A PROJECTION OF ADVANCEMENTS IN AERODERIVATIVE
GAS TURBINE TECHNOLOGY FOR THE NEXT TWO DECADES
(with specific emphasis on off-shore applications)

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ABSTRACT
This paper presents the authors' perspective regarding the growth of gas turbine technology as applied to the industrial market for the next two decades. Although emphasis is placed on off-shore (platform and floating production) applications, the effects of the advance in technology of gas turbines for land based operations is included. Past trends in the advancement of basic gas turbine technology are utilized as the basis to establish this forecast.

An introduction and a description of the Air Bottoming Cycle, the Intercooled Gas Turbine Cycle, and a hybrid gas turbine combining aeroderivative and heavy frame design are also included.

INTRODUCTION
The off-shore oil and gas industry has played a key role in the development and evolution of gas turbines and, as a market segment, has employed large numbers of aeroderivative gas turbines. Off-shore platform applications have been particularly suited to take full advantage of the inherent attributes of the aeroderivative gas turbine – low weight, small footprint, high power-to-weight ratio, quick startup, quick changeout, etc. Today, gas turbines are employed in all phases of off-shore service, ranging from waterflood for secondary oil recovery to the production of electricity for the isolated platform grid. Correspondingly, combined cycle arrangements incorporating large, heavy frame industrial gas turbines have emerged to dominate the utility power generation segment of the global industrial gas turbine market. Both heavy frames and aeroderivative units have also been utilized for cogeneration and combined heat and power (CHP) applications.

Other recent applications of gas turbines include the all electric platform concept and the floating production vessel or FPV. For the all electric platform application, variable speed electric motors are employed as the drivers of any required rotating machinery. The technical advances in the state of the art of variable speed motor control systems have made this approach a viable and economical alternative. In the past, there was a general industry reluctance to accept a power source other than direct coupled gas-fueled reciprocating engines or gas turbines for gas compression applications. This situation is undergoing change and electrically driven gas compressors, water injection pumps, etc. are now being actively considered for pipelines, platforms and floating production vessels. A unique advantage of an all-electric solution is that it provides a single, rather than a multiple, source of emissions for the same required power output. The ability of the aerodervative gas turbine to withstand the roll and pitch motions associated with shipboard applications has given the aerodervative gas turbine a decisive edge in FPV applications.

Over the past few years, industry acceptance of operation at higher turbine inlet temperatures, coupled with an almost universal infusion of methodologies developed for aircraft flight engines into large stationary industrial gas turbine (Type H - Heavy Frame/Heavy
Duty) designs, has produced a new series of gas turbines. These units (termed ‘F technology’) exhibit increased thermodynamic performance with a simple cycle thermal efficiency increase approaching five (5) percent above similar Type H industrial gas turbines introduced into service some 15 years ago. Gas turbines are still subject to significant technological developments leading to great potential future performance improvements. On a world wide basis, approximately one-half billion dollars are spent each year to achieve increasingly advanced prime propulsion systems for both military and civil use. The technical advancements emanating from these programs are generally made available to the industrial gas turbine sector in a space of a few years. Past examples of this technology transfer include high temperature metallurgy, improved rotor blade and stator vane cooling, and high impulse/wide-chord compressor blading.

This paper presents the authors’ perspective of the course of the gas turbine in industrial applications for the next two decades. This outlook is based upon past industrial trends and technological developments now underway. Consideration is also given to those efforts that are

ENVIRONMENTAL CONSTRAINTS

In the past several years, the gas turbine industry has faced market and regulatory pressures for greater efficiency, coupled with stringent environmental constraints with respect to exhaust emissions - NOx, CO, and, in certain locations, CO2. These pressures have been accompanied by the imposition of emission-related taxes that have a significant impact upon the operating costs of the gas turbine. CO2, however, is the product of complete combustion of hydrocarbon fuels, and the amount of CO2 produced is directly proportional to the amount of fuel consumed. In the case of aeroderivative gas turbines, improvements in fuel efficiency are a normal development as the importance of fuel efficiency for flight propulsion is a major project driver in powerplant design. These improvements resulted from advances in component aerodynamics and increases in cycle pressure ratio and turbine inlet temperature as improved turbine materials and blade cooling techniques became available. At the same time, methods of reducing NOx emissions were developed, first involving water or steam injection into the combustor section of the gas turbine (at a penalty of increased CO production) and, more recently, through the development of dry low emissions (DLE) combustion systems.

It is beyond the scope of this paper to present a position on the effects of CO2 emissions on global warming or to either advocate or refute carbon taxation. The supplier of gas turbines can only accept these emissions criteria established by the legislative body of the host country and work within those criteria. For example, the CO2 tax established for Norway is levied on the amount of fuel consumed by the gas turbine, and this tax levy has created a new governmental revenue stream of many millions of dollars. A revenue stream of this magnitude, once established, is exceedingly difficult to relinquish. It is the authors’ opinion that, although a large amount of promising work has been done in the area of exhaust gas scrubbing to separate carbon dioxide (CO2) from the effluent of the gas turbine, this approach will face many obstacles in the political arena before existing legislation is altered sufficiently to give benefits in the form of lower taxation to such a scheme. A less remunerative, but probably a more direct and less costly approach, would be to concentrate on reducing what is presently taxed (i.e., fuel consumed) by the application of systems that increase the overall thermal efficiency of the prime mover equipment. The air bottoming cycle (ABC), the intercooled gas turbine, and the steam-injected gas turbine (STIG) are some examples of this type technology.

It should be noted that a carbon tax, when imposed on the fuel consumed, provides additional incentives for the application of those gas turbines possessing the highest thermal efficiencies. Recent developments in gas turbine technology have resulted in gas turbines with simple cycle efficiencies of over forty (40) percent and combined cycle units with efficiencies of fifty-one (51) to fifty-three (53) percent. Current developments promise to raise these levels even further in the next five (5) years. At current fuel prices, a five (5) percent increase in thermal efficiency of a 40 MW simple cycle gas turbine results in an annual fuel savings of approximately USD 400,000 per unit, with a comparable reduction in CO2 taxation, when applicable.

NEAR-FUTURE APPLICATIONS

There are several promising technological approaches to improving the fuel efficiency of gas turbine engines for on-shore and off-shore industrial operations. By directly reducing fuel consumption, these techniques reduce operating costs. They also have the attractiveness of reducing the financial penalties associated with CO2 production. These techniques include material substitutions emanating from the latest developments in aircraft engines that permit operation at higher turbine inlet temperatures and higher compression ratios and innovative enhancements to the basic gas turbine thermodynamic cycle. The case of off-shore platforms in the oil and gas industry offers particular opportunities for innovations to improve efficiency. Up until now, the economics of off-shore (platform) operation have
resulted in universal use of simple-cycle gas turbines. The growing need to restrict the generation of CO₂ has led to some attractive alternatives that offer a practical proposition for near-future consideration.

MATERIAL SUBSTITUTION

Of prime importance are turbine blade and stator materials to accommodate increases in turbine inlet temperature. These include monocrystal turbine blades and vanes, and ceramic shroud materials. In addition, Thermal Barrier Coatings (TBC’s) are finding increasing applications in aircraft gas turbines and are available to extend the capabilities of the industrial gas turbine as well.

The importance of turbine inlet temperature lies in its impact on gas turbine specific weight and fuel efficiency. Figure 1 shows the trend in turbine inlet temperature with time over the last 40 years illustrates a sharp increase in turbine inlet temperature for the Type G (aeroderivative units) in the mid 1970’s. This increase is attributed to the advanced turbine technology (metallurgy and turbine cooling techniques) associated with the introduction of the ‘second generation’ aeroderivative gas turbine. Temperatures have increased from a value near 925°C in the early 1950’s to approximately 1290°C in the early 1990’s. The Type G (aeroderivative units) have displayed an average growth in turbine inlet temperature of approximately of ten (10) degrees Celsius per year. The incremental growth in turbine inlet temperature of the Type H (heavy frame) units, however, has averaged approximately five (5) degrees Celsius per year. This difference is due to the fact that the manufacturers of Type H gas turbines did not introduce high temperature or ‘F technology’ until the late 1980s. With the advent of ‘F technology’, these latter Type H gas turbines now operate at turbine inlet temperatures approximately the same as that of the higher compression ratio Type G gas turbines. Future developments of both Type G and Type H gas turbines are expected to result in an increase of turbine inlet temperatures of 100-200 degrees Celsius in the next two decades.

Beyond its effects on the specific weight and performance of the gas turbine, increasing turbine inlet temperature also has a major beneficial impact on the size, weight and cost of the complete installation. Increased turbine inlet temperature reduces the inlet and exhaust mass flows of the turbine, thereby reducing the size of the associated ductwork. This, in turn, reduces the installed cost of the gas turbine and improves life cycle economics.

Figure 2 shows the trend of gas turbine weight/power ratio with time. The increase of turbine inlet temperature shown in Figure 1 has led to a reduction in weight per unit of output on the order of a factor of two (2). This same trend is visible both for Type G (aeroderivative) and Type H (Heavy Frame) gas turbines. Figure 3 shows the corresponding trend in simple-cycle gas turbine thermal efficiency over the same time period. The total improvement of approximately 35% in fuel efficiency is due in part to increased turbine inlet temperature, higher cycle compression ratio, and improvements in basic designs and efficiencies of the components comprising the turbo machinery.
To increase overall gas turbine performance, considerable attention was focused over the past decade on methods to improve component efficiency and aerodynamic design. With the advent of computer aided design techniques, improved and unique rotating blade shapes are now available for the industrial gas turbine. These new airfoils improve the aerodynamic performance of the rotating members. Aerodynamic performance of the gas turbine will continue to be improved by the development of more innovative gas path sealing techniques. Advancements in cooling techniques for hot gas path components leading to operation at increased turbine inlet temperature conditions are also predicted to increase rapidly in the next two decades.

In some applications, compression ratios are reaching the point where advanced turbine disk materials will be required to accommodate the required high levels of cooling air temperature. The reason for this is that gas turbine efficiency is significantly improved by raising cycle compression ratio. The attendant penalty, however, is that the weight of the gas turbine increases per unit of output. This can be offset by increasing turbine inlet temperature. Figure 4 shows the trend in cycle compression ratio with time over the past 40 years.

Material substitutions are the principal near-term drivers in allowing simple-cycle gas turbines to achieve higher levels of thermal efficiency. As turbine inlet temperatures and cycle compression ratios are increased in the quest for energy efficiency, the use of aircraft technology materials will become more widespread in gas turbines for both off-shore and on-shore operation. Directional solidified alloys, single crystals, eutectics, ceramic matrix composites and new super alloys will see increased applications in the next 5-7 years.

All types of gas turbines show an increasing trend, although the aeroderivatives have received a greater benefit due to their aero-engine heritage and the greater emphasis that designers of aero-engines place on fuel efficiency. As seen in Figure 4, the compression ratio of the Type H gas turbines has been fixed at a compression ratio of approximately 13:1 to provide a better combined cycle arrangement. Although this compromises simple cycle thermal efficiency, an improved combined cycle efficiency is attained. Figure 5 shows the correlation between simple-cycle gas turbine thermal efficiencies and cycle compression ratio over the same time period. This figure depicts the same 35% improvement in fuel efficiency, shown in Figure 3, and which is attributable to the combined effects of higher turbine inlet temperature, cycle compression ratio, and turbomachinery efficiency.
Figure 6 depicts both the historical and projected capability of turbine blade materials with respect to the surface temperature which these materials can withstand in operation. This figure also indicates the types of materials required for those temperatures. Given the rate of growth of turbine inlet temperature shown in Figure 1, it is predicted that the growth in material capability shown in Figure 6 will continue at a similar pace for the next two decades. New coating systems will also be introduced. These coating systems will compliment, but will not supplant, new developments in materials. Due to the environment in which turbine parts must operate, these sacrificial coatings will only provide partial (time limited) protection for the basic material employed.

TECHNOLOGY TRANSFER

World-wide expenditures for advanced military and civil aircraft gas turbines propulsion systems were: ten (10) billion US dollars between 1940 and 1980; two (2) billion US dollars between 1980 and 1985 and, an average of about twenty-five (25) percent in the early 1950's to one-half billion US dollars per year from 1985 through 1994.

The technical advancements and achievements of these aircraft engine programs have been made available for industrial stationary applications in a surprisingly few years. This trend in technology transfer will continue in the next two decades.

In addition to being capable of reaping the benefits available from the developments derived from both military and civil aircraft propulsion engines, the industrial gas turbine can also incorporate the design innovations and improvements that emanate from new type applications. Examples of these new type applications include marine propulsion and not-normally-manned off-shore and on-shore installations.

Aeroderivative gas turbines, due to their high power to weight ratio, are now being applied to a number of fast ferry commercial vessels. Work is also underway to develop a recuperated cycle and an intercooled and regenerative cycle for military marine propulsion. The lessons learned and the technology derived from this marine experience will be available for transfer into the industrial sector. It should be noted that the advanced coating systems now available for the high pressure turbine airfoils of today's gas turbines can be traced to the efforts that were previously instigated for the marine market sector.

Another area of potential technology transfer is the not-normally-manned off-shore and on-shore installation. During the next decade increasing numbers of remotely controlled unmanned gas turbine sites will be commissioned. This movement toward not-normally-manned installations will be driven by the benefits that can be realized (by the end-user of the equipment) in terms of economic viability and overall safety. Recent studies, for the UK sector of the North Sea, have indicated that the difference in normal operational expenditures between a manned and unmanned platform, over a period of approximately one (1) year, can more than compensate the end-user for the initial capital investment required for the electronic controls and the diagnostic and communications associated with operation from a remote location.

HEAT RECOVERY CYCLES

An obvious area of efficiency enhancement is the use of heat recovery systems to extract waste energy from the gas turbine exhaust and put it to practical use. Land-based gas turbines, particularly those used for electrical power generation, make widespread use of exhaust heat recovery boilers to generate high-pressure steam. The steam generated is then used either to drive a separate steam turbine, or it is injected directly into the gas turbine for power and efficiency enhancement. In cogeneration power plants some, or all, of the steam is provided directly for process use. Other practical applications of heat recovery systems include district heating and preheating feedwater for coal fired power plants.

Heat recovery cycles of possible future interest for offshore operation include the combined cycle, the STIG cycle, the air bottoming cycle, and the regeneration cycle.

Combined Cycle

A straight-forward method for recovering waste exhaust heat is the combined cycle. The exhaust heat generated by the gas turbine is used in an exhaust heat recovery boiler to generate steam to drive a separate steam turbine. The steam portion of the arrangement is referred to as a “bottoming cycle”. Combined cycle gas turbines have been in use since the 1950's and have produced fuel efficiency improvements on the order of 2-35% over simple-cycle gas turbines. The degree of improvement is dependent on the relative amount of waste heat available for recovery. More efficient simple-cycle machines tend to have less waste exhaust heat available and, therefore, show a smaller improvement with the addition of a steam bottoming cycle. On the other hand, more efficient simple-cycle machines require physically smaller steam bottoming cycle to deliver a desired total power output. This could prove to be an advantage for off-shore applications.

Figure 7 shows the evolution of simple-cycle and combined-cycle gas turbine efficiencies over the period 1950-1995. Simple cycle efficiencies have progressed from about twenty-five (25) percent in the early 1950's to...
over forty (40) percent today. Improvements in gas turbine and steam cycle performance are likely to result in only modest increases in combined-cycle efficiency - to the 58-62 % range - but it will be possible to achieve those levels with relatively smaller steam bottoming plants. Since the steam plant capital costs per unit of output are generally three (3) to four (4) times the costs for a gas turbine plant, this trend will offer significant improvements in overall plant economics.

Gas fired combined cycle systems have emerged, by virtue of their rapid technological improvements during the past two decades, as the dominant new technology of the 1990's. Combined cycles, when applicable, have the advantage of high levels of thermal efficiency at full load conditions. Their high incremental capital costs for the heat recovery plant, however, coupled with their relatively long start-up and cool-down times, tend to make them unsuitable for applications other than continuous full power operation. In the next two decades one can expect to see new combined cycle arrangements optimized for both full and part load operation that incorporate design innovations to reduce the time required for both start-up and cool-down.

Steam Injection / STIG

The steam-injected gas turbine (STIG) cycle is another example of an exhaust heat recovery system that enhances both power and efficiency. STIG versions of some contemporary aeroderivative industrial gas turbines are currently in use in land-based power generation applications. The use of steam injection has increased gas turbine power and efficiency to the extent depicted in the following table:

<table>
<thead>
<tr>
<th>Nominal Rating</th>
<th>Power Increase</th>
<th>Heat Rate Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 MW</td>
<td>23%</td>
<td>9%</td>
</tr>
<tr>
<td>22 MW</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>35 MW</td>
<td>48%</td>
<td>16%</td>
</tr>
</tbody>
</table>

The performance improvement available from the incorporation of a STIG cycle is, of course, dependent on how much steam can be injected into the gas turbine, which is in turn dependent on turbine nozzle sizing to accommodate the increased mass flowrate. A gas turbine that is designed specifically for STIG applications in mind can achieve very high thermal efficiency levels, thus reducing CO₂ production per unit of fuel consumed.

The STIG and heat recovery gas turbine cycles discussed above have a drawback when used in offshore applications. They require the availability of treated, pure water for use in the boiler, the steam turbine, and the gas turbine. The associated system complexity (condensers, purifiers, heat exchangers, etc.) coupled with large space requirements offers a substantial challenge. Additional complications arise in areas of the world where water availability and treatment are difficult to obtain.

Air Bottoming Cycle

There is another "bottoming cycle" concept that does not use water to enhance gas turbine performance. This is the Air Bottoming Cycle (ABC) and it is now under development for offshore and on-shore applications. A schematic of the Air Bottoming Cycle is shown in Figure 8. In the ABC, an air turbine is used for the bottoming cycle. Multiple air compressors of the air turbine raise the pressure of the inlet air stream. Intercoolers are utilized after each of the air compressors to reduce the total amount of power required to drive the compression process. The temperature of the compressed airflow is then raised in a heat exchanger that extracts energy from the exhaust of the primary gas turbine. This arrangement is practically identical to the heat exchanger found in a regenerative (recuperative) gas turbine. The heated airflow is then expanded through an air turbine to drive the compression process in the bottoming cycle and provide a net shaft output power gain. A typical ABC can be expected to increase the power output and thermal efficiency of a gas turbine by 25-30%. This is comparable to the improvement associated with a
combined cycle using a boiler and additional steam turbine.

Regenerative Cycle

The Regenerative Cycle approach offers significant improvements for applications requiring a significant amount of part-power operation. Simple cycle gas turbines have an operating characteristic such that their efficiency drops off significantly as power is reduced. Specific fuel consumption (units of fuel per unit of power output) is typically 40% higher at 25% power than it is at full power for a Type G unit and 60% higher for a Type H unit. This results from the reduction in cycle compression ratio and turbine inlet temperature, as well as reductions in the efficiency of the turbomachinery that occur at reduced power. A method to mitigate this characteristic efficiency loss is to use a regenerative cycle (sometimes called a recuperative cycle).

In the regenerative cycle, the compressor discharge airflow is ducted to a heat exchanger (regenerator) in which it is heated by energy transferred from the turbine exhaust flow. The heat energy extracted from the exhaust flow reduces the amount of fuel energy that must be normally supplied to operate the gas turbine. Performance improvements available from this technique are greater at lower power than at higher power. The improvement at maximum power is partially offset by a small loss associated with the pressure losses of the heat exchanger. Studies of regenerative cycles for marine propulsion indicate that fuel efficiency improvements on the order of 20% are achievable at 25% power, and 15% at 40% power, decreasing to no benefit when approaching full power. A schematic diagram of a typical regenerative gas turbine cycle is shown in Figure 9.

Intercooling

Cooling of the gas (air) stream exiting the compressor of a gas turbine is a method of increasing the part load efficiency of the gas turbine. This technology provides a reduction in gas (air) temperature together with an increase in mass flow. The net result is a decrease in the work required to compress the gas stream by the turbomachinery. An intercooler is, in essence, a heat exchanger that cools the partially compressed airstream of the gas turbine down to a temperature near to that which existed at the start of the compression process. The cooled airflow is then returned and compressed by the remainder of the compressor to the desired level of exit pressure. A schematic diagram of an intercooled compression process is shown in Figure 10.
As seen in Figure 10, to accomplish this cooling of the compressed gas stream, the gas stream exiting the compressor is ducted to an external heat exchanger or 'intercooler' and then returned to main gas path of gas turbine. The utilization of intercooling also allows operation at increased pressure ratios while still employing the turbine cooling technology which exists today. The Intercooled Aero-Derivative Gas Turbine (ICAD) provides a machinery configuration of higher compression ratio and increased mass flow without sacrificing the fast start-up and thermal cycling capability associated with the aeroderivative gas turbine. During the next two decades, the technology associated with intercooling will undergo increased development. Increased application on both Type G and Type H gas turbines should follow.

COMBUSTION

During the 1980's and early 1990's industrial market pressures led to the development of dry low emission combustors of varying degrees of sophistication. As these low emission combustors were introduced, local emission regulatory levels (primarily with respect to permissible levels of NOx emissions) were being reduced. Continuous reduction in permissible levels was premised on the basis that each new application had to provide the best available emissions suppression technology. During the next decade, it is predicted that this "down-spiraling" of emissions criteria will level off at a value which is both technically achievable and economically practical. The industrial market should also see, in this same time period, the further development and operational introduction of stoichiometric and flameless catalytic combustion systems to minimize the emissions levels of gas turbines. Catalytic combustion can provide a means of initiating the reaction process between fuel and oxygen at a lower temperature than conventional flame combustion. The next decade should also bring new state-of-the-art developments with regard to non-diffusion type combustor designs for the purpose of NOx reduction.

Although consistent with controlling the level of NOx emissions and desirable from an environmental impact standpoint, these developments in combustion technology will tend to restrict the levels of gas turbine firing temperature. This in turn, will restrain improvements in thermal efficiency that would otherwise be enhanced through the application of higher firing temperatures. In summary, efforts to control NOx emissions will still tend to prevent significant reductions in carbon dioxide (CO2) emissions that are an unavoidable consequence of burning carbon based fuels.

COMMERCIAL CONSIDERATIONS

The driving considerations in prime mover acquisition are capital cost, operating cost and rate of return on investment. Advanced technologies can offer significant improvements in operating cost at the expense of higher capital cost. One, therefore, must be vigilant when assessing any new cycles to insure that due consideration is given to the commercial aspects of these innovations. Whereas, only limited incremental costs may be associated with modernization of existing cycles, the costs associated with the development and application of a new or unique cycle may prove too great for product viability.

LONGER-TERM OPPORTUNITIES

The foregoing discussion dealt with prospects for improving the energy efficiency of gas turbines in the relatively near future, i.e., over the next 10 years. These prospects represent the best opportunities for significant improvements in fuel efficiency and reductions in CO2 emissions and taxation at a reasonable cost during that time period. In the longer term, further potential exists in the use of more "exotic" materials to raise cycle efficiencies through higher cycle pressure ratios and turbine inlet temperatures, as discussed, and the use of intercooled compression and "hybrid" Type G/Type H gas turbine designs. It is projected that the trend will be toward greater use of basic turbomachinery performance enhancements, although bottoming heat recovery cycles will continue to be important.

In the area of material developments, there are technical initiatives for aircraft propulsion, such as the IHPTET (Integrated High Performance Turbine Engine Technology) program that promise to develop high-temperature turbine airfoil materials far in advance of today's capabilities. As previously stated, Figure 6 shows temperature capability vs. time for high-temperature turbine materials out through the first quarter of the next century. In the early 1990's, using Thermal Barrier Coatings (TBC) in conjunction with monocrystal internally cooled blading, it was possible to operate at material temperatures on the order of 1200° C in new gas turbine designs. By early in the next century, it is anticipated that an increase of 100° C (to 1300° C) will be achieved. With the introduction of ceramic and composite blade materials, it is anticipated that temperatures in excess of 1700° C will be achievable, for a total potential increase of 500° C. In order to make efficient use of such high turbine inlet temperatures, gas turbine cycle pressure ratios in excess of 55:1 will be required. This would normally drive compressor exit temperatures to unacceptably high levels (in excess of 750° C) from a substantially reduced through the incorporation of an
The late 1950's ushered the introduction of the aeroderivative gas turbine into the industrial marketplace. These gas turbines evolved from the efforts to provide high performance gas turbines to power military aircraft. Since that time industrial gas turbines, both heavy frame and aeroderivative, have undergone significant change in both aerodynamic and thermodynamic features. This paper summarizes these changes and offers a perspective of the changes that are projected to occur in the next two decades. These changes in the gas turbine will be in response to market pressures for increased performance in the areas of thermal efficiency and specific power.

High levels of performance, reliability and availability have become synonymous with gas turbines operating in industrial service. The projected technology advances delineated in this paper will be directed to ensure that gas turbines, offering both high efficiency and operational flexibility, remain the choice prime mover for the foreseeable future. In addition, these advances in technology will also insure that the overall operational readiness of gas turbine driven equipment, a function of performance (how well), reliability (how long) and availability (how often), will remain unexcelled in the future.

REFERENCES: