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# **INDUSTRIAL APPLICATION OF GAS TURBINES COMMITTEE**

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## **Shared Technologies in the Development of the Titan 250<sup>™</sup> Gas Turbine System**

**by**

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## ABSTRACT

The *Titan 250*<sup>™</sup> gas turbine, 22.4 kW (30,000 HP), and scaled C85 pipeline gas compressor are the latest additions to the Solar Turbines Incorporated product family. These new products leverage core technologies that have been developed and proven in several other well-established products. This paper discusses the *Titan 250*'s evolutionary design approach, which was based on shared aerodynamic, thermal, mechanical, and combustion technologies borrowed from three proven production gas turbine systems (Figure 1).

The *Titan 250* utilizes a conservative hybrid-type design grounded in advanced aerodynamic, thermal, and mechanical design tools and methodologies. Thorough combustion system testing, use of proven materials, and hot section cooling experience at the same firing temperature provided a solid design basis.

Along these same lines, the C85 gas compressor is the latest in a long string of aerodynamically scaled models from a durable gas transmission product family.

The *Titan 250* has a best in class shaft efficiency of 40%. The engine is a two-shaft design that includes a 16-stage axial-flow compressor (PR 24:1), a dry low emissions combustor (<15 ppmv NO<sub>x</sub>), a two-stage gas producer turbine operating at a turbine rotor inlet temperature (TRIT) of 1204°C (2200°F), and a three-stage, all-shrouded blade power turbine for maximum efficiency.

For additional technical information, data sheets, brochures and video see the *Titan 250* link on the [www.solarturbines.com](http://www.solarturbines.com) website.

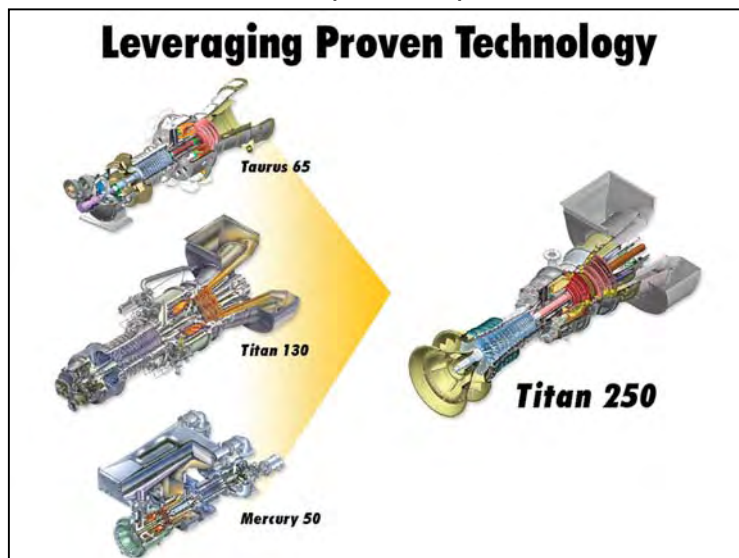


Figure 1. *Titan 250* Hybrid Design

## INTRODUCTION

The *Titan 250* industrial gas turbine system was introduced in 2006 in response to increasing customer demands for higher performance industrial gas turbine products in the 15-30 MW (25,000-45,000 hp) power range, for both the Oil and Gas market, as well as for the Electrical Power Generation and Combined Heat and Power markets.

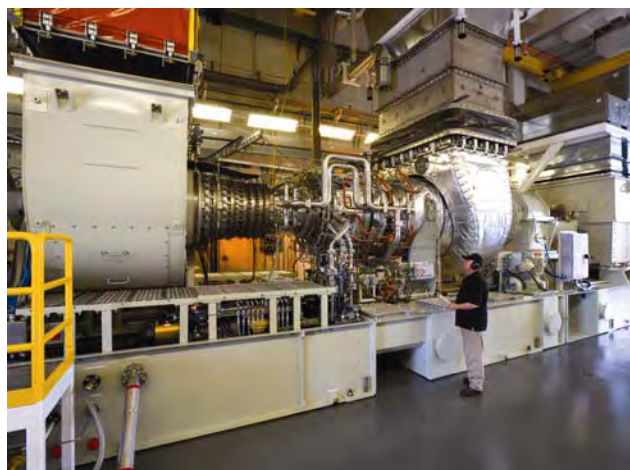


Figure 2. *Titan 250* Generator Set (21.7 MWe)

Product development began in 2005, and full-scale testing started in 2008 (Figure 2). The first production gas compressor package has been installed at a natural gas transmission station in the United States for start-up in late 2009 (Figure 3). A second compressor set will start up in 2011 at a natural

gas transmission site also in the United States. In 2010, the first 21.7 MWe generator set is planned to ship for an industrial CHP application in southern Europe.

This new turbine leverages core technologies that have been developed and proven in several well-established gas turbine models, and is a hybrid of core technologies developed and proven on the *Taurus 65*<sup>TM</sup>, *Titan 130*<sup>TM</sup>, and *Mercury 50*<sup>TM</sup> gas turbine systems. These shared core technologies included a conservative design approach grounded in advanced aerodynamic, thermal and mechanical design tools

and methodologies, thorough combustion system modeling, proven materials and hot section cooling experience. These technologies have been validated through full-scale laboratory and field-testing and extensive operating experience. The core technologies and materials incorporated have a combined operating experience of over 15 million hours, in a wide a range of applications in almost every geographic location in the world.

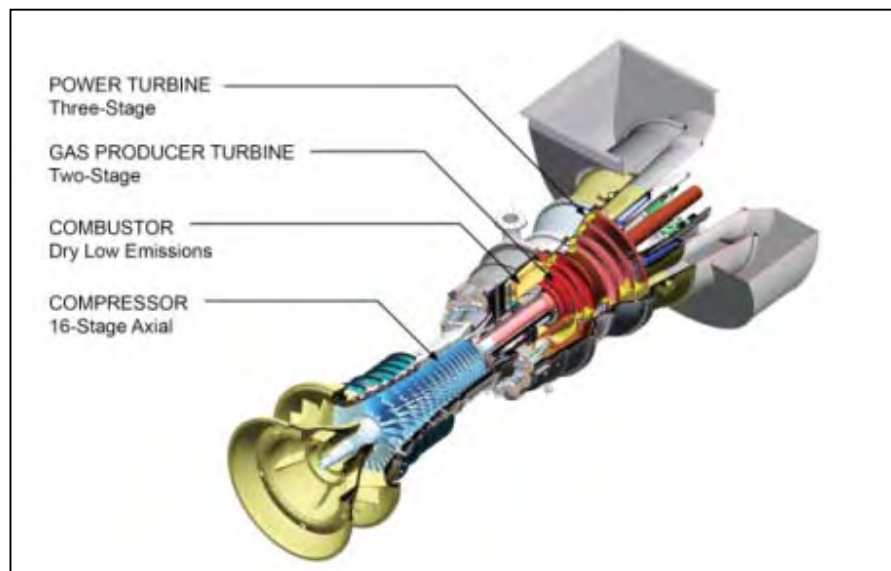
The turbine's operating-cycle and overall mechanical design is similar to that of the 15 MW size class *Titan 130* introduced in 1998 (Rocha, 1995). Over 95% of the materials in the *Titan 250* are the same as those used on the *Titan 130*. Proven aerodynamic modeling techniques, developed and validated on the *Taurus 65* and *Mercury 50* gas turbines, were implemented to establish flow path and airfoil component designs. The dry, lean-premixed, combustion system produces the same turbine rotor inlet temperature as the *Taurus 65*,

1204°C (2200°F), and the backside cooled liner and gas producer nozzles and blades utilize similar cooling schemes (Figure 4).

In addition, considerable attention has been paid to reliability, maintainability, durability and safety in the design of the *Titan 250* gas turbine, package and driven equipment. A multi-disciplined system engineering design approach resulted in Solar's most integrated, modular and serviceable turbine and



**Figure 3. Titan 250 Compressor Set Package**



**Figure 4. Titan 250 Major Components**

package system to date. These advances include a comprehensive equipment health monitoring system and an integrated service rail system to expand in-situ service capability to help minimize maintenance costs and increase system uptime.

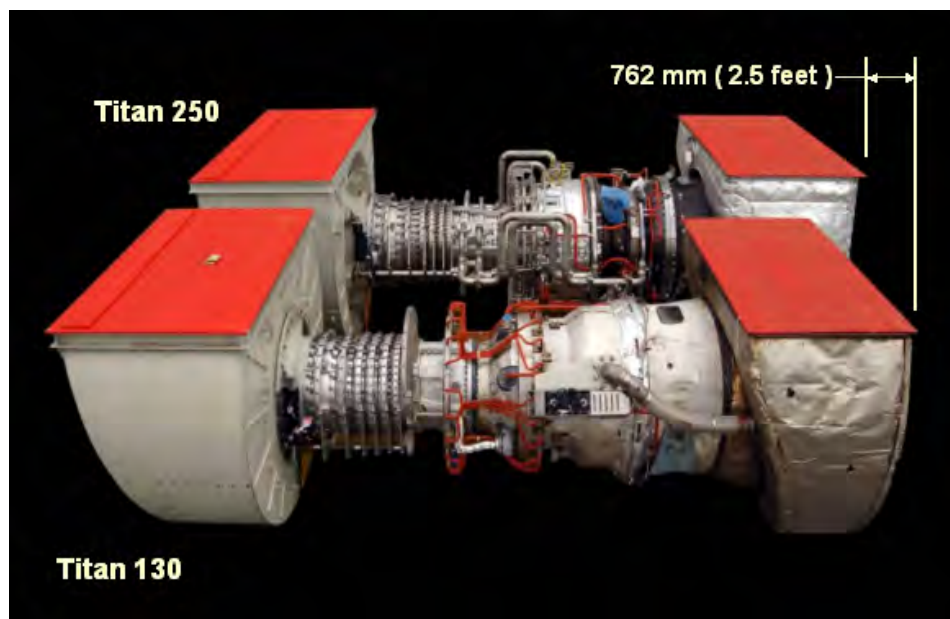


A comparison of key operating parameters between *Titan* 130 and *Titan* 250 is shown in Table 1.

Parameter	Titan 130	Titan 250
Power Output , kW	15,287	22,371
Efficiency, %	36.2	40.0
Pressure Ratio	17:1	24:1
Exhaust Flow, kg/hr	180,049	245,049
Exhaust Temperature, °C	503	463
DLE Operating Load Range, %	50 - 100	40 - 100
DLE Operating Temp. Range, °C	-18 - 49	-29 - 49
Power Turbine Speed - Optimum	8,345	6,300
Power Turbine Speed - Maximum	9,180	7,000

**Table 1. Performance Comparisons**

Although the gas turbine is only 1 meter (3 feet) longer than the *Titan* 130, the *Titan* 250 delivers almost 50% more power and extends the DLE operating range down to 40% load (Figure 5). The *Titan* 250 package is only 0.15 m (6 inches) higher and 0.3 m (1 foot) wider than the *Titan* 130 package. Because many of the fuel, lube and control subsystems are integrated within the package, the total installed equipment footprint is very small for turbines above 20 MW.



**Figure 5. Gas Turbine Size Comparison**

A comparison of materials in the various components between the *Taurus* 65, *Titan* 130 and *Titan* 250 engines further illustrates how similar these turbine systems are (Table 2). Except for a small alloy change in the aft compressor case, the core turbine materials are identical.

Component	Location	Taurus 65	Titan 130	Titan 250
Case	Forward Compressor	WC-6	Nodular Iron	Nodular Iron
Case	Aft Compressor	(single case) WC-6	WC-6	CA-15
Blades	Forward Compressor	17-4PH	17-4PH	17-4PH
Blades	Aft Compressor	17-4PH	IN-718	IN-718
Case	Diffuser	WC-6	WC-6	CA-15
Liner	Combustor	HAST-X	HAST-X	HAST-X
Case	GP Housing	CA-15	CA-15	CA-15
Nozzles	GP Stage 1	MAR-M-247	MAR-M-247	MAR-M-247
Blades	GP Stage 1	SCRY-4	SCRY-4	SCRY-4
Nozzles	GP Stage 2	MAR-M-247	MAR-M-247	MAR-M-247
Blades	GP Stage 2	SCRY-4	SCRY-4	SCRY-4
Tip Shoes	GP	HAST-X	HAST-X	HAST-X
Case	PT Housing	na	CA-15	CA-15
Nozzles	PT Stage 3	IN 939	IN 939	IN 939
Blades	PT Stage 3	IN 792	IN 792	IN 792
Nozzles	PT Stage 4	na	IN 939	IN 939
Blades	PT Stage 4	na	IN 792	IN 792
Nozzles	PT Stage 5	na	na	IN 939
Blades	PT Stage 5	na	na	IN 792
Bearings	GP	Waukesha	Waukesha	Waukesha
Bearings	PT	Waukesha	Waukesha	Waukesha

**Table 2. Material Comparison**

## C85 GAS COMPRESSOR

The C85 centrifugal gas compressor has been optimally matched to the power output and shaft speed of the *Titan* 250 gas turbine, and is the largest in a scaled-family of pipeline



**Figure 6. C85 Centrifugal Gas Compressor**

compressors (Figure 6). Hundreds of Solar Turbines compressors from this design family are in operation today, demonstrating superior reliability and high efficiency over a wide operating range. Like all other Solar Turbines gas compressors, the C85 employs the concept of a modular rotor and pre-engineered components. The use of pre-engineered, standardized aerodynamic and mechanical components enables accurate and reproducible predictions of design and off-design compressor performance and contributes to high reliability.

## TURBINE DEVELOPMENT PROGRAM

Market studies and customer feedback indicated increased interest in turbomachinery products with higher power and efficiency requirements for both Oil & Gas and Industrial Power Generation applications in the market segment above 15 MW (20,000 hp). In response to these market indicators and a commitment to meet customer expectations, general product specifications for output performance, efficiency, emissions, availability, durability, reliability, and lifecycle costs were defined for the *Titan 250*.

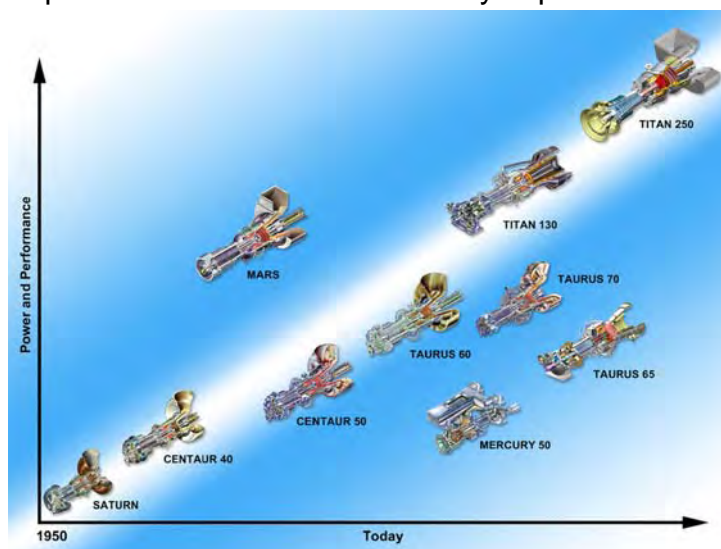
A New Product Introduction (NPI) team was formed consisting of representatives from all organizations within Solar to establish and execute an integrated product development strategy. Over the past 15 years, twenty new turbines, along with major turbine uprates and six new gas compressors, have been successfully introduced into the Solar Turbines product line following this low risk design approach.

An extensive benchmarking exercise was conducted including over twenty competitive site visits, customer surveys, and customer focus groups. The analysis covered six market application segments.

- Oil and Gas - Onshore, Gas Transmission
- Oil and Gas - Onshore, Electrical Generation
- Oil and Gas - Offshore, Gas Compression, Re-injection, Pump/Oil, MD
- Oil and Gas - Offshore, Electrical Generation
- Power Generation - Onshore, Electrical Generation
- Power Generation - Combined Heat & Power

The benchmarking feedback was analyzed and weighted by market segment to develop a composite list of product requirements for the engine, gas compressors, package, and service approach. Some of the top requirements included higher efficiency, durability and reliability with ever-lower emissions output. Across almost all market segments “Availability” generally ranked near or at the top of the requirements. System uptime generally becomes more important as the output size of the power plant increases. Whether the turbine package application is a gas transmission plant, an offshore gas compression set, or a hospital combined heat and power plant, they are all expected to run when needed, all the time, every time.

Lessons learned from previous developments and additional durability improvements were folded into the *Titan 250* to extend operating lifecycles, increase uptime and reduce lifecycle costs (Figure 7). Additional and redundant instrumentation has been added to minimize non-critical shutdowns and alarms, and to provide a richer suite of diagnostics and equipment health monitoring capability. On the package side, availability was improved by using larger (dual) oil filters that have three times the debris carrying capacity of previous models to help extend run times before filter service. In addition, there is a broader range of air filtration options to ensure the optimum performance.



**Figure 7. Gas Turbine Family Evolution**



# PERFORMANCE

Compressor sets are available for gas transmission applications, teamed with the C85 gas compressor (Figure 8), and for higher- pressure upstream compression applications teamed with either the C61 or C51 gas compressors.

Since the gas turbine, gas compressors, package and field service tooling were integrated from the beginning of the program, peak performance is ensured over a wide operating range. A higher-ambient temperature matched second-stage turbine nozzle will be available to provide increased performance for warmer geographic locations.

The modular gas compressor design facilitates re-staging and ensures optimum performance should inlet or outlet conditions change.

Electrical generator sets are available for 50 Hz and 60 Hz applications (Figure 9). An epicyclic gearbox reduces the turbine output speed accordingly. Due to its high simple cycle efficiency, the gas turbine can provide high efficiency levels in either combined heat and power or combined cycle applications. In combined cycle, the gas turbine/steam turbine combination can achieve lower heating value efficiencies of 50%. In combined heat and power applications, the exhaust can be duct-fired to extend steam production up to more than five times the unfired value of 35,000 kg/hr (77,000 lbs/hr). Corresponding efficiency ranges from 75% to 84% (LHV) depending on duct-firing rate.

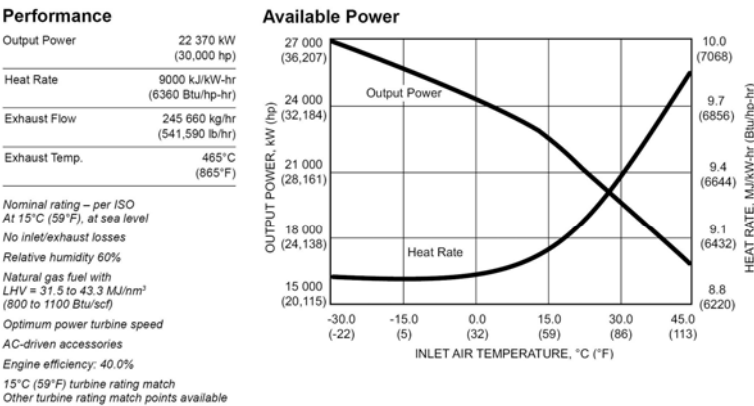


Figure 8. Titan 250 Mechanical Drive Performance

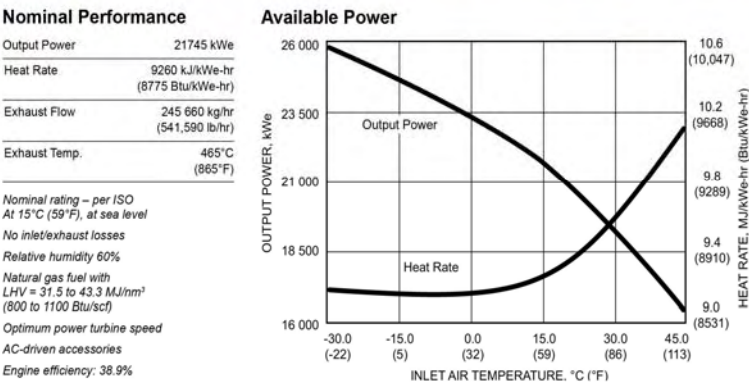
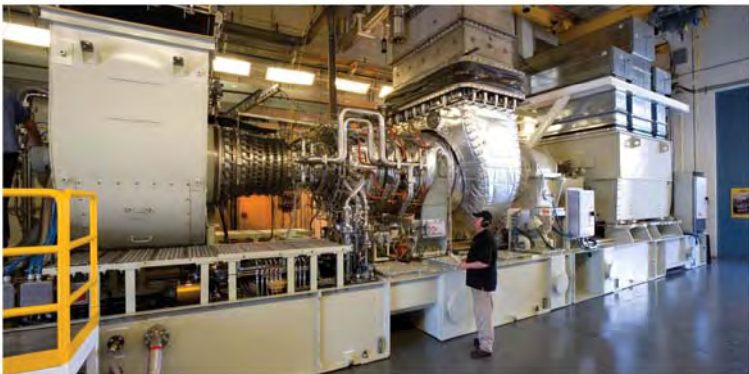


Figure 9. Titan 250 Generator Set Performance

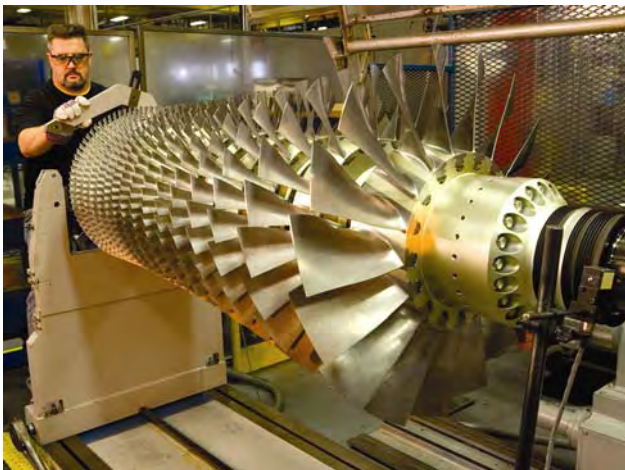


## GAS TURBINE HERITAGE AND DESIGN

The *Titan* 250 gas turbine is the next step in the evolution of modern Solar Turbines gas turbines that began with the *Centaur*® 40. Each step in the evolution through the *Titan* 250 gas turbine has built on experience gained from previous gas turbine designs, along with the introduction of thoroughly tested technologies in critical areas such as compressor aerodynamics, combustion, materials and cooling.

## AXIAL-FLOW AIR COMPRESSOR

The 16-stage *Titan* 250 axial-flow compressor is sized for an inlet-air flow of 67.3 kg/s (148 lb/s) and sets a new standard in compressor efficiency (Figures 10 and 11). It is designed to provide maximum efficiency over a wide range of operating conditions. The compressor has six stages of variable guide vanes to ensure surge-free, stable engine performance throughout starting, acceleration and steady state operation.



**Figure 10. Sixteen-Stage Axial Compressor**



**Figure 11. Split Compressor Casing**

As in the *Mars* 100™ and *Titan* 130 rotors, the *Titan* 250 compressor rotor assembly consists of durable welded drums for rigidity and long life. All compressor blades are individually replaceable in the field. The vertically split, cast outer case of the *Titan* 250 axial-flow compressor is similar to that used in the *Mars* 100 and *Titan* 130 gas turbines, and facilitates field service by providing maximum accessibility for inspection, repair and cleaning.

Access ports to the rotor provide to two-plane trim balance capability, thereby allowing the minimization of vibration issues and maximizing engine performance, operability and safety. A protective coating is applied to the Stage 1-12 compressor blades to protect against corrosion and increase durability. An online/offline compressor waterwash system is included to minimize performance degradation due to removable deposits on the compressor blades and stators.

A low-rpm electric turning gear is used to keep the gas producer rotor spinning during cool-down. This protects against rotor bowing and allows tighter compressor tip clearances to be maintained, improving compressor efficiency and overall cycle performance

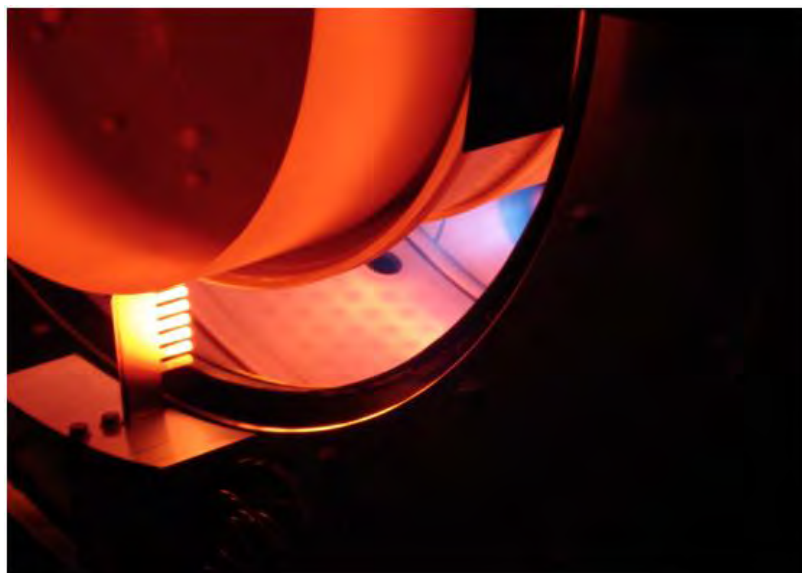
## COMBUSTOR

The in-line, annular combustor is situated between the compressor and turbine assemblies within the gas generator module. The combustion system features 14 lean-premixed gas or dual fuel injectors similar in design to the *Titan* 130 and *Taurus* 65 injectors, and a combustor liner with advanced impingement/effusion-cooling technology (Figure 12).

The combustor's SoLoNOx technology incorporates proven design features that maintain reliability, reduce emissions and broaden fuel flexibility. These features include Solar's latest controls technology and the augmented backside cooled (ABC) combustion liner that reduces metal temperatures and extends the liner operating life.

The combustor is an annular, lean-premix, dry low emissions design that controls gas turbine NOx emissions at or below 15 ppm over an expanded operating range from 40 to 100% load. The combustor produces the same turbine rotor inlet firing temperature of 1204°C as the *Taurus* 65 gas turbine, and employs the same SoLoNOx dry low emissions combustion technology proven on the full range of Solar gas turbine products. The fuel injectors are of a radial inflow type, similar to those proven on the *Taurus* 65 gas turbine. The combustor incorporates a modular design to facilitate in-situ replacement or repair. The liner and fuel injectors can be easily removed for replacement or cleaning if necessary.

The *Titan* 250 is currently available for natural gas fuel applications through 2010. The design team is developing the capability for liquid/dual fuel and lower Wobbe gases for shipments beginning in 2011.



**Figure 12. Combustor Development Testing**

## GAS PRODUCER TURBINE

The two-stage gas producer turbine in the *Titan* 250 provides the power to drive the axial-flow compressor (Figure 13). The temperature at the turbine rotor inlet is 1204°C (2199°F), the same as that of the *Taurus* 65 gas turbine, and is only 27°C (50°F) higher than the *Titan* 130 gas turbine. This firing temperature was chosen for the *Titan* 250 gas turbine to achieve a balance between the desired cycle efficiency and lifecycle maintenance cost targets.



**Figure 13. Gas Producer Turbine**

The gas producer is very similar in size to the *Titan* 130 turbine. The cooling schemes and material selections are similar to the *Taurus* 65, which operates



at the same firing temperature, and have been verified through extensive component and full-scale testing.

The nozzles and first-stage turbine blades are internally cooled with compressor discharge air delivered internally within the gas turbine. The turbine nozzle and blades are investment cast from the same high strength, nickel-based superalloys as the *Titan 130* and *Taurus 65*. Protective diffusion-aluminide coatings for corrosion/oxidation resistance are applied to the first two stages.

A proven passive tip clearance control system, together with the cylindrical profiles of the turbine blade tips and tip shoes, allows tighter rotor clearances to be maintained thereby improving performance across the entire operating range. Clearance control combined with the slow roll turning gear allows hot-restart at anytime without rubs, rotor bow, or lock-up.

The gas producer turbine hot gas path components are of a modular design that allows them to be repaired and/or overhauled in-situ. Removal of the gas producer rotor allows easy access to the combustion liner.

## POWER TURBINE

The power turbine module is an independent three-stage axial design. All three stages of blades are shrouded to maximize efficiency and flatten the power output curve over a wider operating range (Figure 14). The choice of shrouded power turbine blades is based on Solar's proven experience with the *Mercury 50*, *Taurus 65*, *Taurus 70<sup>TM</sup>* and *Titan 130* gas turbines.

The power turbine case and structure are similar in design to those of the *Titan 130* gas turbine. The design output speed of 6300 rpm and exhaust temperature of 460°C (860°F) result in low power turbine blade and disk stresses, contributing to extended component life. The maximum continuous power turbine operating speed is 7000 rpm, along with the very flat output curve from 90 to 110% of optimum speed, provides a broad operating range.

The independent module is flange mounted to the aft end of the gas generator module turbine housing in a close-coupled arrangement. The two modules can be separated in the horizontal position requiring less than 50 mm (2 in) of axial disengagement distance for lateral clearance between modules. This minimal disengagement distance between modules facilitates removal and replacement of either module assembly from either side of the turbomachinery package skid.



**Figure 14. Power Turbine Disk Assembly**

The three-stage power turbine's performance is very high over a wide load range (Figure 15).

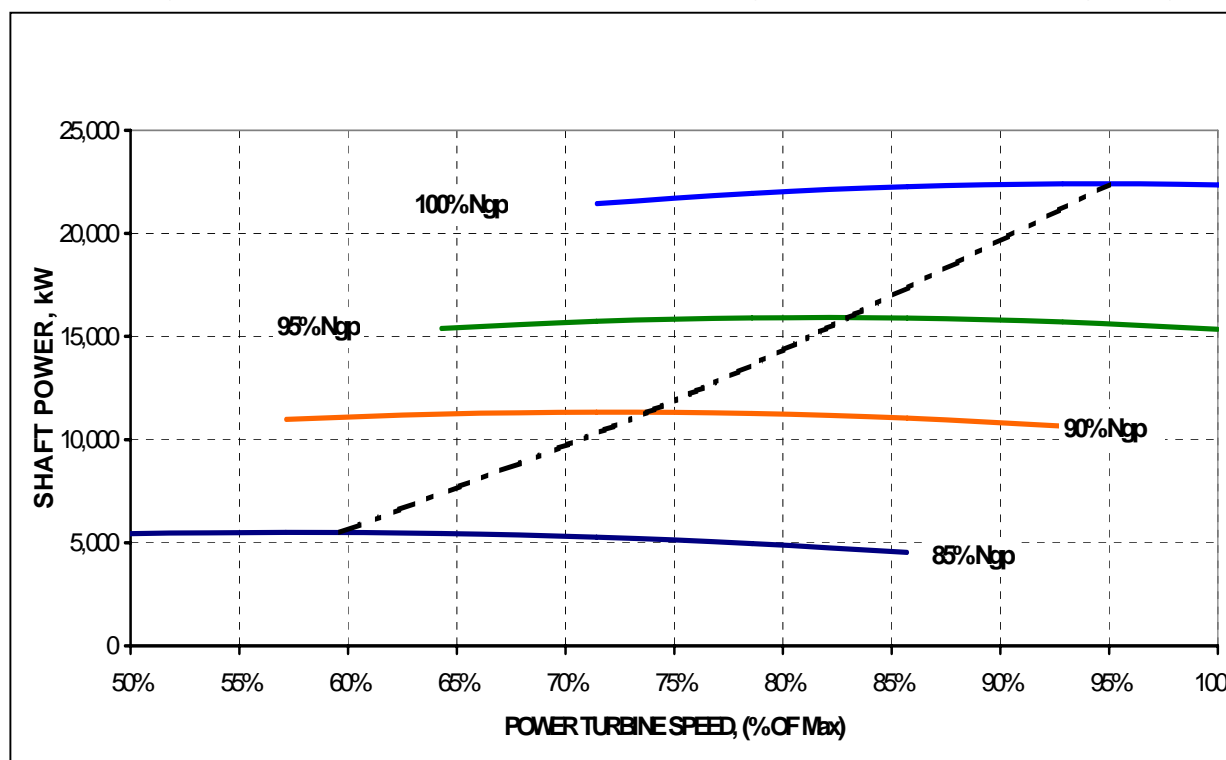


Figure 15. Power Turbine Performance

## ROTOR BEARINGS AND SEAL SYSTEM

Similar to the *Titan* 130 two-shaft gas turbine, the *Titan* 250 gas producer rotor is supported by three tilt-pad journal bearings and the power turbine rotor is supported by two tilt-pad journal bearings (Figures 16 and 17). These bearings employ the latest fluid-film bearing technology so as to promote stable rotordynamic operation. The physically larger journal bearings have a length-to-diameter ratio greater than that of the *Titan* 130 to provide additional damping and to enhance rotordynamic stability through all modes of operation.



Figure 16. Axial Thrust Bearing



Figure 17. Radial Journal Bearing

The thrust bearing for the gas producer rotor is located at the front end of the gas turbine adjacent to the front (No. 1) journal bearing in the compressor. The thrust bearing for the power turbine rotor is located at the aft end of the gas turbine adjacent to the rear (No. 5) journal bearing in the power turbine. The thrust bearing assembly consists of self-aligning, tilt-pad type bearings on the forward, active-side with a fixed, tapered-land bearing on the aft, inactive side.



## INLET AND EXHAUST OPTIONS

The *Titan* 250 air-inlet housing is a radial design to minimize footprint, which can be beneficial in applications where space is limited, such the re-powering of existing facilities, or on offshore platforms and floating production systems. The air inlet can be oriented vertically or at a 45° angle on either side of the package. The selection is typically site dependent based on available space and accessibility.

The *Titan* 250 exhaust duct can be oriented vertically or horizontally to either side of the package. The exhaust ducting and silencers can be arranged to minimize the footprint of the overall turbomachinery package.

## C85 CENTRIFUGAL GAS COMPRESSORS

The C85 centrifugal gas compressor is a single-casing unit designed to meet the needs of natural gas pipeline applications and is specifically matched to the characteristics of the *Titan* 250 gas turbine driver.

The C85 is a linear scale of the *Solar* C65 compressor, which is matched to the *Mars* 100 and *Titan* 130 gas turbines and extends the family of modern *Solar* pipeline compressors started in 1994 with the C40 compressor (Figure 18). The C85 compressor is designed to precisely match the specified profile of pipeline operating conditions using the *Titan* 250 as the driver. Its high efficiency and wide operating range enable the overall gas turbine compressor set package to minimize fuel consumption and emissions over the entire operating profile.

*Solar* incorporates vaneless diffusers in all its compressor designs to ensure the widest possible operating range (Figure 19). Inlet systems and volutes are likewise optimized for highest performance. *Solar*'s pipeline compressors meet or exceed the performance of traditional axial inlet designs, while offering the important flexibility of either one or two impellers. Another benefit incorporated into the C85 compressor design is impeller-eye flow measurement capability, which provides accurate flow measurement input to process and anti-surge control without the need for additional flow measurement devices in the suction or discharge piping (Figure 20).

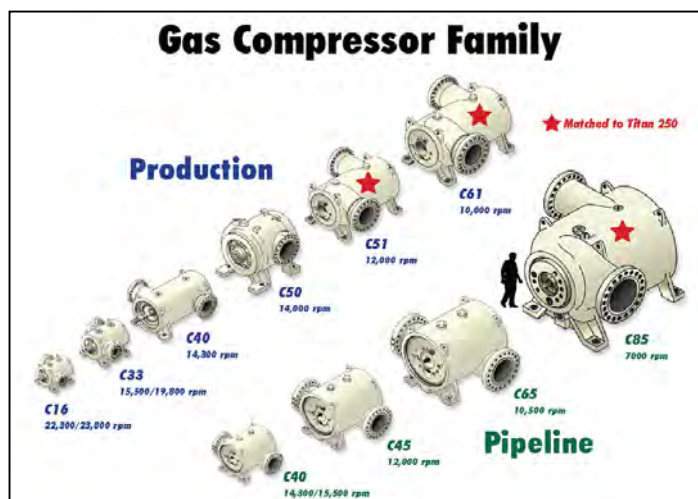


Figure 18. Gas Compressor Evolution



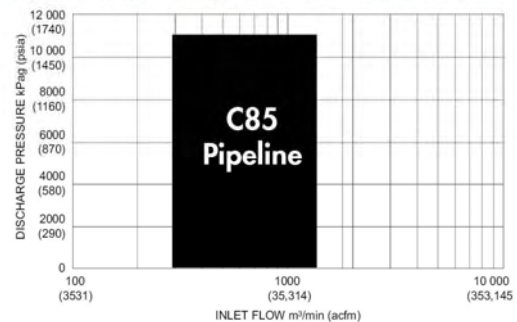
Figure 19. Gas Compressor Assembly



### Key Features

Number of Stages	1 - 2
Seals	Tandem dry gas
Bearings	Journal: Tilting-pad Thrust: Self-equalizing, tilting-pad
Inlet/Discharge Flanges	42/42 in. Class 900
Efficiency	> 89% isentropic
Maximum Speed	7000 rpm
Maximum Flow	1274 m <sup>3</sup> /min (45,000 acfm)
Maximum Total Head	108 kJ/kg (36,000 ft-lbf/lbm)
Maximum Casing Press.	11 030 kPag (1600 psig)
Maximum Torque	79 090 Nm (700,000 lbf-in.)
Instrumentation	Fully instrumented with vibration, temperature, and pressure monitoring per API 617
Vibration Limits	Within API 617

### Operational Range (Pressure vs Flow)

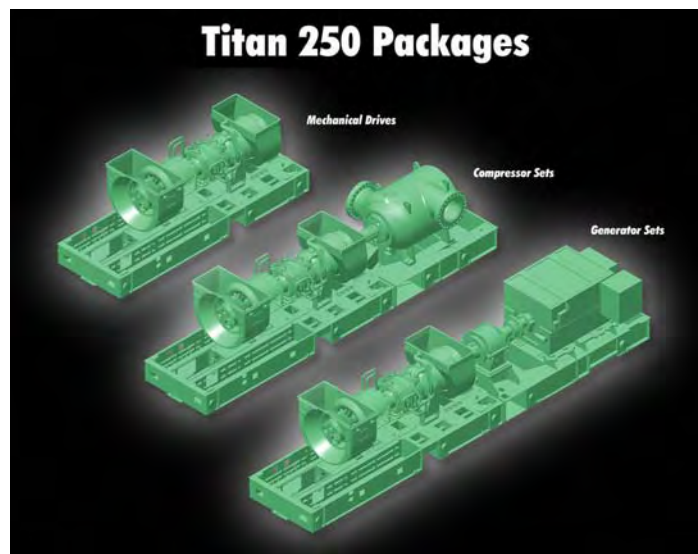


**Figure 20. C85 Gas Compressor Specifications**

## PACKAGE SYSTEMS

As with other Solar Turbine gas turbines, the *Titan 250* is usually shipped as part of a complete turbomachinery package where the turbine is the driver for a generator, gas compressor, or pump. The package contains all the sub-systems necessary for operation including start, fuel, and lubrication (Figure 21). A control system sequences and monitors all functions including those of the driven equipment.

In keeping with Solar Turbine's traditional modular designs, the complete lube oil, fuel and control systems are located on the package (Figure 22). Modular inlet, exhaust and ancillary system designs can be configured to

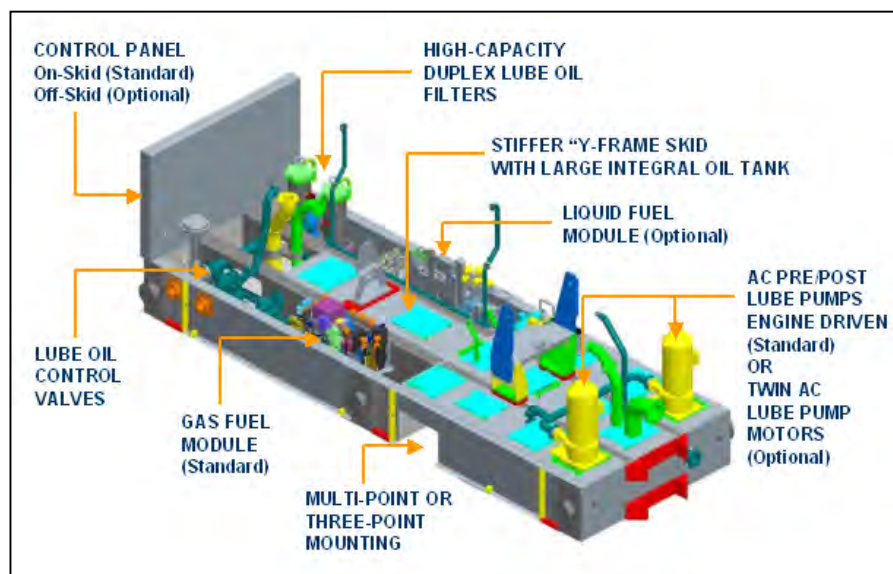


**Figure 21. Package Configurations**

cover a wide range of applications in both enclosed and unenclosed configurations. The two-piece driver and driven package is only 3.35 meters (11 ft) wide. The package is supplied with a direct-drive AC starter, turbine-driven main lube oil pump, AC motor-driven pre- and post-lube oil pumps, a DC motor-driven backup pump, compressor water wash system, Div II electrical system, and an on-skid control system. A motor-driven rotor turning gear system is also supplied to prevent rotor bow and potential lock-up or tip rubs.

A new base frame has been developed for the *Titan 250* compressor set. The structural elements are located closer to the centerline of the gas turbine and centrifugal compressor where the loads are highest. This structure also supports another innovation from Solar: a lateral and axial repair and maintenance rail system. The new system allows the gas producer turbine to be easily and safely disconnected from the power turbine. The gas producer turbine rotor can then be rolled forward along an integral rail system, providing ready access for inspection, repair, or replacement of hot section components. The gas producer turbine can also be removed from the package independently of the power turbine. This avoids the need to realign the power turbine with the driven equipment, thereby significantly improving package availability.

The lubrication system circulates oil under pressure to the gas turbine and driven equipment. The lube oil tank is integrated into the driver frame. The system includes pressure and temperature regulators, filters, strainers, oil level, and pressure and temperature indication. Pre and post lube pumps ensure adequate oil circulation before start up and after shutdown to protect equipment bearings. A battery powered DC backup post lube pump provides post lube in the event AC power is interrupted.



**Figure 22. Package Systems**

The fuel system, in conjunction with the control system, includes all necessary components to control ignition and fuel flow during all modes of operation. Three standard fuel system configurations will eventually be available: dry low emissions gas fuel, dry low emissions dual fuel (gas and liquid) and associated gas. High force electrically actuated gas fuel valves provide precise fuel control with position feedback.

The start system consists of two direct-drive AC starter motors driven by a common solid-state variable frequency drive. The system provides torque to initiate engine rotation and accelerate the engine to self-sustaining speed.

The package includes Solar's comprehensive Turbotronic™ control system that provides control, monitoring, and data collection for the package. In the standard configuration, all key control components are installed on the package skid permitting full operator control at the skid-edge. This is of benefit during commissioning and service. The control system's internal network can be extended to other locations such as a control room for routine equipment operation and monitoring. Serial links to customers' supervisory systems can transmit both real-time operating data and historical data files.



In addition to controlling the turbine, the system also controls the driven equipment and can provide a range of functions. For generator sets these include: synchronization, kilowatt, kVAR and power factor control, load sharing, and import and export control. For driven compressor packages, available functions include process control and compressor anti-surge control.

The *Titan 250* package can be supplied unenclosed, with a driver-only enclosure, or with a full package enclosure. Overhead trolley rails are provided for removal and handling of heavier components.

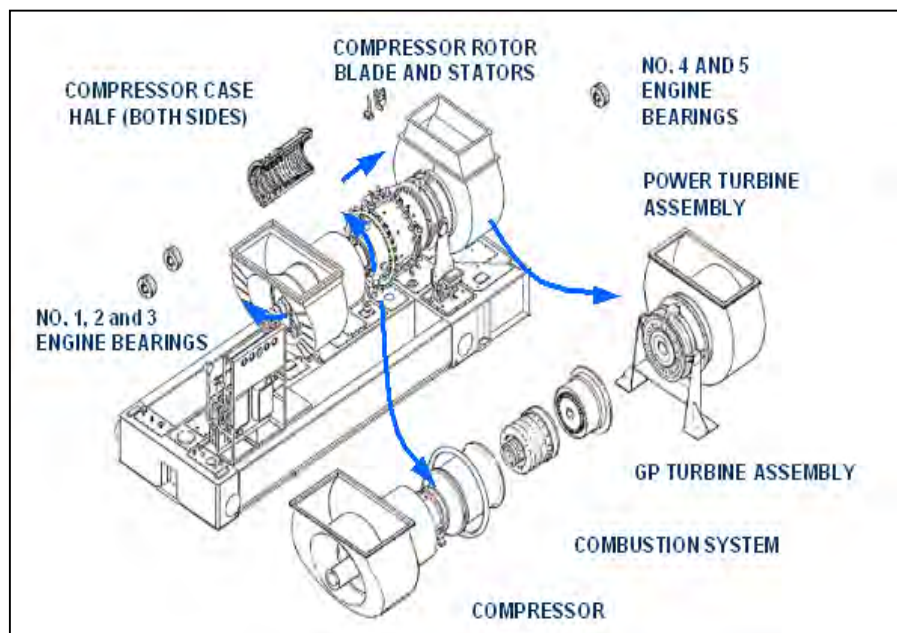
## MAINTENANCE AND SERVICE

The design of the gas turbine, the package, and the service strategy has been closely integrated to ensure maximum equipment uptime. Field service tooling was developed in conjunction with the turbine and package design to expand in-situ repair capability, and a majority of this tooling was proofed-out during the development test phase.

All regularly serviced package items have been placed near the edge of the skid for ready access. The enclosure doors can be easily removed to gain further access when needed. Additional instrumentation has been added to more closely monitor the turbine's performance and health.

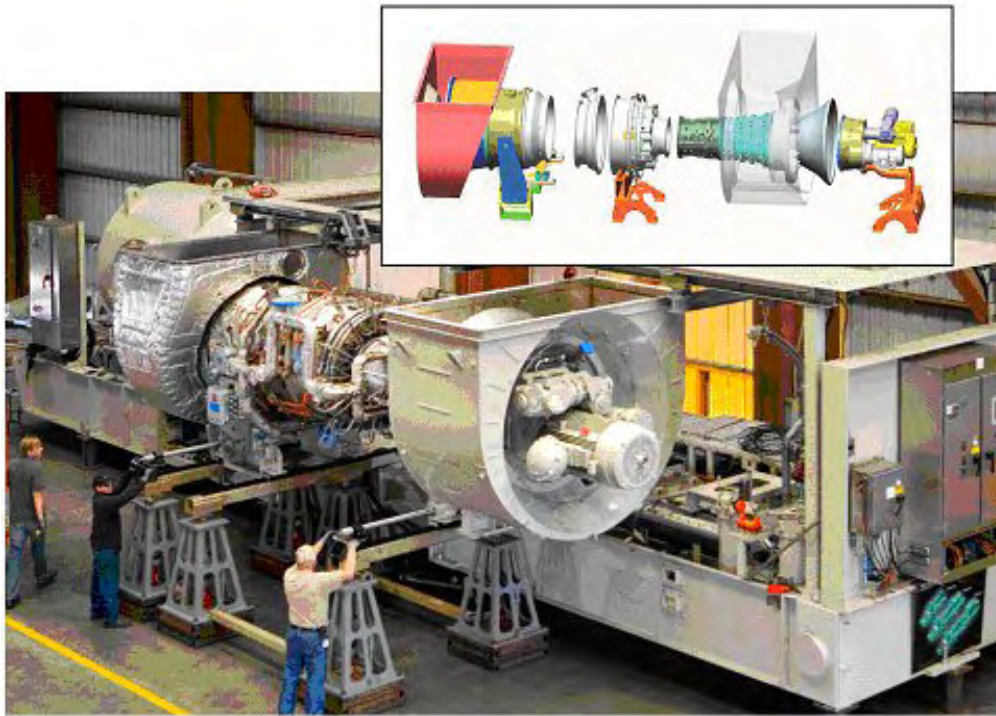
As described above, to take advantage of the *Titan 250* gas turbine modularity (Figure 23), a new gas turbine maintenance rail system was developed to improve maintenance capabilities (Figure 24). The underside-supported rail system is faster and intrinsically safer than many overhead lift methods.

In addition to these features, a comprehensive equipment health management system is available. This feature enables a transition from traditional time-based maintenance practice to one that is condition-based. The system's capabilities include: remote monitoring and diagnostics (RM&D), secure connectivity, equipment condition assessment, and collaborative communication and information management. Given these capabilities, issues once only detected through hands on means can now be discovered, diagnosed and remedied half a world away.



**Figure 23. Service Capabilities**





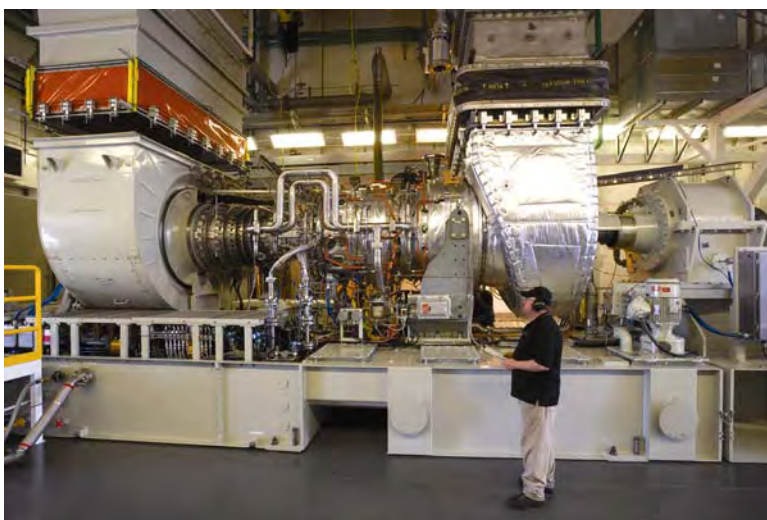
**Figure 24. Gas Turbine Service Rail System**

## DESIGN VALIDATION AND TESTING

As previously discussed, the development and validation of the *Titan* 250 and C85 gas compressor followed an approach proven over a long history of successful gas turbine and centrifugal compressor product developments and upgrades. This approach, used most recently on the *Titan* 130, *Mercury* 50 and *Taurus* 65 gas turbine programs, as well as the C51 and C65 centrifugal compressor programs, continues to advance the state-of-the-art in component efficiency, firing temperature, and hot gas path cooling capability.

Sub-scale and component testing included injector and combustion rig development, hot cascade rig testing, thermal paint, blade frequency, and validation of internal cooling passage flow for the cooled nozzles and blades.

The full-scale development test plan included a dedicated development engine with a



**Figure 25. Titan 250 Test Cell**

production-style package and dynamic load source using a gearbox- driven generator(Figure 25). Several full-scale development tests on multiple engine builds were completed to validate the aerodynamic and thermodynamic performance, mechanical integrity, durability, rotor dynamics, trim balance sensitivity, bearing loads, emissions and combustion system mapping, performance optimization, transient and part-load performance, and the functionality of the control system.

Development and factory testing of the C85 gas compressor was conducted at the new world class gas compressor test facility. Three different impeller stagings have already been tested including the first commercial unit. All the tests showed higher than expected efficiency and surge margin. These test results will be used to validate design tools and methodologies and will serve as a basis for further design refinements.

The new product development team will continue to follow and monitor commercial shipments for the first two years as part of the field evaluation program. This approach helps provide early closed-loop design feedback.

## SUMMARY

Developed based on Solar's traditional design philosophy of product evolution from proven technology, the *Titan* 250 gas turbine and C85 centrifugal gas compressor are the latest additions to the product line. The *Titan* 250 features similar operating cycle parameters, design approach, and materials as the *Titan* 130 and *Taurus* 65 models. The C85 is a direct aerodynamic-scale of the C65 gas compressor (Figure 26).

The *Titan* 250 offers best in class efficiency, and the dry low emissions combustion continues the trend towards ever-lower NO<sub>x</sub> and CO output across a broader operating load range. Additional design considerations were given to the turbine and gas compressor to reduce and minimize maintenance intervals to increase equipment availability.

The package's total installed footprint is smaller than all units in this class. It is only 0.15 m (6 inches) higher and 0.3 m (1 foot) wider than the *Titan* 130 package. Almost of the necessary subsystems (lube, gas, controls) are integrated and contained within the package.

The gas turbine and gas compressor have been thoroughly tested in component, subsystem, and full-scale development, and will be starting field operation in late-2009 where performance and mechanical integrity under all operating conditions will be verified.



**Figure 26. C85 Compressor Module Exchange**

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