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LM6000 Engine Testing

A Unique Concept

by

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of

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Biography

Dale Goehring, P.Eng., MBA is a Senior Project Engineer at TransCanada Turbines Ltd. in Calgary, AB. Dale graduated from the University of Manitoba in 1993 with a Bachelor of Science in Mechanical Engineering and from the University of Calgary in 2001 with a Master of Business Administration (Finance). During his 10-year career, he has worked in the gas turbine, aerospace, manufacturing and consulting engineering fields. He has worked at TransCanada Turbines since the company's formation in 1998 where he has been working with the Rolls Royce Avon and RB211 as well as General Electric LM2500 and LM6000 aeroderivative industrial gas turbines. He is a registered member of the Association of Professional Engineers, Geologists and Geophysicists of Alberta (APEGGA).

Abstract

TransCanada Turbines (TCT) repairs and overhauls General Electric (GE) LM6000 aeroderivative industrial gas turbines as part of its OEM authorized Level 4 Maintenance operations in Calgary. This paper describes the unique project undertaken by TCT with respect to post-overhaul testing of the LM6000 engine. While most gas turbine testing takes place in special-purpose built test cells, this proved to be cost prohibitive in this situation. As a result, TCT pursued an opportunity to modify an existing GE Stewart & Stevenson LM6000 PC package into a quick change-out test cell. The facility is located just east of Strathmore, AB at the EnCana Cavalier Power Station. TCT managed this project with an engineering team comprised of Wood Group Power Solutions and Fern Engineering. Some of the key details of this project include the skid mounted engine design, the quick change-out concept, and the modifications to the existing control system to allow for testing of both LM6000 PA and PC engines. In addition, TCT pursued a data acquisition system from Yanos Aerospace for post processing of the test data for both the LM6000 facility and the TCT's current test cell in Calgary. This system allows TCT to easily manage testing data, in a database, to facilitate quick comparisons and engine troubleshooting.

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Introduction

TransCanada Turbines Ltd. (TCT) is the industry's newest, authorized depot for repair and overhaul of industrial gas turbines. TCT is authorized to maintain, repair and overhaul mainstream aero-derivative gas turbines manufactured by both Rolls-Royce and General Electric (GE). TCT's scope of work includes the Rolls Royce Avon and RB211 as well as the General Electric LM2500, LM2500+, and LM6000.

In the repair and overhaul aftermarket for the GE LM6000, TCT's competitors with OEM authorized Level 4 licenses are MTU in Germany and GE in Houston. Both of these shops have testing capability so as the overhaul market on the LM6000 grows, TCT saw the need to develop testing capabilities in Calgary in order to compete in the marketplace. Several options were pursued before TCT decided to convert an existing GE LM6000 PC package at the 110 MW EnCana Cavalier Power Station near Calgary, Alberta, to enable testing of overhauled LM6000 PA and PC engines. This unique concept provides TCT the opportunity to use a portion of the plant as a test cell while minimizing the cost of building and operating such a facility.

Using one turbine generator package as a test cell requires disconnecting and removing EnCana's engine from the package, installing and connecting the test engine, running the test engine, disconnecting and removing the test engine, and reinstalling and reconnecting the EnCana engine all within a short time span. In order to accomplish these tasks in the time allotted, both engines require quick disconnect connections for all the connections except for the gas supply, which has the standard ANSI bolting flange.

History

In terms of the market, there are now 429 LM6000 engines in operation[1] since the first unit was installed in December 1992. Approximately 55% of these engines are PC units and 26% are PA units with 56% of the total units located in North America. The engine produces about 43 MW of power (56,000 SHP) at over 40% thermal efficiency and is one of the fastest selling gas turbines in the marketplace.

The original capital cost estimates to build a standalone test cell at TCT's facility ranged between $10-12 million CDN depending on the design of the test cell. Several different designs were considered including modifying an existing package, constructing a built for purpose test cell, and even building a peaking power plant by connecting to the power grid. Because the engine overhaul market is just starting to grow and is quite cyclical over the next 10 years, the business case didn't support this type of investment.

Partnering with EnCana

TCT found EnCana which operates the Cavalier Power Station as a merchant power plant which means that based on fluctuations in the price of power on the Alberta Power Pool there are times when the plant is not operating. As a result, TCT was able to strike a commercial deal with EnCana for the right of access to the plant as well as the ability to make the modifications necessary for testing. This concept proved to be a fraction of the cost of a standalone test cell due to the fact that most of the infrastructure is already in place.

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[1] Data as of September 4th, 2002 from GE Power Systems Aeroderivative Users' Conference in Houston, TX

Design team

TCT hired Wood Group Power Solutions (WGPS), based in Tulsa, OK, to provide a turnkey solution for the test cell. One of the subcontractors to WGPS was Fern Engineering for the mechanical work. Design work on the LM6000 conversion began in January and modifications will take place this spring and extend into fall.

WGPS offers world-wide solutions for EPC power projects as well as services in the refurbishment, relocation, resale and upgrade of used and new surplus power equipment to operators in the global power generation, oil & gas, and marine industries. WGPS provides engineering, procurement, and construction services (EPC) for the new gas turbine generator as well as the balance of plant equipment, and installation on a turnkey contract basis.

Fern Engineering, Inc. is an experienced turbo machinery engineering company that provides expert consulting services and products to the global power industry. Since 1967, the company has established a worldwide reputation of excellence among users and manufacturers of turbo machinery. Based on Cape Cod, Massachusetts, the company was involved with the original design of the GE Houston test cell for Stewart & Stevenson (S&S).

In addition to the mechanical, electrical and controls work, TCT contracted Yanos Aerospace to provide a data acquisition system for both the LM6000 test cell as well as TCT's current testing operations in Calgary.

Yanos Aerospace Inc., located in Cochrane, Alberta, provides products, engineering services and specialized support services to aircraft and industrial gas turbine engine users, engine overhaul shops and engine production facilities. Yanos is a systems integrator and specializes in the provision of gas turbine engine test equipment including complete steady state and dynamic data acquisition systems, instrumentation systems and control systems for engine production and overhaul shops.

Design Features

Package B at the EnCana Cavalier Power Station is a GE S&S with a LM6000 PC Sprint and Enhanced Sprint which means water is injected into both the Front Frame and LPC inlet. Water is also injected with the fuel nozzles in order to control NOx emissions. Attached to the package is a once-through heat recovery steam generator (HRSG) supplied by ISI as shown in Figure 1.

Figure 1 - Package B at the EnCana Cavalier Power Station

During testing the HRSG is to be operated dry and no water injection for Sprint or NOx suppression.

New Building

TCT designed and constructed a new building adjacent to Package B. The 7.2m by 18.3m (24' x 60') pre-engineered building is constructed on a grade beam foundation with piles. Lawson Projects Ltd in Calgary provided construction and project management services.

A key feature of the building is the 15 tonne overhead crane which is needed to lift the engine and the container. An overhead door is located at either end of the building to facilitate the process of engine removal, installation and shipping. The building was located as close as possible to the existing package so that the doors of the package and the air filter act as walls and a roof during engine removal.

Figure 2 - New building adjacent to Package B

Control System

A new fuel control system was required in order to operate the package as both a power plant and a test cell. The current control system is a GE Mark VI Millennium fuel control system as shown in Figure 3.

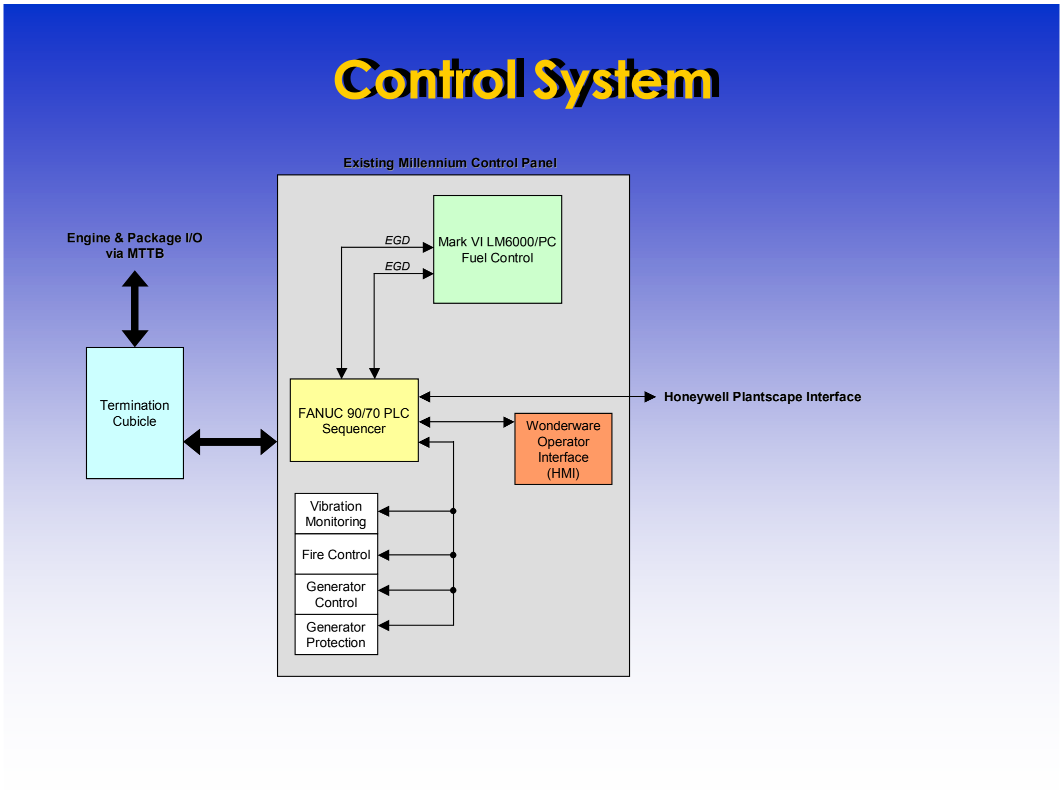

Figure 3 - Existing Fuel Control System

In order to achieve the desired results, a MicroNet Based Control system replaced the MK VI fuel control as well as those parts of the Fanuc PLC in order to accommodate the different models of LM6000 engine as shown in Figure 4. The Beckwith Power System Stabilizer, Ground detector, Wonderware HMI for commercial operation and the Bentley Nevada vibration system remained.

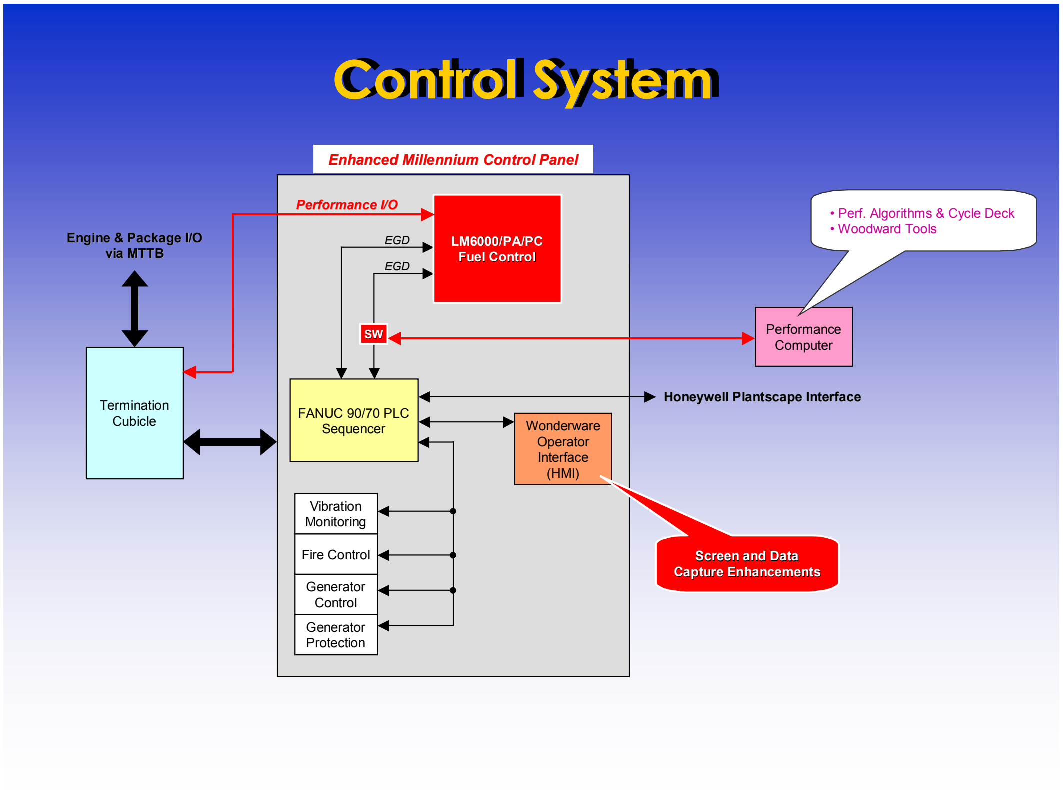

Figure 4 - Fuel Control System after Modifications

As part of the Woodward MicroNet Control System, the existing 90-70 PLC is reconfigured to be a gateway to the Field Bus I/O and interface with the system RTU. The existing Wonderware HMI is kept and not changed for commercial operation of the unit, however it is disabled when in test cell mode. A separate HMI is supplied on a wheel around cart for use during test cell operation. This HMI also stores the MicroNet software for downloading over the network to the MicroNet Control System.

There are additional ports on the supplied network switch for a data acquisition system and for communication to the DCS, configured as a modbus TCP/UDP port.

The system has several modes of operation including:

- Commercial Operation
- Test of an LM6000 PA engine
- Test of an LM6000 PC engine

The control hardware for the PD engine is included in the MicroNet although no valves or other mechanical components or drivers are included. No consideration has been given to the PB engine at this time.

Loading the appropriate software into the MicroNet Control System activates these modes of operation. The software is stored on the test HMI and downloaded over the network for the engine that is to be tested. Using a canon plug and digital bit electrical loop, TCT ensures the correct software is loaded for the engine being operated. When in commercial operation mode the unit is operated the same as it did prior. When the test cell mode is used, the control automatically starts the turbine and brings it to idle speed and waits for operator action. The control at this point is completely manual providing limiter type functions to protect the engine if the operator commands the engine to go outside of the safe operational envelope.

Extra instrumentation has been added to the package in order to calculate performance. In general, the extra instrumentation is limited to transducers that have different electrical connections for the same function (i.e. speed sensor is eddy probe in one engine design and piezo-electric in the other engine design).

GE has provided TCT with a data reduction program for both the LM6000 PA and PC engines. This performance program gives a comparison of the power output from the engine to average new production engine.

Skid Design

Another key piece of this project is the skid design provided by Fern Engineering. This involved modifying the package to permit quick turn around.

Removal and replacement of an engine requires removal and reinstallation of several auxiliary components, disconnection and reconnection of numerous fluid lines, the gas turbine inlet and exhaust ducts, the drive coupling, and finally the gas turbine itself. In order to reduce the change out time, most of these interface connections were modified to incorporate quick disconnect features. Functionally the gas turbine and package remain unchanged with all of the modifications being "add on" items so that the package can be reverted to its original configuration at any time if desired.

A package layout showing the sub-skid installation and other connection features is shown in Figure 5.

Figure 5 - PC Engine on skid

Sub-Skid

The sub-skid serves as an intermediate attachment between the engine and the package main base. The main purpose of the sub-skid is to provide a mounting stand for the engine so that the connections that service and control the engine can be made in an assembly area rather than in the package itself thereby minimizing downtime.

Another important feature of the skid is that it eliminates the need to realign the engine after each removal. The sub-skid has large alignment dowels that are permanently located during the initial alignment and assure exact repositioning of the sub-skid on all subsequent change outs. With the sub-skid, the engine mounting stanchions are not removed further assuring proper positioning. The engine is bolted to the sub-skid and the sub-skid is, in turn, bolted to the main base.

The sub-skid has different mounting locations to accommodate the different lengths of engine between the PA and PC as the PA engine is approximately 14 cms (5.5 inches) shorter than the PC engine.

Inlet Connection

The standard inlet has inner and outer bolted flanges with 46 bolts each that connect the engine to the inlet air plenum. In the modification, all but four of the bolts in each flange have been replaced with large diameter “V” clamps (also known as “Marman” clamps).

“V” clamps depend on a wedging action created by tapered flanges to generate a clamping force on the flange faces. However, the existing flanges have parallel faces so that wedge rings were created that attach to the parallel flanges to form a tapered flange.

Because there are several loose parts that make installation of the “V” clamp difficult unless the loose parts were held in place, the four bolts are used to hold these pieces before the “V” clamp is actually fitted.

The internal pressure of the inlet duct is slightly below atmospheric pressure; hence, there is no separating load on these flanges.

Exhaust Connection

The exhaust connection utilizes similar "V" clamps as the inlet connection. The exhaust differs only in that there are two outer flanges, one fore and one aft of the split duct (clam shells) whose removal permits rearward displacement of the exhaust diffuser thereby providing room for the engine rearward movement required for removal.

The comments concerning the inlet duct apply similarly to the exhaust duct except that the internal pressure of the exhaust duct is slightly positive (2 to 2.5 kPa or 8 to 10 inches w.c.) which gives a separating load of less than 8 kN (1800 lbsf).

Electrical Connections

All the electrical cable connections to the four patch panels have been routed to junction boxes that are mounted on the sub-skid as shown in Figure 6. The cables have been "ganged" to three large canon plugs thereby reducing connection time.

Figure 6 - Electrical Connections

Fluid Connections

There are approximately 30 fluid connections that service the engine or monitor critical engine parameters. Most of these have been fitted with quick disconnect fittings to reduce the connection time. Those connections that were not fitted were either too hot, too high a pressure, or, as in the case of the fuel supply connection, too crucial.

Generally, all fluid connections from the engine sub-skid to the package have flexible hoses. And, in most cases, these hoses had to be lengthened so that they could be folded down into the main base recess and out of the way.

All plumbing that is above the package grating was lowered to a level below the grating so as not to impede removal or re-entry of the engine and sub-skid.

Internal Package Crane

The internal crane inside the package was replaced with one with a higher capacity. Because the crane is now lifting the engine plus the sub-skid, the added weight required a 12-tonne crane in place of the existing 8.6-tonne unit.

Generator Coupling

The bolted connection remains unchanged.

Thrust Balance Valve

The PA engine is only configured for the orifice plate design which necessitated that the package be modified per GE Service Bulletin 187 which removes the electronic thrust balance valve and replaces it with an on-engine orifice plate. The electronic valve was, however, kept in place in order to test PC engines that still have the electronic valve installed. This modification takes into account the concurrent implementation of Product Bulletin 172 for control system software modifications as per Software Action Request 129.

Collector Diffuser

Fern Engineering designed a transition piece to adapt the PC collector diffuser to accommodate the PA turbine rear frame. The inner liner is baffled to adjust the diffuser area ratio from 2:1 to 1.5:1. The outer diffuser liner and piston ring was modified to accommodate the shorter PA turbine rear frame using a spacer as shown in Figure 7.

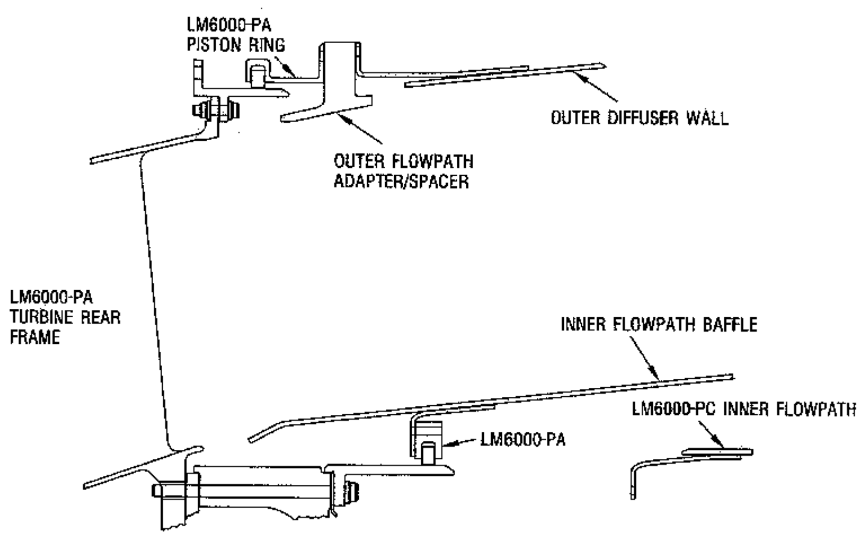

Figure 7 - Collector Diffuser modification

Data Acquisition System

TCT engaged Yanos Aerospace to provide a new Data Acquisition System (DAS) to perform all data archiving, performance calculation, logsheet, reports, trending and diagnostic features. This DAS system is based on the Yanos Aerospace EngineTest© Logsheet (ETLS) software package that is currently in use worldwide for post-overhaul and production testing of gas turbine engines.

Using Microsoft© SQL Server or Microsoft© Access, complex database queries are easily developed to create "views" of data that cross the boundaries of TCT's systems. For example, a Microsoft Excel template takes the current test data, all of the customer information for payment terms from the accounting database, the total new and repaired parts from the production database and finally the total hours spent by each individual while the engine was in-house.

The traditional overhaul process is shown in Figure 8.

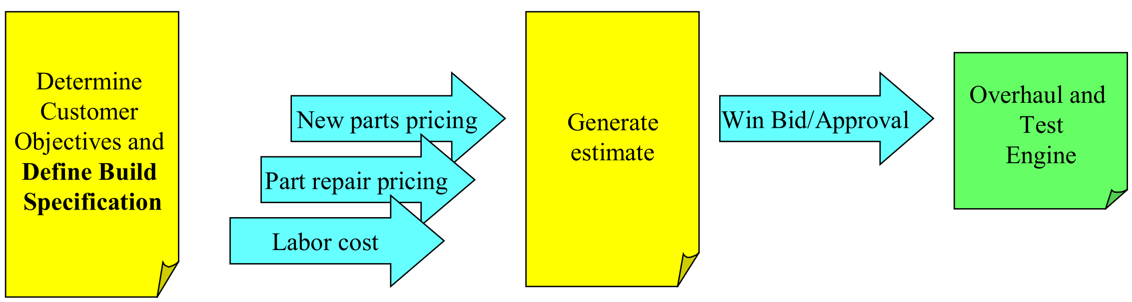

Figure 8 - Traditional Overhaul Process (Simplified)

With the new DAS system, TCT is able to combine the test results (first test pass rate, number of tests, margin, etc.) with the actual build process to identify patterns in the data. For example, TCT can find out the historical difference in margin for all engines that ever passed through the facility with repaired versus new vanes in order to generate build standards based on this information and customer requirements. Patterns can then be used to drive build details even if tolerances are kept to the minimum side of the allowable limits. Using the data, changes to the build procedures can even be discussed with the OEM if there is potential for an improvement. This changes the overhaul process into that shown in Figure 9.

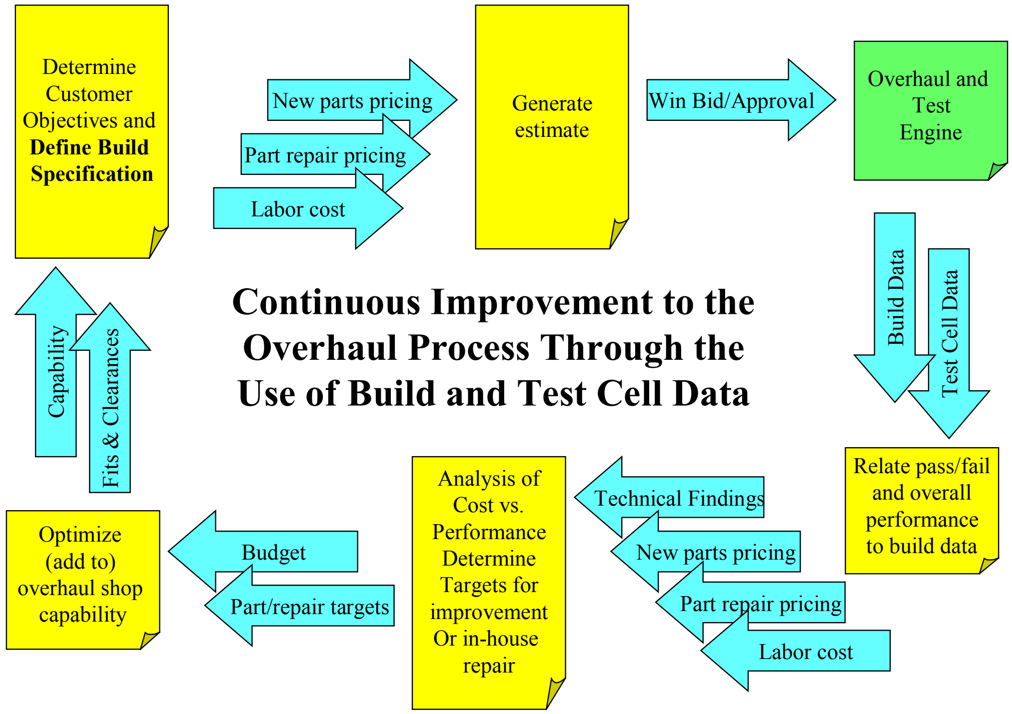

Figure 9 - Additional benefits to the Overhaul Process

What does this mean for Engine Operators?

This means savings in the fact that significant performance gains can be accomplished by tightening up build procedures beyond those in the manual. It is possible to also reduce the number of tests per engine and improve the first test pass rate.

Through the use of this approach, a significant reduction in direct operating costs to the customer can be demonstrated. New tooling and processes can also be developed to guarantee repeatability and further reduce costs.

How does the EngineTest© work?

The EngineTest© product takes the required engineering unit values from the Fuel Control System. When the Get Data button is clicked, all of the Real Time data is automatically recorded to the database. EngineTest© then carries out all required standard day corrections and other required performance calculations in accordance with the OEM approved calculation method to produce the final performance values upon which the engine is rated.

The EngineTest© product provides a fully relational database for the organized storage of all recorded test data and allows direct access to the Level 1 diagnostics provided with the product. All calculated performance values together with all the raw input data are stored in the database. The software is configured with the fuel control system for semi-automated test procedures in accordance with the OEM's test instructions. Any existing Microsoft Excel plots are fully automated into the EngineTest© application which allows for automatic schedule or performance plotting in accordance with the required procedures.

For TCT, EngineTest© has been configured for the RB211, Avon, and LM2500 which are tested at the TCT Calgary facility as well as the LM6000 test facility at the EnCana Cavalier Power Station.

Engine-Specific Performance Calculation Routines

Performance calculation routines come in various forms from the OEM. Each performance calculation routine is implemented as a stand-alone object into the program or contained within the database so that it is customer configurable.

Printed Reports

All tabs of the logsheet (functional, acceptance, logsheet and diagnostic) may be selected and printed as standard reports.

Figure 10 depicts a standard engine acceptance report exported to Microsoft Excel.

TRANSCANADA TURBINES
The Independent Alternative
Calgary, Alberta, Canada

Engine Model: Avon 1533
Engine S/N: 37549
Customer: Energy Corp
Work Order: EN101082A
Sales Order: SV1501702
Run #: 1
Test Cell: TC1
Operator: John Doe
Observer: Glen Frank

Test Program Tool #: 3.0.125
Test Database Tool #: 0.0.1

	S/N	W/O	MNG # (hrs)
Compressor	SLAVE	SLAVE	SM21071
Turbine	NSN	TT7029	SM21071
	.	.	.

Liner Type: LEII
Diffuser Installed: No
Date: 2002-03-18
Test Purpose: Repair

Comp Boost: Lot C
Oil: Exxon-2380
Fuel: LPG/Air

	Spec Conditions	
Spec HP:	7400.00	HP
Pred Turbine Inlet Temp:	1975.00	F
Spec Turbine Inlet Temp:	2005.00	F
Delta TIT From Spec Temp:	-30.00	F
Pred Heat Rate At Spec HP:	7520.00	BTU/HP-HR
Spec Heat Rate:	7925.00	BTU/HP-HR
Delta Fom Spec Heat Rate:	-5.10	%

	Fuel Sample
SG:	0
Temp:	0
LHV:	0

Points Used To Determine Predicted Data

	RATING POINT 1	RATING POINT 2	RATING POINT 3	RATING POINT 4	RATING POINT 5	RATING POINT 6
Date:	3/18/02	3/18/02	3/18/02	3/18/02	3/18/02	-
Time	12:14:25 PM	12:19:23 PM	12:25:08 PM	12:31:06 PM	12:36:28 PM	-
Corr TIT:	1707	1809	1904	1933	1973	-
Corr SHP:	4869	5681	6635	6983	7328	-
Corr WF (PPH):	2097	2364	2617	2585	2713	-
Vibration Comp. Front:	-	-	-	-	-	-
Vibration Turbine:	-	-	-	-	-	-

	a	b	c
Fuel Fit (ax^2+bx+c):	-5.44E-05	9.16E-01	-1078.03
TIT Fit (ax^2+bx+c):	-7.98E-06	2.03E-01	907.83

Wf(pph) @ spec:	2725.35
Derived lhv:	20418.69

Calculation Version:	1.0.19

Figure 10 - Engine Acceptance Report

Engine Diagnostics

In order to have access to diagnostic tools for the test cell operators, EngineTest© offers integrated parametric analysis along with interfaces to internal or external diagnostic products. An example of the internal parametric analysis (Level I diagnostics) is shown in Figure 11. This figure shows the current engine on test (red line) vs. other selected engines in the historical database and corrected engine temperature is plotted vs. corrected power.

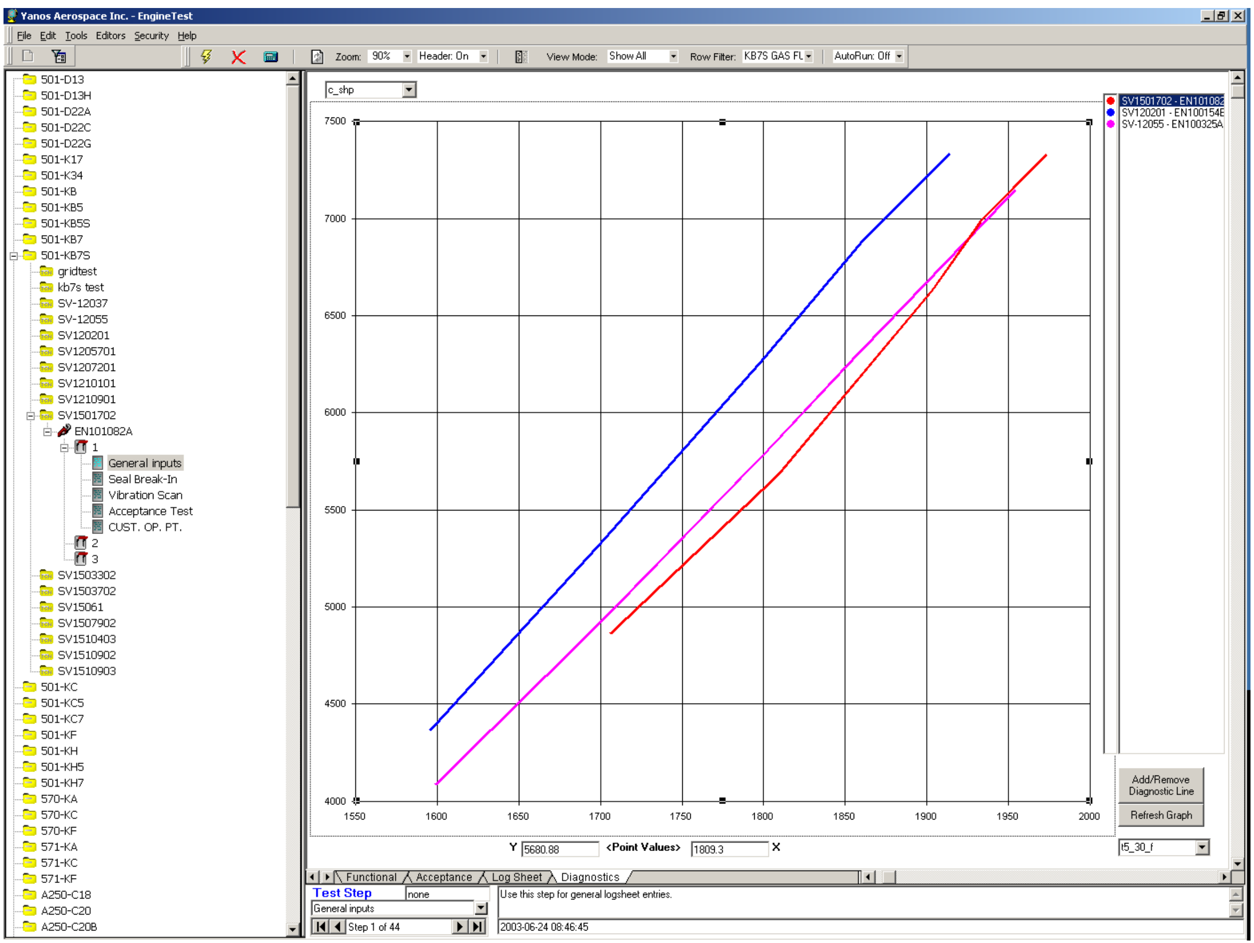

Figure 11 – Level 1 Diagnostics

Challenges

There were many obstacles to overcome in completing this project.

Environmental

TCT completed the process of amending the existing Alberta Environment (AENV) approval of the Cavalier Power Station by submitting an application and getting public approval. The current stack limit for NOx emissions at EnCana is 29.3 kg/hr for each stack. NOx emission levels during turbine testing falls under the CCME National Emission Guidelines for Stationary Combustion Turbines December 1992 which states that "combustion turbines under repair or being tested are not applicable to these emissions standards". In this case, however, TCT had to amend the current approvals because the stacks are continuously monitored.

TCT engaged Jacques Whitford Environment Ltd. of Calgary to perform an air quality assessment of NOx emissions during testing. For the purpose of the study, the maximum load conditions during testing from an LM6000 PA engine were considered as an expected worst-case scenario. During the simple cycle operation of testing, there is a higher exit temperature and almost two times the exit velocity. At the same time, the NOx emission rate for testing is almost five times that of the EnCana turbine, but because of the short duration of testing, the cumulative case did not adversely affect the NOx emissions for the station.

Risk Assessment and Safety Issues

Both TransCanada and EnCana risk management and insurance groups performed a complete risk assessment study. As a result of this study, safety was of critical importance to the design. Insurance issues were dealt with as part of the agreement between TCT and EnCana.

The Powerpool

The Alberta Electric System Operator (AESO) brings together two former entities, the Power Pool of Alberta and the Transmission Administrator of Alberta, which were created with the evolution of Alberta's competitive electricity marketplace. By bidding into the pool as a price taker, all of the power created during testing is absorbed by the electric grid system.

Engine Handling

The monorail support assembly was modified to bring out the gas turbine by rotating the engine only 90 degrees as shown in Figure 12.

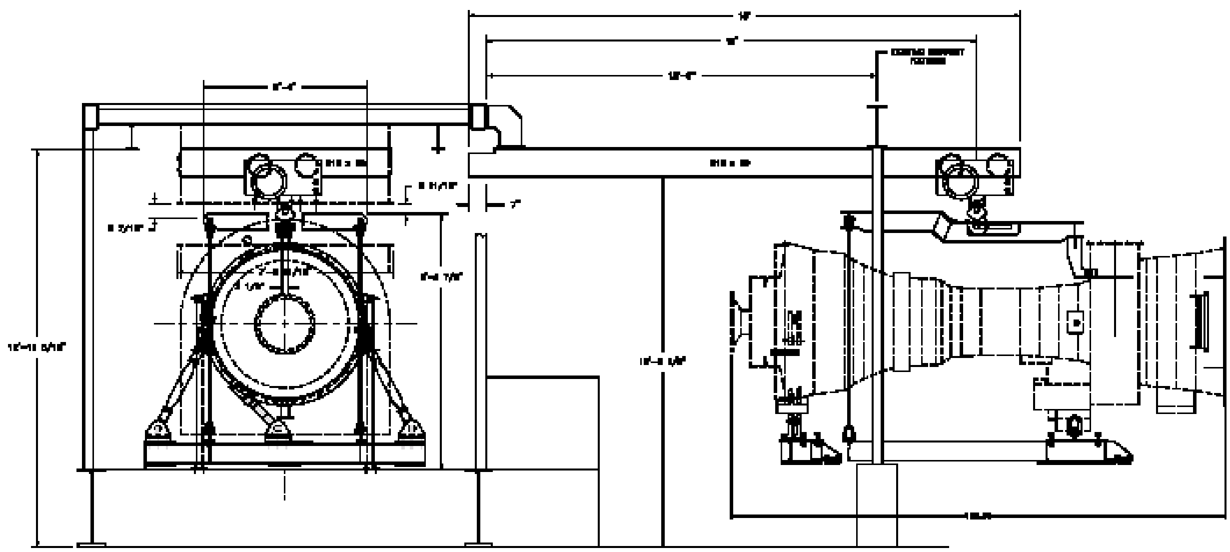

Figure 12 - Engine Removal

The engine/skid assembly is removed from the package in much the same way as a typical package as shown in Figure 13. Using a combination of the monorail system and the building crane, the engine/skids are removed and installed into the package with ease.

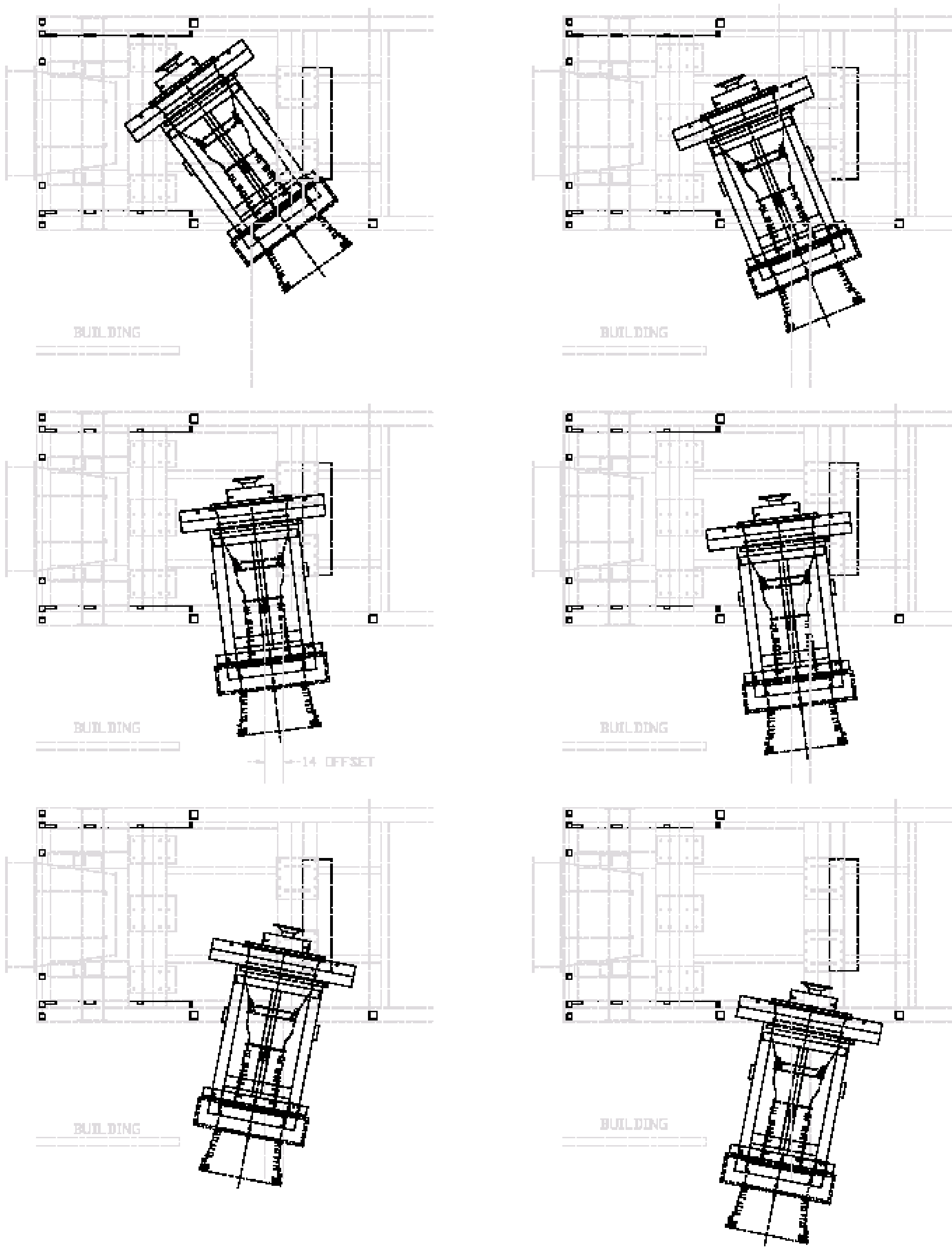

Figure 13 - Plan view of engine/skid removal

Testing Operations

TCT performs LM6000 PA and PC gas turbine testing as per GE Test Data Folder R99AEB155 Rev 0, 4/14/00. Both of these models are SAC engines – single annular combustor. TCT may decide to add DLE (Dry Low Emission) capability to this test facility in the future.

Testing of a newly refurbished gas turbine begins with a Break-in and Functional Check-out Procedure. During this procedure, the gas turbine is checked for correct VIGV (Variable Inlet Guide Vane), VSV (Variable Stator Vane) and VBV (Variable Bleed Valve) angle operation as well vibration data. Graphically, this test procedure looks as shown in Figure 14.

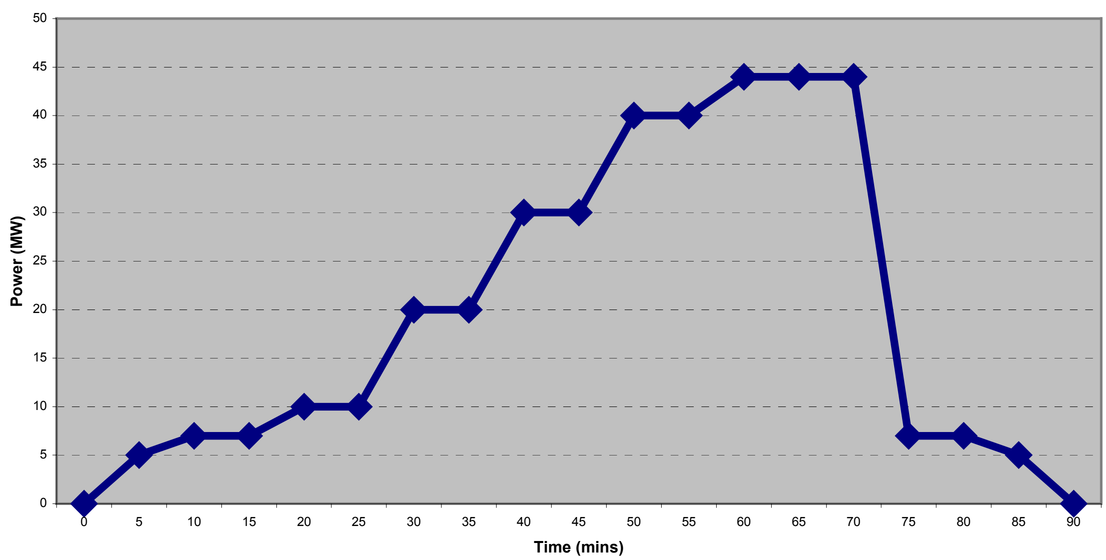

Figure 14 – Break-in and Functional Check-out procedure

Following this test, the Schedule “A” – Acceptance Test is accomplished as per Figure 15.

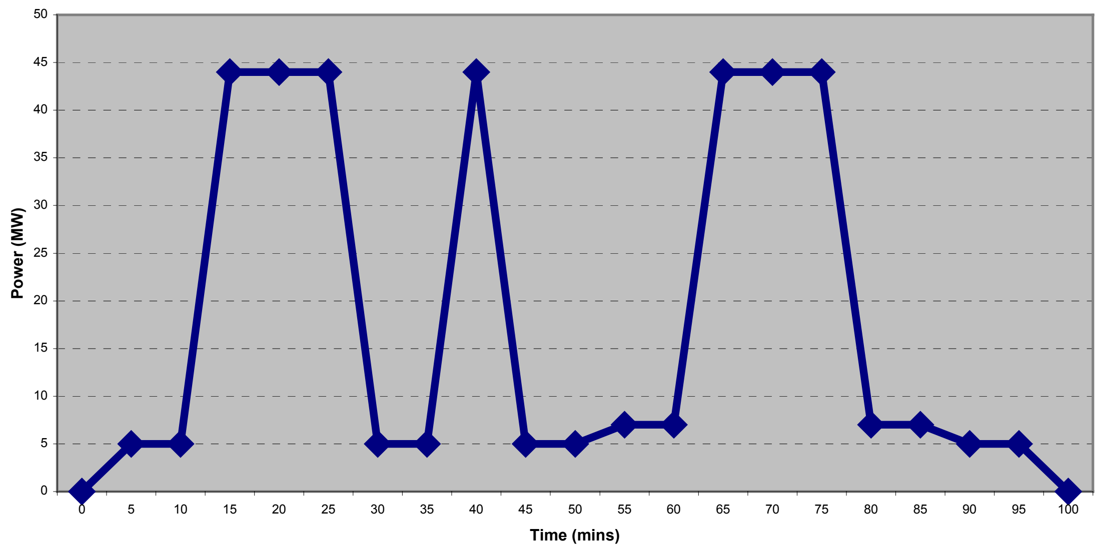

Figure 15 - Schedule "A" Acceptance Test

Parameters are recorded each time a reading is taken (e.g. speed, temperature, vibration, pressure, mechanical positions, etc.) If faults are incurred or observed during the Schedule "A" test then the appropriate Penalty Test is accomplished with satisfactory results and inspections.

Conclusion

In conclusion, TCT constructed a one-of-a-kind test cell for performance testing the LM6000 industrial gas turbine. The end result is a win-win for all parties involved and as there are several benefits associated with testing in a package.