INDUSTRIAL APPLICATIONS OF AIRCRAFT-DERIVATIVE GAS TURBINES

by

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INTRODUCTION

The aircraft-derivative gas turbine as a stationary ground-based prime mover has achieved a spectacular record in its short history of 13 years. During October 1960, in a remote Kentucky gas compression station located on Possum Trot Ridge, Columbia Gulf Transmission Company commenced operations of the prototype unit for base load industrial duty. The 10,500 BHP gas turbine package, made up of a Pratt and Whitney Aircraft modified J-57 plus a Cooper-Bessemer RT48 free power turbine, was utilized to drive a centrifugal pipeline booster to compress 10 tons of natural gas per minute from 750 PSIG to 950 PSIG through a 24-inch diameter pipeline.

At that time, the prototype program was primarily intended to demonstrate that an aircraft-derivative gas turbine could operate a period of 8000 hours without requiring major maintenance. Aircraft J-57 engines were operating 1400 hours between overhauls and only a field prototype experience could prove the integrity of seals, bearings, and auxiliaries components. It was a high risk adventure and perhaps the first major attempt to translate aircraft technology to industrial uses. It is interesting to reflect that no comparable attempt was made to translate aircraft reciprocating technology to industrial applications in the years prior to the advent of the aircraft jet engine.

DEFINITION

This paper will be directed only to industrial base-load applications of aircraft-derivative gas turbines, and their requirements. No attempt will be made to describe the peaking power generation or the marine markets, although very sizable segments of the overall gas turbine industry, carry unique requirements and experiences.

Base load applications are those calling for a very high utilization factor. There are 8760 available hours in the average year and typical base load utilization involves operation of equipment between 7500 and 8760 hours per year over the project life. 8000 hours per year would be typical of gas or oil pipeline operation whereas 8700 hours per year would be typical of chemical or refinery operations. In all cases, the product being handled has a high market value and the user selects equipment that will be highly reliable and available for use in his system. To minimize scheduled plant downtime, the “base load” user will also select equipment that requires a minimum of inspection and major maintenance. Typically, the user will specify equipment requiring inspections on an annual basis with major maintenance after three years of operation.

Manufacturers, in turn, must carefully rate their equipment to satisfy the user requirements. Turbine inlet temperatures, operating speeds, and materials must be optimized to achieve the long life criteria. Generally, the rating for industrial service approximates an aircraft engine in the “cruise” condition. The “take-off” ratings for an aircraft engine are seldom used in the base load application due to the high maintenance trade-off. Commonly, this reserve power is utilized for the emergency or “peaking” power generation application, where high specific output is required for infrequent periods of operation.

The jet gas turbine consists of two major components—an aircraft-derivative gas generator and a free power turbine. The gas generator serves as a producer of gas energy or gas horsepower. It is derived from an aviation gas turbine engine in that fuel system and control modifications are made to burn applicable industrial fuels, and design innovations are incorporated to insure the required long life characteristics in the ground-based environment. Typically, it serves to raise combustion gas products to conditions of 30 PSIA and 595° C. (1100° F.) at the exhaust flange.

The free power turbine serves to convert the gas energy to mechanical rotative energy or brake horsepower. Closely coupled to the gas generator by a transition duct, the power turbine expands the gas generator combustion products through one or two turbine stages and the residual gas energy is exhausted to atmosphere. The rotative power produced in the power turbine is then available for mechanical couplings to the driven equipment. The power turbine is not aircraft derived and is generally designed and manufactured by the package supplier.

The package supplier becomes the prime contractor in furnishing the complete jet gas turbine, which includes as well the baseplates, oil systems, fuel and governing systems, and control panels for operation and protection.
(see equipment schematic, Figure 1). The equipment and auxiliaries are then factory assembled and mechanically tested as a package prior to delivery to the installation site.

COMPETITION

The entry of the jet gas turbine for base-load use was not simply a matter of demonstrating a successful prototype unit. Conventional or “heavy-duty” stationary gas turbines were designed shortly after World War II and had been introduced into base-load service in the early 1950’s. A great deal of operating experience in a variety of applications had been accomplished prior to initiation of the jet gas turbine concept. The early heavy-duty gas turbine design philosophy largely was an extension of stationary steam turbine designs. Since weight and space restrictions were not important parameters, design characteristics included heavy wall casings split on horizontal centerlines, sleeve (hydrodynamic) bearings, large diameter combustors, thick airfoil sections for blades and stators, and large frontal areas. Overall simple-cycle efficiencies were low and regenerative-cycle designs were introduced to obtain higher cycle efficiencies.

Needless to say, the jet gas turbine’s introduction in the early 1960’s created a proper share of skepticism and raised eyebrows as would be expected in an innovative concept. Consider the design philosophy of the jet engine designer who faces criteria of weight, altitude, temperature, and size substantially different from the stationary prime mover designer. In this case, the resulting gas turbine product features lightweight casings of annual design, anti-friction (ball and roller type) bearings, small auxiliary modules, and minimum frontal areas with corresponding reduced rotor and combustor diameters. Power-to-weight ratios and simple-cycle efficiencies were high due to the state-of-the-art component efficiencies and the use of high temperature superalloys. When introducing this design for industrial service, the anti-friction bearing system was the largest unknown as bearings of this type had never been utilized in high horsepower base-load machinery and design techniques were known only to the aircraft industry.

Despite the initial differences in design objectives, the skills and technologies have moved towards each other over the years. Materials and turbine cooling techniques evolving from aircraft developments have flowed to stationary industrial gas turbines. Aircraft-derivative gas generator components and auxiliaries have been improved for increased life and reliability using techniques familiar to the heavy-duty machines. As will be discussed later, the trend has been set for continued blending of the best of the two technologies.

One other interesting observation is the flow of the base-load experiences on jet gas turbines back to the aircraft designs of the same engine. In the early years, it was assumed the vast quantity of aircraft engines in service would continually feed durability improvements to the industrial units. However, the base-load units accumulated time so rapidly that operating hours per given engine quickly surpassed that of their aircraft counterparts. As a result, as problems arose and rectification schemes were devised for the industrial units, these schemes became available to the benefit of the aircraft engines.
DEVELOPMENT PROGRAM

The development problems in adapting the aircraft-derivative gas generator to the ground level environment have been well documented within the technical societies. In brief, the ground level air density environment created two situations in the early days that required design modifications. First, the greater air density (compared to air density at 30,000 feet) created more aerodynamic buffet than expected in the combustion chambers to the point where heavy wear occurred and caused eventual breakup of the chamber locating surfaces. Design changes were necessary to improve the clamping and fitting of rubbing surfaces, plus the addition of chrome carbide flame plating to improve wear resistance. This treatment was very effective and combustion chambers are rarely a life-limiting component today. Second, the air density had to be allowed for, in controlling the axial loads on the gas generator rotor thrust bearing. To prevent an overload on the thrust bearing, which is a ball-type bearing, an air seal is attached to a compressor disk and sized to limit the air pressure acting on the air compressor and ensures that the axial load remains within design limits throughout the operating range. As an example of the effectiveness of this design scheme, the Rolls-Royce Avon gas generator has not experienced a mainline bearing failure in over 2 million hours of operation in base-load applications.

Another problem area that became evident after several years of experience was the reliability of the aviation auxiliary modules, which contain the engine driven oil and hydraulic pumps and control systems. After accumulating several years of experience, it appeared the basic gas generator liability was being limited by the reliability of the auxiliaries—a not too uncommon problem in the development of all prime mover machinery. Considerable work has been undertaken to improve the integrity of auxiliary drives, pumps, governors, variable guide vanes and bleed valves. In one case, Cooper-Bessener and Rolls-Royce jointly developed a program to delete the entire aviation auxiliary module and replace it with an off-engine system made up of selected industrial-type auxiliaries. The program succeeded in increasing overall reliability of the jet gas turbine package as well as reducing auxiliary system maintenance and operating costs.

MAINTENANCE CONCEPT

The maintenance concept inherent in the jet turbine is worth noting in some detail as it is a factor that sets it apart from competitive machines. Similar to aviation practice today, industrial users have found the "black box" method of maintenance to be attractive and of economic value in their system operation. Basically, this involves the "changeout" of the gas generator for scheduled or unscheduled maintenance, and its replacement with a spare engine—an operation involving three to six hours elapsed time. Spare gas generators are either owned, leased or exchanged by the user, dependent on unit population and plant requirements.

The gas generator requiring maintenance is then transported to a maintenance base qualified to inspect, repair, recondition, and test the model involved. With the increasing number of jet gas turbines in service (in the order of 1000 units in North America), aviation maintenance facilities are retooling up for the increased industrial requirements. Presently 14 maintenance facilities are in operation for industrial work in North America, broken down as follows: Airlines, 2; Manufacturers, 7; Independently-owned, 5.

The user benefits economically in that he does not require investment in 1) specialization and training of maintenance personnel; 2) parts inventory required for the shop repair or reconditioning; and 3) supervision and administration required to conduct an "in-house" maintenance program. In addition, periods of reconditioning are utilized to incorporate durability modifications designed to improve engine performance and reliability. This practice is direct from the aviation industry and is enthusiastically accepted by the industrial user, although the procedure was considered unusual initially. In fact, gas generators are continuing to self-improve durability-wise as after each reconditioning it is projected to achieve a longer life expectancy than its previous operating cycle (see Fig. 2).

From a maintenance cost viewpoint, the increase in life expectancy (gas generator reliability) has more than offset the increases in material and labor costs. Using the Avon as an example (Fig. 3), average costs of reconditioning have increased from $30,000 to $43,000 over a seven-year period, but actual cost/operating hour has decreased due to the longer life expectancy.

Because of the changeout concept, the overall downtime of a given jet gas turbine powered unit or plant is significantly less than for the conventional gas turbine, or any other stationary prime mover. All other types of equipment require on-site inspections, repairs, and overhauls and the downtime involved can range from two days for a routine inspection to 30 days for an overhaul. As most base-load applications involve a high cost of product, wherein outage costs can vary from $10,000 to $100,000 per day, the savings gained by brief interruptions, as opposed to more lengthy although less frequent intervals, become a significant consideration in overall plant economics.

Field experience has also determined that a great number of on-site repairs and adjustments can be made with the gas generator remaining in the package. These operations are akin to field maintenance techniques developed by the airlines and the military. Field inspection

![Figure 2. Avon reconditioning record.](image-url)
In summary, the aviation-derived gas generator, often considered too unusually complex mechanically, has been found to lend itself to normal maintenance techniques and skills consistent with high performance industrial machinery. The economics of how and where the reconditioning work is performed is determined by the user location and the quantity of gas generators involved. The "black-box" technique becomes more compelling as the site location becomes geographically remote and the environment becomes more hostile. The quick changeout feature permits maximum "on-stream" capability compared to conventional equipment, and has established unprecedented records for gas turbine availability.

APPLICATIONS

The acceptance of the jet gas turbines can best be substantiated by noting the number of manufacturers presently engaged in the various applications. Table 1 lists the gas generators presently in service in baseload applications.

In addition to the 413 units listed engaged in baseload applications, approximately 750 units are being utilized in marine applications and 1250 units in power generation (peaking) applications—a total of 2413 units for all applications.

Table 2 indicates application, uses, and geographical location of the various prime movers utilizing the gas generators listed in Table 1.

Gas transmission represents approximately 80% of the base-load horsepower installed. Basic reasons for selection of jet gas turbines by gas transmission users include:

1. Favorable Installation Cost. The equipment involved is of a size and weight that it can be packaged and tested as a complete unit within the manufacturer's plant. Generally, this will include the driven pipeline booster, all auxiliaries and control panels specified by the user. With the equipment thus matched and then debugged during testing, the package can be installed at the jobsite with less construction and startup effort than equipment that is matched for the first time at the jobsite.

2. Adaptation to Remote Control. Users strive to reduce operating costs by automation of their pipeline systems. All new stations today are designed for remote unattended operation of the compression equipment. Jet gas turbine equipment lends itself to automatic control as auxiliary systems are not complex, water cooling is not required (cooling by oil-to-air exchanges), and the starting device (gas expansion motor) requires little energy and is reliable. Safety devices and instrumentation adapt readily for purposes of remote control and monitoring the performance of the equipment.

3. Maintenance Concept. The off-site maintenance plan fits in well with these systems where minimum operating personnel and unattended stations are the objective. Technicians conduct minor running adjustments and perform instrument calibrations. Otherwise, the jet gas turbine runs without inspection until monitoring equipment indicates distress or sudden performance change. Trend analysis equipment is being developed and installed and will serve to automatically scan instrumentation and to print out appropriate maintenance instructions and schedules. (see Figures 4 and 5)

Figure 3. Gas generator reconditioning costs, 1967-1973.

techniques using boroscopes, vibration and temperature analysis, and infrared pyrometry serve to aid in diagnosing engine performance. Obviously, any repairs that can be made on the gas generator on-site in a timely manner will eliminate a time consuming roundtrip to a maintenance facility. Examples of such operations include replacement of inlet guide vanes and first stage compressor blades damaged by foreign objects, inspection and/or replacement of fuel nozzles and combustion chambers, replacement of auxiliary system modules—all operations requiring less than eight hours.

In one unusual situation, an engine was repaired in Western Canada by undertaking a bulk disassembly of the unit in a space adjacent to the skid. The supervision and special tools were supplied by the gas generator manufacturer in this case. The gas generator was placed on its nose in a fixture and each major assembly (exhaust unit, turbine shaft and rotor, nozzle vanes, and combustors) was removed to gain access to a faulty bearing supporting an auxiliary drive shaft. Upon replacement of the faulty part, all other parts were reinstalled; however, any components could have been replaced had it been necessary. The repair work in this case required 24 hours, with the total downtime of the plant, including removal and reinstallation, amounting to just 37 hours.

Future maintenance techniques, for new generation of gas generators, will involve modular replacement of assemblies rather than replacement of complete gas generators. These new engines are designed for easy modular disassembly in the horizontal position and therefore the reconditioning exercise can be limited specifically to a compressor, combustor, or turbine module.
### TABLE 1. DATA ON GAS GENERATORS—BASE LOAD APPLICATIONS

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>JSO Rating, SHP</th>
<th>Thermal Efficiency-%</th>
<th>Power Turbine and Packaging Supplier</th>
<th>Base Load Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avco-Lycoming</td>
<td>TF25</td>
<td>2,250</td>
<td>22</td>
<td>A</td>
<td>4</td>
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<tr>
<td>Allison</td>
<td>501 K-13/16</td>
<td>4,000</td>
<td>27</td>
<td>DE/I</td>
<td>79</td>
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<tr>
<td>Cooper-Bessemer/Rolls-Royce</td>
<td>RCT-30/Proteus</td>
<td>3,800</td>
<td>24</td>
<td>C</td>
<td>5</td>
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<tr>
<td>General Electric</td>
<td>LM100</td>
<td>1,150</td>
<td>21</td>
<td>I</td>
<td>13</td>
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<tr>
<td></td>
<td>LM350</td>
<td>3,500</td>
<td>21</td>
<td>I</td>
<td>4</td>
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<td></td>
<td>LM1500</td>
<td>15,500</td>
<td>26</td>
<td>De/I/Dr</td>
<td>94</td>
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<td></td>
<td>LM2500</td>
<td>23,000</td>
<td>24</td>
<td>C/I</td>
<td>8</td>
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<tr>
<td>Orenda</td>
<td>OTF-370/390</td>
<td>8,900</td>
<td>22</td>
<td>O</td>
<td>25</td>
</tr>
<tr>
<td>Rolls-Royce</td>
<td>Avon 75/76</td>
<td>15,500</td>
<td>26</td>
<td>C/Dr/G/I</td>
<td>152</td>
</tr>
<tr>
<td></td>
<td>Avon 121</td>
<td>20,000</td>
<td>29</td>
<td>C/I</td>
<td>10</td>
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<tr>
<td></td>
<td>RB-211</td>
<td>26,000</td>
<td>34</td>
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<td>1</td>
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<tr>
<td>Pratt &amp; Whitney Aircraft</td>
<td>GG12A</td>
<td>3,100</td>
<td>20</td>
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<td>17</td>
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<tr>
<td></td>
<td>GG3C</td>
<td>14,400</td>
<td>26</td>
<td>C/Dr/I</td>
<td>21</td>
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<tr>
<td></td>
<td>GG4A</td>
<td>20,000</td>
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<td>C/T/W</td>
<td>28</td>
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<td></td>
<td>GG4C</td>
<td>35,000</td>
<td>30</td>
<td>U</td>
<td>1</td>
</tr>
</tbody>
</table>

**Totals**: 413 / 7,804,200

**CODE**: Power Turbine and/or Packaging Supplier (Prime Contractor)

A = Avco Lycoming  
C = Cooper Industries, Inc., Cooper-Bessemer Company  
De = Delaval Turbine, Inc.—Deltax Division  
Dr = Dresser Industries—Gas Turbine Division  
G = GEC—English Electric  
I = Ingersoll-Rand Company, Turbo Products Division  
O = Orenda, Ltd.  
T = Turbo Power and Marine Systems  
U = United Aircraft of Canada  
W = Worthington Turbine International/Turbodyne Corporation

### TABLE 2. JET GAS TURBINES IN BASE-LOAD APPLICATIONS

<table>
<thead>
<tr>
<th>Application</th>
<th>Driven Equipment</th>
<th>Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Transmission</td>
<td>Centrifugal Pipeline Boosters</td>
<td>U.S.A., Canada, Netherlands, West Germany, United Kingdom</td>
</tr>
<tr>
<td>Gas Reinjection (Gas Conservation and Secondary Oil Recovery)</td>
<td>Natural Gas Centrifugal (Multi-stage) Compressors</td>
<td>Canada, Venezuela, Algeria, Libya</td>
</tr>
<tr>
<td>Ammonia Production</td>
<td>Synthesis Gas Centrifugal (Multi-stage) Compressors</td>
<td>Australia, Qatar</td>
</tr>
<tr>
<td>Helium Production</td>
<td>Centrifugal Air Compressor</td>
<td>U.S.A.</td>
</tr>
<tr>
<td>Power Generation, On-Site for Process Plant</td>
<td>Electric Generator</td>
<td>U.S.A., United Kingdom, Libya, Qatar</td>
</tr>
<tr>
<td>Oil Transmission</td>
<td>Centrifugal Oil Pumps</td>
<td>Venezuela, Alaska (future)</td>
</tr>
<tr>
<td>Water Flood (Secondary Oil Recovery)</td>
<td>Water Injection Pumps</td>
<td>Venezuela, Libya</td>
</tr>
<tr>
<td>Gas Regeneration</td>
<td>None-Exhaust gas ducted to catalyst regenerator</td>
<td>U.S.A.</td>
</tr>
</tbody>
</table>

*Oil transmission* has the same general characteristics as the gas transmission applications noted above. A future installation of jet gas turbine involves the proposed 800 mile oil pipeline across Alaska. An interesting design feature of the prime mover package (13,500 SHP rating) is that space and weight envelopes permit it to

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**Figure 4.** SHP jet gas turbine driving pipeline booster in Netherlands gas transmission station. Acoustical panels reduce sound levels within compressor building.
be air-lifted by Lockheed Hercules, if logistics require this mode of transportation (see Fig. 8).

Gas re-injection (including gas lift) and water flood applications are characterized by their geographically remote locations at sites of large oil field discoveries. The plants are normally designed for local operation as the compression process is not system integrated as in a long distance pipeline. The jet gas turbine maintenance concept is attractive in that minimum maintenance personnel and minimum inventory requirements blend well with the isolated plant sites. In the case of gas lift plants in Venezuela, compression units are singly located on offshore platforms (with no quarters for personnel) and crew boats provide the only method of transportation. (see Figure 6)

Ammonia production, helium production, and on-site power generation have similar requirements. In particular, the value of the process product is very high and “on-stream” availability is paramount. In about all cases, the gas turbine exhaust gas heat content is ducted to a “waste heat” exchanger where the exhaust energy is converted to a useful process requirement—to generate steam or heat process oil as examples. As a result, the gas turbine is credited with the process cycle efficiency increase and can become a key economic factor in the choice of equipment. (see Fig. 7)

Gas regeneration is an application wherein no mechanical horsepower is developed. The gas generator exhaust gas is ducted directly to a regenerator wherein the heat energy is added to a catalyst bed for the production of butadiene.

There are several interesting subjects worth noting that are receiving considerable attention and which are common to all base-load applications today.

Air Handling—Installations today are extremely diverse; from arctic to desert to off-shore platforms. Each is unique with respect to techniques to handle the air to prevent erosion or corrosion to the front-end blading of a gas turbine axial compressor. Air filtration and inlet

Figure 5. 20,000 SHP unit in gas transmission service. Gas generator is a derivative of CF-6 aircraft engine.

Figure 6. 12,500 SHP jet gas turbine driving compressors in gas lift service on Lake Maracaibo.

Figure 7. Ammonia production plant in Australia with 16,000 SHP unit driving three synthesis gas compressors L to R: Air filter and inlet system, gas turbine inside acoustic cab, control panels inside masonry structure. In background is waste heat boiler generating steam from gas turbine exhaust energy.

Figure 8. 13,500 SHP Prime Mover for Oil Transmission service fully assembled for factory testing. Unit is modularized for air transport to Arctic station sites, if logistics require.
systems are being "customized" increasingly to fit a particular environmental, rather than the general-purpose designs of the past.

In the winter climate installations, where near-freezing conditions are prevalent, methods had to be developed to prevent the formation of ice in inlet systems to avoid the possibility of ice ingestion. Where environmental pollutants cause performance deterioration to an axial compressor, various different cleaning techniques have been developed and evaluated to restore performance with the unit remaining in operation.

Noise—Like all equipment and machinery today, the jet gas turbine must be a good neighbor. To the surprise of the uninitiated, these units are relatively easy to silence with the use of external inlet and exhaust silencers and acoustical enclosures. There are many examples where the overall noise level of gas turbine equipment has been reduced to meet residential criteria. In addition to the gas turbine itself, attention must be given to radiators and ventilation fans, air filter blowers, and auxiliary pumps when designing for very low ambient noise installations. As the tradeoff to noise reduction is increased cost and construction effort plus higher pressure drop (decrease in available SHP), the user should select a design criteria consistent with local ambient conditions or regulations to avoid over-complex designs.

Appearance—Increasing emphasis placed on plant design is the requirement for a pleasing appearance. Package suppliers frequently provide the filters, silencers, and enclosures for jet gas turbine equipment so a variety of materials, colors, and configurations have emerged to meet the individual requirements.

FUTURE TRENDS

Observing the performance and experience record accumulated in the past ten years, the jet gas turbine industry is more optimistic than ever in its ability to meet market requirements of all varieties. As the aviation-derived gas generator continues to serve the base-load applications, the models involved will continue to improve durability-wise. The high-time unit just achieved 33,558 hours (4 years of operation) without requiring reconditioning. The ultimate lifespan is unknown at this point and only further operating experience will resolve the question. New models are being introduced, the most significant of which are the new generation of engines for heavy transport aircraft. These engines feature fuel savings of 30% over previous designs, due to high temperature/pressure cycle designs and improvement in materials and material cooling techniques. The LM2500 gas generator, a derivative of the CF6 and TF39 aircraft engines, has been in gas transmission service for nearly three years. The first industrialized RB-211 will be placed into gas transmission service in October, 1974. The JT9, CF6-50, Olympus 593, Spey, and M-45 aircraft engines are similar state-of-the-art engines and are expected to be introduced to industrial applications in the future.

Certain models of gas generators, having entrenched themselves in ground-based service, are now spawning variants which will never see aviation service. The Avon 76, as an example, has spun off the Avon 101 (maxi-Avon) which raises the SHP by 18% and lowers the fuel rate by 7%. The uprating is accomplished through the introduction of a higher temperature cycle plus air-cooled first stage turbine blades. Another spin-off, the Avon 121 (maxi maxi-Avon) will be introduced shortly which will raise the Avon 101 power level by 10% and the fuel rate by 3%.

The Pratt and Whitney GG4A has spawned the GG4C which features an additional axial compressor stage plus turbine-end modifications to permit higher temperature cycles. These variants were developed and justified on industrial forecast only and will remain unique to ground-based applications.

Another trend becoming evident is the pooling of industrial and aircraft technologies in the development of future gas generators. Several companies have formed joint ventures or cross-license arrangement to exploit this opportunity for future industrial activity.

Future industrial gas generators will continue to utilize the advanced metal technology, component design, and manufacturing techniques as it becomes available from the aviation industry. As a result, more efficient simple cycle designs will become available that are competitive with present regenerative cycle gas turbines. Throughout these new developments, it is expected that gas generators will continue as separable compact assemblies in order that the quick changeout maintenance technique will be retained.

SUMMARY

The jet gas turbine has established itself as a viable and competitive product in the marketplace. The technology and practices evolved within the aircraft industry have had a major impact in the successful development and application of this product as a reliable industrial prime mover. In particular, the maintenance concept has proved to be of economic benefit to the base-load industrial user.

Future opportunities are optimistic in that improved and more efficient designs will become available which will combine the best of skills and technologies from both aircraft and industrial resources.

REFERENCES

2. Sawyer’s Gas Turbine Catalog, Gas Turbine Publications, Inc.