Phase II were completed in prior quarters and their technical results are discussed in the quarters and their technical results are discussed in the corresponding Quarterly Technical Progress Report and in Topical Reports. Technical progress covered in this report, then, is confined to Task 4 and the nine subtasks under Task 8, "Design and Test of Critical Components." These nine subtasks address six ATS technologies as follows:

- Catalytic Combustion - Subtasks 8.2 and 8.5
- Recuperator - Subtasks 8.1 and 8.7
- Autothermal Fuel Reformer - Subtask 8.3
- High Temperature Turbine Disc - Subtask 8.4
- Advanced Control System (MMI) - Subtask 8.6
- Ceramic Materials - Subtasks 8.8 and 8.9

Subtasks 8.4 through 8.9 were added to the content of Task 8 by Revision A003 to the contract effective September 27, 1994.

Two papers relating to ATS Phase II were presented by Solar at the ATS Annual Review on November 9, 1994, as follows:

"ATS Program Overview," by Dr. D.A.Rohy, Director, Advanced Turbine Systems.

"Industrial System Concept Development," by K.W.Karstensen, ATS Phase II Program Manager.

Contract labor and cost status as of January 31, 1995:

Labor: 17,969 hours versus 21,712 hours planned.
Total Program Cost*: \$2258K versus \$3289 planned.

*Including Solar's contractual cost share.

8,552 labor hours have been charged to an internally funded project directly related to ATS. This represents cost sharing of approximately \$770,000 in addition to that provided for in the contract.

1.0 WORK STATUS

Tasks 1, 2, 3, 5, 6 and 7 have been completed and Topical reports have either been submitted or are in preparation.

1.1 TASK 4 - CONVERSION TO COAL

Start of work on Task 4 was delayed until near-final cycle conditions for the ATS system selected in Task 3 as well as for interim systems identified by Tasks 5, 6 and 7 were established. Now that this data is available work has been started.

Four approaches to handling coal- and biomass-derived fuel have been identified. They are direct firing, pressurized fluidized bed combustion (PFBC), gasification and indirect firing. Direct firing is being evaluated in the light of experience gained from prior DOE-METC sponsored work over the past ten years. Gasification is the approach most useable with the ATS combustion system modified to some extent. PFBC and indirect firing will present significant control challenges during an engine start up and during large scale load changes. The large air volume in these systems will increase reaction time.

The infrastructure required for all of these systems is significant and will be a major factor in the selection of one for further development in the future. Sizing of the direct fired system – combustion zone and injectors – is under way based on data obtained during the Coal-Fired Centaur Program. Upon completion of the definition of a direct fired system, work will continue on the other three options.

1.2 TASK 8 - DESIGN AND TEST OF CRITICAL COMPONENTS

During this quarter, work progressed on all nine of the Task 8 subtasks as reported in the following discussion.

1.2.1 Subtask 8.1 - Low Pressure Drop Recuperator

Subtask 8.1 has three objectives: to measure performance of the ATS recuperator over the range of operating conditions; to determine the basic heat transfer and flow loss characteristics of the core geometry; to validate analytical methods employed to predict core creep life. The subject of these investigations is the low pressure drop core selected for incorporation in the Primary Surface Recuperator (PSR) to be used with Solar's ATS.

The first objective is addressed by operation of the steady state recuperator test rig located at the Caterpillar Technical Center near Peoria, IL. This testing was completed during the quarter having produced data at 35 different operating conditions of pressure temperature and mass flow. At this point the core developed sufficient air leakage to offset the test results significantly, so the test was terminated. 45 operating points were selected in the original test plan. The missing data is internal to the planned array of operating conditions and does not represent a curtailed range of data. The development of leakage has been attributed to fabrication expedients used in the test core which will not appear in full sized engine recuperators. Data from this test is currently being analyzed and the results will be reported in a Topical Report next quarter.

Transient testing of the recuperator core was also performed in order to obtain data on the core's transient performance. This data will eventually be used in validation of a transient recuperator model. The raw data are shown in Figure 1. The test was run by operating the rig at steady-state for a period followed by a sudden step change in gas temperature – effected by cutting off fuel flow to the rig combustor. This is observed in Figure 1 by a sudden decrease in gas inlet temperature followed by slower decay of other temperatures – gas outlet and air outlet. The air inlet temperature remains constant having been set at its steady state level.

The second objective is addressed by the transient test rig, or "f & j rig," also located at the Caterpillar Technical Center. This rig provides data for calculation of the Fanning friction factor and Colburn heat transfer modulus. These parameters define the flow loss and heat transfer capacity, respectively, of a heat transfer surface and are used in the design and performance prediction and analysis of recuperators. The gas-side surface test article has been delivered to the Technical Center and the air-side test article will arrive early in next quarter. In the interim, the integrity of the rig was evaluated by a repeat test of a "calibration" core first operated in the rig in 1973. Figure 2 shows that the calibration of the rig has remained stable for over 20 years.

Creep evaluation, the third objective, is conducted using a flattened tube to simulate a scaled-up cross section of the recuperator primary surface folded profile. The scale-up is necessary in order to provide a test article of sufficient size to attach strain gages. A room temperature pressure test shows that strain measurements are in good agreement with an ANSYS finite element model at pressures below 200 psi—the normal range of operation of ATS recuperators (Figure 3). The test work has advanced into the high temperature creep test stage and has progressed past the point of strain gage saturation. From that point forward, creep strain is being measured by dimensional measurements of the tube itself.

1.2.2 Subtask 8.2 - Subscale Catalytic Combustion Rig

This task was formerly titled "Low Pattern Factor Combustor." and had as its objective the reduction of combustor outlet temperature pattern factor to a level compatible with very high average temperature levels. Revision A003 to the contract added Subtask 8.5, originally titled "Low Emissions Combustor." Both subtasks are now addressing the development of very low emission and low pattern factor catalytic combustion for Solar's ATS. Subtask 8.5 is now titled "Full Scale Catalytic Combustion Rig." and will feature a single full-scale ATS combustor can.

During the period covered by this report, subscale rig was operated with a longer bed (10.5 inches versus the earlier 6.5 inch bed) than in the previous work. This earlier work had produced very low NO_x emissions (down to 4 ppmv) but apparently incomplete combustion resulted in CO and UHC emissions exceeding 100 ppmv. Increased bed length was selected to address this issue.

The longer catalyst bed was operated in the subscale rig at 115 psig catalyst inlet pressure and with the inlet temperature varied from 850°F to 1080°F. Stable catalytic combustion (i.e., the auxiliary burner downstream of the catalyst bed is extinguished and the temperature rise across the catalyst is maintained) was maintained at catalyst inlet temperatures above 1020°F with the catalyst inlet air/fuel ratio (mass-based) between 39 and 45. Emissions results were worse all the way around than with the shorter bed. The bed was returned to the supplier, Engelhard Industries, for evaluation.

A second 10.5-inch long bed was obtained but testing is being deferred until an unacceptable catalyst inlet velocity profile has been corrected. Further analysis of the earlier test results suggest that the fuel flow measurement may have been in error in that actual fuel flow was less than indicated. Before further testing, a new fuel control valve will be installed in order to regulate fuel flow in so as to maintain a constant air/fuel ratio. The velocity profile problem is being addressed through modifications to the fuel pre-mixer. Testing will resume when these modifications have been completed.

Figure 1. Transient Response Curve of Recuperator

Figure 2. Standard f&j Core Tests

Figure 3. Flattened Tubes Tests and FEM Strain Comparison at Room Temperature

1.2.3. Subtask 8.3 - Autothermal Fuel Reformer (ATR)

Autothermal fuel reformation consists in reacting a hydrocarbon fuel such as natural gas (methane) with steam in order to produce a "reformed" fuel with a high hydrogen content – on the order of 70 percent or greater. Since hydrogen burns in leaner mixtures and at lower temperatures than other fuels, this "reformed fuel" will produce inherently lower NO_x emissions. In an ATS, a combustor can with a built-in ATR has the potential of very low emissions. In addition, ATRs can be designed for use with a wide variety of alternate fuels – coal- and biomass-derived gaseous fuels, for example – and can also increase gas turbine efficiency when the steam required for the process is produced with recovered exhaust heat. Solar's ATR project was begun using a tube reactor as shown in Figure 4. This rig has been used to establish the basic characteristics of the process and, further, to address several durability issues such as catalyst life and the effect of certain acidic compounds (H₂S, HCl, for example) often found in raw natural gas. These results were reported in the previous quarter. The tube reactor is now being modified in anticipation of future work on diesel fuel and coal- and biomass-derived fuels.

During the period covered by this report, an ATR rig as shown in Figure 5 was completed, installed in the test cell and operated through a shakedown test. This rig will evaluate performance of an ATR under actual ATS operating conditions. An injector is used for the premixing of fuel and steam. A pilot combustor partially oxidizes the fuel to provide the heat required for preheating this mixture to reformation temperature. Following a mixing section, the reforming catalyst produces the high hydrogen secondary fuel to be burned in a post-combustor where its heat content and other characteristics can be determined. This rig will be in operation early in the next quarter.

Figure 4.

Tube Reactor for Reforming Catalyst Screening Tests

Figure 5.

Autothermal Fuel Reforming test Rig

1.2.4 Subtask 8.4 - Dual Property Turbine Disc

The objective of this subtask is to provide Solar's ATS with a turbine disc with improved high temperature creep strength in the rim portion while maintaining current levels of low cycle fatigue (LCF) strength/life at the hub. This dual property disc technology has additional application in increasing the efficiency of Solar's current and future non-ATS product.

The approach will be to achieve a mechanical bond between a cast high temperature alloy (such as MAR-M-247) in the rim area with a conventional turbine disc alloy in the central hub. An initial statement of work developed with the subcontractor, Howmet, proposed to use Howmet's Vacuum Plasma Structural Deposition (VPSD) process for producing dual property discs. As the design definition of Solar's ATS progressed, however, it became apparent that the design required discs that were too large for this process.

The statement of work was then revised to define a program based on solid-to-solid bonding techniques such as hot isostatic pressing (HIPing). Activated diffusion bonding will also be examined with an early (July, 1995) down selection between the two processes. A supply of the rim alloy (MAR-M-247) has been procured and is ready for the spray casting process. During the next quarter, heat treatments compatible with both alloys will be determined and single point machining methods for the bonding couple will be developed, positioning the project for the first bonding trials.

1.2.5 Subtask 8.5 - Full-Scale, Single-Can Catalytic Combustor Rig

This subtask was added by revision A003 to the contract and was originally titled "Low Emissions Combustor." As part of an overall catalytic combustor project along with Subtask 8.2, it is now defined as catalytic combustor development using a full ATS scale single can rig.

During this quarter, design of the test rig proceeded up to the point of detail definition of the combustor based on results from Subtask 8.2. These results have led to the conclusion that the full-scale combustor should have provisions for varying the air flow split between the catalyst, part-load injector and the dilution zone. This feature is being incorporated in the rig design.

Rig design will proceed up to the detail drawing stage based on current results from the sub-scale rig in Subtask 8.2. Completion of detail definition and procurement of these hardware items will be deferred until problems with the sub-scale rig are resolved. These problems are related to an unsatisfactory velocity profile of the gasses entering the catalyst bed.

Measurements of the velocity profile of gases entering the catalyst were made on the cold flow bench. A five-hole pitot probe was traversed directly downstream of the premixer section in two radial directions. These tests were completed at ambient conditions (70°F, 1 atms). The results, included in Figure 6, are plotted as velocity versus position across the 4 inch cylindrical injector catalyst inlet cross-section. On this plot 2 inches corresponds to the flow path centerline. Tests were conducted at two different inlet flowrates (1 and 2.5 percent DP/P) and at perpendicular diameters (A and B). The repeatable test results indicate a +44 percent peak-average variation in the flow field for these test conditions. Our goal has been a +10 percent peak-average variation. Modifications to the premixer inlet by installing flow straightening screens and improving the inlet radius had little effect on the profile. Plans have been made to examine three additional premixer configurations intended to flatten the catalyst inlet velocity profile. These changes include replacing the diffusing inlet duct with a constant area duct, placing a one-inch diameter ceramic rod along the combustor centerline with and without a flow straightener. The flow straightener will consist of a blank (untreated) section of 400 cells/inch catalyst substrate.

1.2.6 Subtask 8.6 - Total Plant Controls

During this quarter the Man-Machine Interface (MMI) data acquisition module was developed for the incumbent hardware, an Allen-Bradley microprocessor and the MMI test work station installed. Initial real-time meters routines, windowing techniques and real-time trending routines were developed. An initial database was constructed from MMI descriptors, scaling and memory identification. The latter includes routines to retrofit existing display systems.

The proof-of-concept task has been completed and a design specification is being developed. In addition to the data acquisition module for an Allen-Bradley Programmable Logic Controller (PLC), another is being developed for a Modicon PLC. During the proof-of-concept phase, it was determined that the system resources required by the Graphical User Interface (GUI) would not allow some of the functions required for the ATS application. Evaluation of an alternate GUI requiring fewer system resources has been started.

Figure 6. Subscale Catalytic Combustor Catalyst Inlet Velocity Profiles

1.2.7 Subtask 8.7 - Recuperator Materials

Thin foil creep testing continued throughout the quarter. Test results accumulated as of the end of the quarter are listed in Table 1.

These tables are cumulative from month to month, so we need use only the last one of the three.)

1.2.8 Subtask 8.8 - Low Cost Combustor Materials (Ceramics)

During the quarter, test articles of three candidate materials were ordered:

<u>Material</u>	<u>Supplier</u>
B-30	LoTEC
Altra KVS 16	International Thermoproducts
System 2.2	AEA Technology

Requirements for the test rig have been identified in anticipation of arrival of the test articles and the start of testing early in the next quarter.

Table 1. Thin Foil Creep Test Results

Test No.	Direction	Material	t (in)	Stress (psi)	Temp(F)	5%Creep Calcul. HRS	5%Creep Actual HRS	Rupture Actual HRS
#3	Unkwn	SS 347	0.0032	17000	1300	127	166	195
#4	Long	SS 347	0.0032	17000	1300	127	165	194
#6	Long	SS 347	0.0032	17000	1200	2715	k	1500
#7	Trans	SS 347	0.0032	17000	1300	127	224	251
#8	Unkwn	SS 347	0.0032	17000	1200	2715	2391	2630
#9	Trans	SS 347	0.0032	17000	1200	2715	f	1203
#12	Long	SS 347	0.0032	17000	1250	560	i	842
#13	Trans	SS 347	0.0032	17000	1250	560	j	842
#14	Long	SS 347	0.0032	17000	1250	560	l	460
#16	Trans	SS 347	0.0032	14000	1300	277	h	220
#17	Long	SS 347	0.003	17000	1250	560	a	725
#18	Trans	SS 347	0.003	17000	1250	560	960	1025
#19	Unkwn	SS 347	0.003	14000	1300	277	b	490
#20	Trans	SS 347	0.003	14000	1300	277	700	1020
#21	Unkwn	SS 347	0.0025	11000	1300	649	1331	2080
#22	Unkwn	SS 347	0.0025	11000	1300	649	e	3773
#23	Unkwn	SS 347	0.0025	9000	1300	1170	2556	4400g
#24	Unkwn	SS 347	0.0032	12000	1250	2154	2687	3158
#25	Trans	Inconel 625	0.0037	30000	1330	1344c	109	436
#26	Long	Inconel 625	0.003	11000	1440	3360c	739	d
#27	Trans	Inconel 625	0.003	11000	1440	3360c	637	1077g

Table 1. Thin Foil Creep Test Results (continued)

Test No.	Direction	Material	t (in)	Stress (psi)	Temp(F)	5%Creep Calcul. HRS	5%Creep Actual HRS	Rupture Actual HRS
#28	Trans	Inconel 625	0.003	8000	1480	4569c	442	696g
#29	Long	Inconel 625	0.003	8000	1480	4569c	409	685g
#30	TBD	SS 347	0.0035	7000	1350	2065	m	
#31	Long	Inconel 625	0.0035	20000	1350	700	m	
#32	Trans	Inconel 625	0.0035	20000	1350	700	m	
#33	Long	Inconel 625	0.0035	30000	1330	1344c	m	
#34	Unkwn	Inconel 625	0.0035	15000	1350	2663	m	
#35	Unkwn	Inconel 625	0.0035	30000	1250	1099	m	

a-Ruptured at 2.5% creep.

b-Ruptured at 3.5% creep.

c-The data is for 0.008 inch foil.

d-The test coupon did not fail. The test stopped after 18% creep.

e-Ruptured at 4.4% creep.

f-Ruptured at 0.8% creep.

g-This is the 10% creep value. The test coupon did not fail.

h-Ruptured at 3.1% creep.

i-Ruptured at 3.8% creep.

j-Ruptured at 2.5% creep.

k-Ruptured at 1.55% creep.

l-Ruptured at 0.87% creep.

m-test is in progress

1.2.9 Subtask 8.9 - Advanced Ceramic Material

The statement of work provided by B.F.Goodrich, the primary subcontractor on Task 8.9 has been modified slightly although they stay well with the scope of the original proposal. The reason for these changes is to direct the research effort to support more fully the gas turbine cycle proposed for Phase III. To this end a turbine transition duct has been substituted for the "combustor transition duct" originally proposed, in order to address a component more critical to the support of high thermal efficiency. The turbine blade that will be produced will now be representative of the power turbine rather than those used in the gas producer section. The use of an uncooled power turbine blade, which this technology will provide, is essential to the success of the Phase III gas turbine

system. A new proposal has been completed that delineates these changes and this will be submitted for approval by DOE together with the justification for the selection of B.F. Goodrich as the subcontractor.

2.0 PROGRAM SCHEDULE AND BUDGET

2.1 SCHEDULE

As of January 31, 1995, Solar's Phase II program continues to run approximately one to one and a half months behind schedule. Tasks 5, 6 and 7 were completed approximately on schedule, although there was some delay in completing the Topical Reports for Tasks 5 and 6. Task 8 continues to operate late to plan primarily due to the fact that "plan" was based on a fixed start date for the Revision A003. The duration of the final contracting process for this revision did not allow this start date to be achieved. For this reason and due to the requirement for revision of the Subtask 8.4 statement of work, Solar will request an extension to the contracted period of performance for Task 8 at no increase in cost to the DOE.

2.2 BUDGET

As of January 31, 1995, a total of 17,969 labor hours have been charged to the contract versus 21,712 hours planned. This is reflected in a total program cost (including Solar's contractual cost share) of \$2,258K versus \$3,289 planned. This apparent underrun is temporary in nature and reflects the "late to plan" status cited above. An additional portion of the underrun is a result of accumulated subcontractor costs that have not yet been billed to Solar or passed on to the DOE. At this point Solar's ATS Phase II work is expected to be completed within the labor hours and cost currently budgeted in the contract as amended by Revision A003. Revised Cost and Labor Plans to be submitted upon DOE approval of a requested extension of the period of performance will provide a plan more reflective of the actual spending pattern.

In addition to the charges to the contract, an additional 8,552 labor hours have been charged to an internally funded project directly related to ATS. This represents cost sharing of approximately \$770,000 in addition to that provided for in the contract.

3.0 FUTURE INVESTIGATIONS

During the next quarter work on all contracted Task 8 projects will continue as planned. Toward the end of the quarter, Subtask 8.1 (Low Pressure Drop Recuperator) and 8.3 (Autothermal Fuel Reformer) will be near completion and their respective Topical Reports in preparation.

During this period, Solar will also carefully review the content and progress on each of the Task 8 projects to ensure that they are in full support of the Phase III ATS and providing the expected program benefits and risk mitigation.

APPENDIX 1

GLOSSARY

ACE	<u>A</u> dvanced <u>C</u> omponent <u>E</u> fficiency. A Solar-funded multi-disciplinary, advanced technology program. It currently includes programs on compressors, turbines, cooling, and ducting.
ATS	<u>A</u> dvanced <u>T</u> urbine <u>S</u> ystem. A gas turbine-based energy conversion system as defined To the U. S. Congress by the U. S. Department of Energy (DOE). An ATS is distinguished from current gas turbines by markedly increased thermal efficiency, reliability, availability and maintainability and by decreased exhaust emissions and cost of power produced.
BASELOAD	Typically describes a specific number of operating hours the power generation system is operating. In this case it represents (on average) 6500 hours.
BZP	<u>B</u> arium <u>Z</u> irconium <u>P</u> hosphate. A family of materials whose composition can be tailored to result in low, or zero, coefficient of thermal expansion. It is resistant to thermal shock, and is stable to 1200°C.
CFATS	<u>C</u> oal- <u>F</u> ired <u>A</u> dvanced <u>T</u> urbine <u>S</u> ystem. An advanced turbine system modified to operate on coal or coal derived fuel.
CFCC	<u>C</u> ontinuous <u>F</u> iber- <u>R</u> einforced <u>C</u> eramic <u>C</u> omposite. A high temperature composite material which consists of a ceramic matrix reinforced with fabric, tape, or rows of a high modulus fiber. CFCC's are typically not as flaw sensitive as monolithic ceramics, and can be fabricated into large parts such as combustion chambers.
CHORD	The axial length of an airfoil measured along a line drawn tangent to the leading- and trailing-edge radii. Chord is the characteristic dimension used in scaling of airfoils.
CSGT	<u>C</u> eramic <u>S</u> tationary <u>G</u> as <u>T</u> urbine. A DOE-funded program contracted to Solar Turbines Incorporated. The program goal is to demonstrate improved performance of a production gas turbine by retrofitting key components with ceramic counterparts for a 4000-hour field test.
EDX	<u>E</u> lectron <u>D</u> iffraction <u>X</u> ray.
EFFECTIVENESS	(ϵ_R for recuperator, ϵ_i for intercooler). A characteristic of a heat exchanger -- the ratio of the amount of heat transferred to the total heat available in the hot fluid between its entry temperature and the entry temperature of the cold fluid.
EFFICIENCY, COMPRESSOR	(η_c). Ratio of the work imparted to the air flow to the total work input. Unless otherwise specified, "adiabatic" efficiency (subscript. - ad) is implied, i.e., flow conditions at both inlet and outlet are in terms of absolute, or total, pressure

	and temperature. "Polytropic" efficiency (subscript. - p) is the theoretical efficiency of a very large number of identical low pressure-ratio stages and essentially normalizes pressure ratio for comparison of differing compressors.
EFFICIENCY, THERMAL	(η_{th}). Also termed cycle efficiency. The ratio of energy input to energy output from a gas turbine. Unless specifically designated otherwise, thermal efficiency of an ATS will be defined on the basis of net power output from the turbine shaft.
EFFICIENCY, TURBINE	(η_t). Ratio of the work produced by a turbine to the work it extracts from the gas flow. When applied to a GP turbine, total-to-total efficiency is implied, this definition being based on total or absolute inlet and exit conditions. When applied to a power turbine, total-to-static efficiency is implied, thus accounting for static pressure recovery as a result of kinetic energy conversion in the exhaust diffuser.
FGM	Functionally Graded Material. A multi-layer material or coating system with each layer graded to provide different properties at the surface of the component relative to the core or substrate. An illustrative example would be a turbine tip-shroud with a top coating tailored for abrasability, an intermediate layer designed for oxidation resistance, and a substrate tailored for high strength.
GAS PRODUCER	(Abbr. GP) An element, or module, of a gas turbine which is required to provide a hot gas stream capable of propelling a power output turbine or other energy conversion device. As a minimum it consists of a compressor, a combustor, a turbine and associated shafting. Each of these components, in turn, may be of any of several types and may consist of one or more stages.
GPT	Gas Producer Turbine. May include HP and LP turbines.
GFATS	Gas-Fired Advanced Turbine System. An advanced turbine system which uses natural gas for fuel.
GP	See GAS PRODUCER.
HCF	High Cycle Fatigue. High cycle fatigue is characterized as the fatigue mechanism where vibratory loads are superimposed onto a steady state loading condition. The typical example is turbine blade under aero excitation. The turbine blade exhibits a significant steady state stress level due to the centrifugal load, where vibratory stresses are induced by high frequency pressure perturbations in the gas stream. Vibratory stress levels are typically within the elastic range of the materials. Failures typically occur due to excitation at the component's natural frequency, setting up a resonant condition. This failure mode is associated with large numbers (10^5 - 10^7) of low stress amplitude cycles.

HIP	<u>Hot Isostatic Pressing</u> . A process for simultaneously heating a component, or powder metallurgy compact while subjecting it to isostatic pressure using an inert gas atmosphere. The temperature and pressure area are high enough to produce densification of the materials.
HP	<u>High Pressure</u> . This prefix is used to designate an individual section of a series pair of aerodynamic components operating in the high pressure regime of the two. HPC designates the high pressure compressor and HPT designates the high pressure turbine of an HP, or high pressure, spool.
INTERCOOLER	A heat exchanger placed between stages of compression in a gas turbine in order to remove heat from the compression air thereby reducing the temperature of air going to and through the succeeding stage(s).
I.O.U.	<u>Investor Owned Utility</u> . There are approximately 260 investor owned utilities in the United States. They are differentiated by the fact that they are owned through a stock ownership plan and are usually traded on the open market. they are more tightly regulated in their service area by regulatory bodies like public utility commissions than the Municipal utilities or the cooperative utilities.
IPP	<u>Independent Power Producer</u> . A non-regulated producer of electric energy. Currently the majority of these IPPs are larger power generation stations much like the Central Power Station that is owned by the Investor Owned Utilities.
LAC	<u>Levelized Annual Cost</u> . The name of the financial model used by the utilities to determine the cost of the capital equipment of the usable life of the equipment. Takes into consideration present worth arithmetic. Sometimes interchanged with book value analysis/life cycle analysis.
LCF	<u>Low Cycle Fatigue</u> . The fatigue mechanism typically associated with large thermal or mechanical loading. The cycles are typically a transient loading condition, such as start-up and shut-down of an engine. Low cycle fatigue is characterized by allowable pseudo elastic strain range for a material whereby a fatigue crack will develop after a specified number of cycles. typically LCF is considered cyclic loading of the base load leading to plastic deformation. Cycles are on the order of less than 10,000 to 15,000 cycles.
LP	<u>Low Pressure</u> . This prefix is used to designate the individual of a series pair of aerodynamic components operating in the lower pressure regime of the two. LPC designates the low pressure compressor and LPT designates the low pressure turbine of an LP, or low pressure, spool.
MCrAlY	A designation for an overlay coating applied to superalloy turbine components for increased oxidation and corrosion resistance. "McrAlY" is derived from the elemental constituents of the coating i.e., Cr = Chromium, Al = Aluminum, Y = Yttrium M = Ni Fe or Co (depending on substrate).
NEPA	<u>National Environmental Policy Act</u> .

PATTERN FACTOR (Abbr. PF). A parameter defining the range of temperatures extant in the exit gas flow from a gas turbine combustor.

$$PF = \frac{T_{MAX\ EX} - T_{AVG\ EX}}{T_{AVG\ EX} - T_{AVG\ INLET}}$$

All temperatures are absolute.

PF See **PATTERN FACTOR**.

PITCH The circumferential distance between two adjacent airfoils in an axial turbomachinery annulus. It is equal to 2 times pi times the radius from the annulus centerline to the subject airfoil divided by the number of airfoils in the annulus.

POWER TURBINE (Abbr. PT). A turbine stage in a gas turbine whose work output is used solely to drive the load with none being used by the compressor. In a 2-shaft gas turbine, the power turbine is fixed to a separate shaft from that of the GP turbine. It is normally -- but not required to be -- the last, or lowest pressure, turbine stage.

PR Pressure Ratio. For a compressor or compressor stage, the ratio of outlet to inlet total pressure. For a turbine or turbine stage, the ratio of inlet to outlet total pressure.

PRIS Particle Rejection Impact Separator. A device located between the primary and secondary zones of a rich-lean coal fired combustor which removes particulates from the gas stream.

PROFILE The distribution of gas temperature within a single radial plane of a gas turbine combustor exit or other downstream annulus. The temperature profile represents the environment experienced by a turbine blade as it rotates through a temperature pattern thus averaging out circumferential variations. A "Profile Factor" can be defined using the Pattern Factor equation but confining the temperature data to a single radial plane.

PSR Primary Surface Recuperator. Solar's proprietary design in which all heat exchange surfaces are "primary," i.e., transferring heat in their transverse direction. (A "secondary" surface, such as a fin, transfers heat in a lateral direction).

PT See **POWER TURBINE**.

RECUPERATOR A heat exchanger placed in the exhaust gas stream of a gas turbine in order to extract heat from the exhaust gases and return it to the cycle by heating the combustor inlet air. The term "recuperator" designates a static device as opposed to a "regenerator" which is a periodic device.

SHROUDED A type of turbine blade design. A "shrouded" turbine features a short circumferential shroud segment attached to each blade tip. Together, these segments make up a full circular, rotating shroud. The outside surface of this

shroud normally carries one or more circumferential seal elements. Conversely, a "non-shrouded" turbine is characterized by open blade tips rotating in close proximity to a stationary shroud.

SPOOL	The compression and expansion element of a gas producer, consisting of a compressor, a turbine and associated shafting. The turbine is designed so as to provide the amount of work required for the compression process plus any mechanical losses. A gas producer includes one or more spools and will be designated as 1-spool, 2-spool, etc.
SR	<u>Stress Rupture</u> . Stress rupture is the failure mechanism where gross rupture occurs due to time dependent deformation caused by steady stress at elevated temperatures. The mechanism at intermediate stages of deformation is called creep and is measured in terms of plastic strain. Stress rupture is usually associated with the Larson-Miller Parameter (LMP) which correlates the relationship between service life in hours and service temperature at a constant stress level. For a given material, Larson-Miller Parameter curves are developed which depict the LMP as a function of steady stress level.
STAGE WORK FACTOR	The ratio of work actually performed by a flow of cooling air within a turbine stage, to that possible if the flow were added to the hot gas stream.
STALL	A condition arising in one or more stages of an axial compressor in which the design pressure-velocity-rotational speed relationship is disrupted such that separation of the air flow from the blade contour occurs.
STANDBY	Use as a descriptor of a power generation station or unit that is only drawn upon when there is a demand. It currently is thought of as an emergency back-up unit in case the primary system fails, or when the primary unit cannot met the load demand. Sometimes called an "on-demand" system.
SURGE	The condition occurring when a compressor is operated below its minimum stable air flow rate for a given rotational speed. Surge is characterized by cyclic backflow of air in the flowpath accompanied by violent pressure fluctuations. During surge all stages of the compressor will be in a stall condition.
TBC	<u>Thermal Barrier Coating</u> . A thermally insulating ceramic coating (ZrO_2) applied to superalloy combustor and airfoil components. The insulative properties of the coating allow increased turbine inlet temperatures while maintaining acceptable metal substrate temperatures.
T&D	<u>Transmission and Distribution</u> . The system used to get the power (or fuel) from the point of origin to the consumer.
TRIT	<u>Turbine Rotor Inlet Temperature</u> . The average gas temperature entering the rotor annulus of the first turbine stage in a gas turbine. It is less than the average combustor exit temperature due to the mixing of spent cooling air flow from upstream sources, primarily the first stage nozzle vanes.

TSSC

Two-Stage Slagging Combustor.

ZWEIFEL
COEFFICIENT

A measure of turbine blade loading based on pitch/chord ratio and gas turning angle as independent variables.