Advanced Turbine Systems Program - Conceptual Design and Product Development

Quarterly Report

November 1, 1995 - January 31, 1996

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For
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EXECUTIVE SUMMARY

This Quarterly Technical Progress Report covers the period, November 1, 1995, through January 31, 1996, for Phase II of the Advanced 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, 4, 5, 6 and 7 of Phase II have been completed in prior quarters. Their results have been discussed in the applicable quarterly reports and in their respective topical reports. Final editions of these topical reports have been submitted to the DOE. This quarterly report, then, addresses only the remaining seven of the nine subtasks included in 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

Two of these nine subtasks (8.1 and 8.3) were completed in prior quarters and Topical reports submitted to the DOE.

Major technological achievements from Task 8 efforts during the quarter are as follows:

- Hot isostatic press (HIP) -bonded subscale dual alloy turbine discs have completed ultrasound inspection both before and after heat treat. There was no evidence of any incomplete bonding or other defects either in the joint or elsewhere in the parts. Specimens have been removed from several of the discs for properties testing.
- Coupons of both EB and laser edged-welded (Type 347 Stainless Steel to Inconel 625) have been successfully folded into primary surface recuperator finned stock at Solar's recuperator facility. These samples were further subjected to the "crushing" process required to produce the cross-flow portion of the air cell. Visually, 100 percent success is apparent and will be confirmed by subsequent sectioning and metallographic examination.

Contract labor and cost status as of January 31, 1996:

Labor: 34,182 hours versus 29,739 planned:
Total Program Cost*: \$4327K versus \$4727K planned.

*Including Solar's cost share.

9249 labor hours have been charged to an internally funded project directly related to ATS. This represents cost sharing of approximately \$633,000 in addition to that provided for in the contract.

1.0 WORK STATUS

Tasks 1, 2, 3, 4, 5, 6 and 7 have been completed and topical reports submitted for each.

1.1 TASK 8 - DESIGN AND TEST OF CRITICAL COMPONENTS

During this quarter, work progressed on seven of nine subtasks in Task 8. Two subtasks, 8.1 -- Low Pressure Drop Recuperator -- and 8.3 -- Autothermal Fuel Reformer -- were completed in prior quarters and topical reports submitted.

1.1.1 Subtask 8.2 - Subscale Catalytic Combustion Rig

This subtask was added by Revision A003 to the contract and has been re-titled from "Low Emissions Combustor." Together with the original Subtask 8.2, it becomes a part of an overall catalytic combustion project.

This subtask is now being closed and a topical report being prepared on work completed. Any further work on the "subscale" rig in support of the "full-scale" rig of Subtask 8.5 will be reported under that subtask. The "subscale" rig essentially isolates the catalyst bed from a complete catalytic combustion "system" as represented in the "full-scale" rig. This allowed detailed study of the bed itself and identified the need to increase bed length and to provide a very even distribution of the fuel air mixture delivered to the inlet face of the bed. This information was used in designing the catalyst bed, fuel injection system and post-catalyst combustion region that make up the complete system of the "full-scale" rig.

1.1.2 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. Improving the high temperature creep strength of the rim portion contributes to gas turbine thermal efficiency by reducing the requirements for cooling air bleed flow. This technology can also be applied to Solar's current and future non-ATS product.

HIP-bonding of the MAR M 247 alloy rim to the Udimet 720 hub material has been very successful. Six prototype rotors have been bonded to date. An ultrasonic inspection technique has been developed for the prototype assemblies by QMI, Inc. in Costa Mesa, CA. This inspection has revealed no defects in 5 of the 6 prototypes. One of the disks (specimen No. 5) showed indications of extensive debond. Review of records at Howmet showed that specimen No. 5 experienced a rupture in the HIP can during the bonding process. It appears that the debond is related to this problem. The five good prototype rotors are currently being solution heat-treated, rapid air cooled and aged. The assemblies will be ultrasonic inspected again after the heat-treatment to determine if any cracking is induced.

Work is proceeding on schedule at Howmet with HIP-bond development. The prototype bonded disks have been ultrasonically inspected in the as-bonded condition by QMI, Inc. prior to heat treatment. The prototypes were then heat treated by Howmet using two solution treatments. The specimens were again ultrasonically inspected by QMI after heat treatment, and apparently no cracks or defects were induced by the quench cycle. Cylindrical specimens have been removed by EDM extraction for tensile and rupture testing across the bondline. Baseline mechanical properties testing of the Udimet 720 and Mar-M-247 unbonded materials has also been initiated.

Work continues on schedule at Southwest Research Institute (SwRI) toward development of an eddy current inspection technique for finding cracks in turbine disk blade slots. EDM-notched standards have been completed and meet all of the dimensional specifications. The standards will be used to develop the inspection technique. Fabrication of the probe scanning fixture was completed in January. A problem was initially encountered in delivery of the ET coils due to the very small size requirement. This problem was solved by SwRI and resulted in a minimal overall delay in the program. Inspection technique development will begin in January using a Nortec 24 ET inspection system provided by Solar. Solar personnel will witness/participate in the inspection of three production Solar turbine discs. The use of Solar equipment and involvement of Solar personnel will assure that the technology transfer from SwRI is complete.

Progress at Southwest Research Institute included completion of several notched rupture test specimens fabricated from the spraycast CM 247LC rim material. Failures are occurring in the specimen notch, indicating that the spraycast material is notch sensitive. This is an undesirable condition for turbine disk materials and its cause is being investigated.

1.1.3 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.

The basic design of this rig was completed earlier and placed on hold in order to allow for the detail design to accommodate changes indicated by the subscale rig test work of Subtask 8.2. Primarily these changes relate to continuing development of fuel injection methods for obtaining satisfactory catalyst inlet velocity and fuel/air mixture profiles and to providing sufficient post-catalyst volume to enable more complete CO burn out. These features have been defined and incorporated into the rig which has completed fabrication and assembly. The rig is now on a short hold for its designated test cell to be come available for its installation.

1.1.4 Subtask 8.6 - Total Plant Controls

During this quarter data has been acquired, scaled and displayed in the prototype Man/Machine Interface (MMI) system. Further system refinements were indicated before a general demonstration of the prototype could be considered. The initial management review was held in late in January and confirmed the selection of Windows NT as the operating system as well as other concepts described in the functional requirements document. Additional reviews are being planned.

Work began on developing the outline for the Detailed Design Specification. This document will serve two purposes. Initially, the decomposition of the system will provide a map of the design and development efforts required for the complete system. This will then be used in developing the project phases and plan. Secondly, the Design Specification document will be the repository for the detailed design of each of the modules, processes and data elements that make up the system. Previous design information for the Unix-based system will be integrated into this document as appropriate.

1.1.5 Subtask 8.7 - Recuperator Materials

Thin foil creep testing continued throughout the quarter. All test results to date (including prior quarters) are listed in Table 1. Results of additional creep testing performed by subcontractor Westmoreland Mechanical Testing and Research, Inc., are listed in Table 2.

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
#1	Long	SS 347	0.0032	17000	1300		discontinued	
#2	Tran	SS 347	0.0032	17000	1300		discontinued	
#3	Unknown	SS 347	0.0032	17000	1300	127	166	195
#4	Long	SS 347	0.0032	17000	1300	127	165	194
#5	Unknown	SS 347	0.0032	17000	1300		discontinued	
#6	Long	SS 347	0.0032	17000	1200	2715	k	1500
#7	Trans	SS 347	0.0032	17000	1300	127	224	251
#8	Unknown	SS 347	0.0032	17000	1200	2715	2391	2630
#9	Trans	SS 347	0.0032	17000	1200	2715	l	l
#10	Long	SS 347	0.0032	17000	1250		discontinued	
#11	Tran	SS 347	0.0032	17000	1250		1741	a
#12	Long	SS 347	0.0032	17000	1250	560	i	i
#13	Trans	SS 347	0.0032	17000	1250	560	j	j
#14	Long	SS 347	0.0032	17000	1250	560	l	l
#15	Tran	SS 347	0.0032	17000	1250		discontinued	
#16	Trans	SS 347	0.0032	14000	1300	277	h	h
#17	Long	SS 347	0.003	17000	1250	560	a	a
#18	Trans	SS 347	0.003	17000	1250	560	960	1025
#19	Unknown	SS 347	0.003	14000	1300	277	b	b
#20	Trans	SS 347	0.003	14000	1300	277	700	1020
#21	Unknown	SS 347	0.0025	11000	1300	649	1331	2080
#22	Unknown	SS 347	0.0025	11000	1300	649	e	e
#23	Unknown	SS 347	0.0025	9000	1300	1170	2556	g
#24	Unknown	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	g

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	4568c	442	g
#29	Long	Inconel 625	0.003	8000	1480	4569c	409	g
#30	TBD	SS 347	0.0035	7000	1350	2065	997	g
#31	Long	Inconel 625	0.0035	20000	1350	700	3580	n
#32	Trans	Inconel 625	0.0035	20000	1350	700	3507	n
#33	Long	Inconel 625	0.0035	30000	1330	1344a	352	m
#34	Unknown	Inconel 625	0.0035	15000	1350	2663	n	
#35	Unknown	Inconel 625	0.0035	30000	1250	1099	n	
#36 340-L	Long	Inconel 625	0.0035	30000	1330	—	274	m
#37 357-T	Trans	Inconel 625	0.0035	30000	1275	—	655q	q
#38 365-T	Trans	Inconel 625	0.0035	30000	1350	—	109	p
#39 334-L	Long	Inconel 625	0.0035	25000	1350	—	202	p
#40 353-T	Trans	Inconel 625	0.0035	22000	1480	—	7.8	23.1
41	Long	Haynes 230	0.003	20000	1300	—	n	
42	Trans	Haynes 230	0.003	20000	1300	—	n	

a- Test stopped at 2.5% creep.
 b- Test stopped at 3.5% creep.
 c- The data is for 0.003 inch foil.
 d- Test stopped at 18% creep.
 e- Test stopped at 4.4% creep.
 f- Test stopped at 0.8% creep.
 g- Test stopped at 10% creep.
 h- Test stopped at 3.1% creep.
 i- Test stopped at 3.8% creep.
 j- Test stopped at 2.5% creep.
 k- Test stopped at 1.55% creep.
 l- Test stopped at 0.87% creep.
 m- Test stopped at 9.5% creep
 n - Test still running
 p - Test stopped at 5% creep
 q - Test stopped at 1% creep

Table 2. Thin Foil Creep Testing Summary

Specimen Number	Material	Test Stress (Ksi)	Test Temp. (°F)	5% Creep (hours)	Rupture Time (hours)
1-347	Type 347 SS	17	1225	670 ^(a)	(a)
2-347	"	12	1300	670 ^(b)	(b)
340-L	Inconel 625	30	1300	275	670 ^(c)
357-T	"	30	1275	670 ^(d)	(d)
355-T	"	30	1350	109.5	(e)
334-L	"	25	1350	201.2	(e)
353-T	"	22	1480	6.6	23.1
394-T	N-155	18	1350	1150.0 ^(f)	(f)
251-L	Hast-X	25	1350	32.6	(e)
171-L	RA-85H	15	1350	3.2	3.3
317-T	Incoloy 800	17	1350	2.9	(e)
214-L	Incoloy 825	17	1350	86.1	(e)
113-T	Incoloy 800 H	17	1350	3.1	(e)
14-L	Haynes 230	30	1350	40.9	(e)
52-L	RA 333	20	1350	87.7	(e)
154-T	HR 120	22	1350	1.23	(e)
—	153 MA	to be determined after elevated temp. tensile tests			

(a) test stopped, total creep .710%

(b) test stopped, total creep 1.28%

(c) test stopped, total creep 9.3%

(d) test stopped, total creep 1.03%

(e) test stopped, total creep 5.0%

(f) test stopped, total creep 2.50%

A dual alloy recuperator is a recuperator constructed of thin foil material that includes a width of one stainless material, such as SS-347, along with a narrower strip of higher temperature alloy, such as Inconel 625 or Haynes 230. A major portion of a recuperator core would experience lower temperatures and could be constructed of a less expensive alloy than if the core were made of only one material. This concept, if successful, could extend the use of stainless 347 to even higher temperature cycles. The present concept is to use approximately one-sixth of Inconel 625 and five-sixths of stainless 347.

During the prior quarter, both EB and laser edge-welded (Type 347 stainless steel to Inconel 625) samples of recuperator sheet were supplied by Belt Technologies, Inc. These samples were then successfully folded into finned recuperator sheet stock at Solar's recuperator manufacturing facility.

Laser welded and electron beam welded bi-material sheets, which were successfully folded, have now gone through the required edge crushing tests without any problems at Solar's recuperator manufacturing facility at Morton Metalcraft. These samples were submitted for laboratory analysis. Visual inspection and metallographic examination revealed no flaws or cracks in the weld or adjacent regions. The crushing operation is the most difficult forming operation in the cell manufacturing process. Therefore, this success is a strong indication that the concept will be viable from a fabrication standpoint. A series of tensile tests of the welded couples were also completed this period, with very encouraging results. Remaining is the creep strength testing, which will be finished by the end of Phase II. If these technical aspects are found to be acceptable, the concept will be carried into Phase III to evaluate the economics of scaling-up a production system.

Modified Type 310 stainless steel being developed by Oak Ridge National Laboratories (ORNL) offers the possibility of adding about 50°F to the temperature capability of Solar's primary surface recuperator over that of Type 347 stainless. This capability will then exist within a cost range typical of stainless steels rather than at the much higher cost of nickel-based alloys.

Prototype samples of Modified 310 Stainless Steel were received from Oak Ridge National Labs. The material was cold rolled by ORNL to 0.020 inch thick for preliminary evaluation of microstructure and tensile strength. These samples were submitted for a series of annealing trials to determine the optimum temperature for recrystallization without grain growth. The remainder of the material will be annealed at the selected temperature and tensile testing will commence. The tests at 0.020 inch gage thickness will form the basis for a decision on materials to carry into Phase III as thin foils.

1.1.6 Subtask 8.8 - Low Cost Combustor Materials (Ceramics)

This subtask was originally titled "Reheat Combustor Material" and was proposed in anticipation of future addition of a reheat combustor to the ICR gas turbine cycle defined in Task 3. With the migration to the optimized recuperated cycle defined in Task 6, the goal of the subtask was changed to the evaluation of materials suitable for use in gas turbine combustion liners. It now supplements similar work being conducted by Solar under DOE Contract No. DE-AC02-92CE40960 titled "Ceramic Stationary Gas Turbine (CSGT) Development." The use of ceramic combustor liner in gas turbines contributes toward emissions reductions by freeing cooling air for use as primary combustion air and by allowing higher wall temperatures which contribute to the more complete combustion of hydrocarbons.

The planned approach is to obtain material properties from flexure bars and then to test each candidate material in an 8-inch diameter combustor can under actual conditions of gas turbine combustion.

The CSGT program has tested subscale combustor cans of silicon carbide composite (SiC/SiC) from DuPont Lanxide Corp. and B.F. Goodrich Aerospace as well as aluminum oxide (Al_2O_3/Al_2O_3) cans from Babcock & Wilcox. The three materials selected for evaluation in Subtask 8.8 are as follows:

- B-30 BZP (Barium Zirconia Phosphate) supplied by LoTEC. This material features a zero coefficient of thermal expansion, eliminating all thermal stresses, and promises to reduce the \$30,000 per can cost of SiC/SiC material by 94 percent.

- CMC SAIC-8 (Nextel 440/ Al_2O_3 - SiO_2) offers the toughness and strength of a CFCC material at a cost 60 percent lower than that of SiC/SiC. This material is supplied by SAIC.
- Altra KVS 16 (Al_2O_3 Fibers/ Al_2O_3 - SiO_2) from International Thermoproducts promises temperature capability to 3000°F at a cost 90 percent lower than that of SiC/SiC.

The LoTec and SAIC liners were instrumented with thermocouples in preparation for rig tests to start in February. Three rows of five thermocouples were oriented 120° apart on the outer surface (cool side) of the liner.

Delivery of the International Thermoproducts (ITP) subscale liners was expected in January but was pushed into February due to a facilities issue. ITP also expects to complete preliminary erosion and thermal cycling coupon tests by the end of February.

1.1.7 Subtask 8.9 Advanced Ceramic Material

The goal of this subtask is to explore the use of advanced ceramic composite materials in gas turbine components. This will include development of a suitable (cost-effective) component fabrication process, the development of a finite element stress analysis to assure 30,000 hours of component life and the actual fabrication of a demonstration article.

The majority of the task has been subcontracted to the Supertemp Division of B.F. Goodrich Aerospace. Materials considered are both carbon-reinforced silicon carbide (SiC) or silicon carbide-reinforced silicon carbide (SiC/SiC).

During this quarter, a hard copy drawing of the combustor duct was delivered to BFG along with its electronic model. Tooling design has continued throughout the quarter and will complete early next quarter. The Brecksville Division of BFG is currently performing a stress analysis of the duct.

2.0 PROGRAM SCHEDULE AND BUDGET

2.1 SCHEDULE

As of January 31, 1996, Solar's Phase II program is approximately on schedule. There are no visible impediments to completion of the entire Phase II scope of work by May 30, 1996, the close of the period of performance set by Revision M004.

2.2 BUDGET

As of January 31, 1996, 34,182 labor hours have been charged to the contract versus 29,739 planned. As of the same date, total program cost (including Solar's cost share) stands at \$4327K versus \$4727K planned. Solar's Phase II contract is expected to finish very close to the current Cost Plans (Revision M004) in spite of an expected labor overrun.

In addition to the charges to the contract, an additional 9249 labor hours have been charged to an internally funded project directly related to ATS. This represents cost sharing of approximately \$833,000 in addition to that provided for in the contract.

3.0 FUTURE INVESTIGATIONS

Four months remain in Solar's ATS Phase II contract. During this period the remaining seven subtasks in Task 8 will be completed and a topical report submitted for each. Work on the contract will be completed with the preparation and submission of a Final Technical Report. These remaining subtasks all have continuing effort on their subject technologies in Phase III of DOE's ATS program under Cooperative Agreement # DE-FC21-95MC-31173 with Solar. Phase III work on these projects is planned so as to ensure an uninterrupted transition from Phase II efforts.

GLOSSARY

ACE	<u>Advanced Component Efficiency</u> . A Solar-funded multi-disciplinary, advanced technology program. It currently includes programs on compressors, turbines, cooling, and ducting.
ATS	<u>Advanced Turbine System</u> . 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.
ATS50	Solar's designation for an ATS designed to meet the contract goal of 50 percent thermal efficiency.
ATS60	Solar's designation for an ATS designed to meet a "stretch" goal of 60 percent thermal efficiency.
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>Barium Zirconium Phosphate</u> . 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>Coal-Fired Advanced Turbine System</u> . An advanced turbine system modified to operate on coal or coal derived fuel.
CFCC	<u>Continuous Fiber-Reinforced Ceramic Composite</u> . 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>Ceramic Stationary Gas Turbine</u> . 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>Electron Diffraction Xray</u> .

EFFECTIVENESS	(e_g for recuperator, e_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	<u>Functionally Graded Material</u> . 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	<u>Gas Producer Turbine</u> . May include HP and LP turbines.
GFATS	<u>Gas-Fired Advanced Turbine System</u> . An advanced turbine system which uses natural gas for fuel.
GP	See GAS PRODUCER.
HCF	<u>High Cycle Fatigue</u> . 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	Hot Isostatic Pressing. 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	High Pressure. 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.	Investor Owned Utility. 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	Independent Power Producer. 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	Levelized Annual Cost. 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	Low Cycle Fatigue. 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	Low Pressure. 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.

McAlY	A designation for an overlay coating applied to superalloy turbine components for increased oxidation and corrosion resistance. "McAlY" 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. $PF = \frac{T_{MAX\ EX} - T_{AVG\ EX}}{T_{AVG\ EX} - T_{AVG\ INLET}}$ <p>All temperatures are absolute.</p>
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	<u>Pressure Ratio.</u> 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	<u>Particle Rejection Impact Separator.</u> 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 <u>pattern</u> 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	<u>Primary Surface Recuperator.</u> 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 meet 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	Transmission and Distribution. The system used to get the power (or fuel) from the point of origin to the consumer.
TRIT	Turbine Rotor Inlet Temperature. 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.