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GTER

A Report Series

Gas Turbine Engineering Report - Performance

B Report Number

GTER 13846

C Issue

1

D Title

Industrial Trent 60: 50Hz DF WLE engine 56 pass-off performance results – Centrax/Gas de France

E Author(s)

L Leclerc

Tel Number

X 7524

F SUMMARY

A factory test was performed on the 9th October 2009 on ESN056. This engine is a 50Hz Industrial Trent DF WLE and is to be packaged by Centrax for Gas De France. The engine passed all internal RR PAT performance criteria.

The baseload data was referred to site reference conditions and RR PAT reference conditions using the ratio method and eTrent version 7.0.2. The results are presented in this report for formal declaration and communication to the customer. They show that ESN056 meets the customer guarantees and the PAT performance criteria. The key results are presented in the tables below.

| | GAS WET | | | | LIQUID WET | | | |
|--------------------------------|---------------------|------------|-------|-------------|---------------------|------------|-------|-------------|
| | Engine 56 corrected | Guarantees | Diff. | STATUS | Engine 56 corrected | Guarantees | Diff. | STATUS |
| Electrical Power (kW) | 58000 | 58000 | 0.0% | PASS | 57999 | 58000 | 0.0% | PASS |
| Electrical Heat Rate (KJ/kWhr) | 8763 | 9002 | -2.7% | PASS | 8739 | 9109 | -4.1% | PASS |

Engine 56 performance relative to contract guarantee

| | GAS WET | | | | LIQUID WET | | | |
|---------------------------|---------------------|----------------|-------|-------------|---------------------|----------------|-------|-------------|
| | Engine 56 corrected | PAT acceptance | Diff. | STATUS | Engine 56 corrected | PAT acceptance | Diff. | STATUS |
| Shaft Power (kW) | 55283 | 53908 | 2.6% | PASS | 55007 | 53965 | 1.9% | PASS |
| Shaft Heat Rate (KJ/kWhr) | 8693 | 8975 | -3.1% | PASS | 8741 | 9107 | -4.0% | PASS |

Engine 56 performance relative to PAT acceptance limits

Note 1: Negative heat rate margin means lower fuel consumption.

Note 2: The 0% margin against contract guarantee power shows the test was conducted at this power limit.

G Additional Keywords

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Date: 27th October 2009

H Engine Type

Industrial Trent 60

J Ref. No.

K Date

27 Oct 2009

L Dept. No.

32

M File

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N

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Rolls-Royce

Gas Turbine Engineering Report

Continuation Sheet

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REVISION LEVEL

| Issue | Reason | Date |
|-------|----------------|-------------|
| 1 | Original issue | 27 Oct 2009 |

Note: Changes made between the current and previous revision levels are indicated by vertical change bars.

| | | | |
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1.0 Summary and Conclusions

A factory test was performed on the 9th October 2009 on ESN056. This engine is a 50Hz Industrial Trent DF WLE and is to be packaged by Centrax for Gas De France. The engine passed all internal RR PAT performance criteria.

The baseload data was referred to site reference conditions and RR PAT reference conditions using the ratio method and eTrent version 7.0.2. The results are presented in this report and show that ESN056 meets the customer guarantees and the PAT performance criteria. This report formally declares this performance, previously communicated in LGT3726.

2.0 Test data & results

ESN056's factory test took place in Test Cell 7 on 9 October 2009, to the Industrial Trent 60 WLE Dual Fuel – Production Acceptance Test procedure, (GTES 10540 issue 4).

2.1 Inputs and Method

Raw data:

A full output of the raw data taken in the factory test and used in the analysis is provided in Appendix A. The engine was fully stabilized at baseload.

The following table summarises storage location, time, power and ambient temperature.

| | ALICE Experiment | Scan | Test Date | Time | TCELL (K) | Generator Power (kW) |
|------------|------------------|------|------------|-------|-----------|----------------------|
| Gas Wet | 90156010 | 22 | 09/10/2009 | 14h18 | 285.8 | 58066 |
| Liquid Wet | 90156010 | 37 | 09/10/2009 | 16h26 | 286.2 | 58075 |

Emissions:

Emission were recorded during the test. The reports are attached in Appendix B:

NOx recorded during the tests:

Gas Wet: NOx = 25.1 vppm

Liquid Wet: NOx = 43.0 vppm

Diesel Analysis:

A sample of Diesel was taken during the test. The result of the sample analysis is attached in appendix C. The Lower Heating Value of the Diesel during the test was 18498BTU/lb.

| | | | |
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Generator efficiency:

To obtain shaft power the generator efficiency curve below is interpolated (linearly) at the generator power obtained during the test. Then a factor of 0.985 is applied to the value obtained. This was derived from cross-calibration with Test Cell #3 where measurements were taken with a torque meter calibrated to traceable standards.

| Power (HP) | Gen. Effic |
|------------|------------|
| 0 | 0 |
| 530 | 0.2528 |
| 1745 | 0.7685 |
| 7143 | 0.9387 |
| 13894 | 0.9639 |
| 27386 | 0.9789 |
| 40878 | 0.9839 |
| 54376 | 0.9863 |
| 67876 | 0.9877 |
| 81371 | 0.9887 |
| 100000 | 0.9887 |

Note: 1HP = 0.7457 kW

Installation losses assumptions:

The assumptions for the installation losses for testcell 7 are as follows:

| | |
|------------------|--------|
| Temp (C) | -0.67 |
| Inlet (mm H2O) | 27.94 |
| Exhaust (mm H2O) | 309.88 |

Analysis Method:

The CWT data was analysed using the ratio method (see attachment in Appendix D for a fuller description) and eTrent 7.0.2.

The spreadsheets containing the calculation details are attached in Appendix E, tables 1 to 4. A summary of the results of referral to contract and PAT reference conditions are provided in sections 2.2 and 2.3.

Note: The emissions used in the analysis came from the lab reports. However eTrent version 7.0.2 can not be run to specified NOx. For the analysis, the NOx of the test were assumed to be 24.3vppm for Gas and 42vppm for Diesel.

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2.2 Results of referral to Contract Reference Conditions

The contract reference conditions and performance guarantees are summarized in the tables below. They are for gas wet and liquid wet applications.

Ambient conditions

| | Saint-Brieuc |
|----------------------------|--------------|
| Tamb (C) | 11 |
| Pamb (kPa) | 99.418 |
| RH (%) | 80 |
| Generator efficiency (%) | 98.3 |
| Installation losses | |
| Temp (C) | 11 |
| Inlet (mm H2O) | 125 |
| Exhaust (mm H2O) | 125 |

Fuel properties

| Gas Properties | |
|------------------------|--------|
| Gas Composition | |
| Methane (%) | 92.40% |
| Ethane (%) | 5.30% |
| Propane (%) | 1.60% |
| n-Butane (%) | 0.00% |
| i-Butane (%) | 0.50% |
| Nitrogen (%) | 0.20% |
| Carbon Dioxide (%) | 0.00% |
| Gas LHV (kJ/kg) | 49397 |
| Gas temperature (C) | 50 |

| Diesel Specification | |
|----------------------|-------|
| Carbon Atoms | - |
| Hydrogen Atoms | - |
| Cp (BTU/lbF) | - |
| LHV (kJ/kg) | 41900 |
| Fuel temp (C) | 15 |

NOx control

| | |
|--------|------|
| Gas | 24.3 |
| Diesel | 42 |

Performance Guarantees:

| | GAS | DIESEL |
|---------------------------------------|-------|--------|
| Electrical Power (kW) - Gas | 58000 | 58000 |
| Electrical Heat Rate (kJ/kW.hr) - Gas | 9002 | 9109 |

The results from the analysis of the factory test, shown in summary below, demonstrate that the engine meets contractual guarantees.

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| | GAS WET | | | | LIQUID WET | | | |
|--------------------------------|---------------------|------------|-------|-------------|---------------------|------------|-------|-------------|
| | Engine 56 corrected | Guarantees | Diff. | STATUS | Engine 56 corrected | Guarantees | Diff. | STATUS |
| Electrical Power (kW) | 58000 | 58000 | 0.0% | PASS | 57999 | 58000 | 0.0% | PASS |
| Electrical Heat Rate (KJ/kWhr) | 8763 | 9002 | -2.7% | PASS | 8739 | 9109 | -4.1% | PASS |

Note 1: Negative heat rate margin means lower fuel consumption.

Note 2: The 0% margin against contract guarantee power shows the test was conducted at this power limit.

2.3 Results of referral to PAT reference conditions

Pass-off Test Acceptance:

Ambient conditions:

| | |
|-----------------------------|-------------|
| Ambient Pressure | 101.325 kPa |
| Ambient Temperature | 25 °C |
| Ambient Relative Humidity | 60% |
| Intake Total Pressure Loss | 0 mm H2O |
| Exhaust Total Pressure Loss | 0 mm H2O |
| Fuel Temperature | 100 °C |
| Frequency | 50Hz |

Fuel properties:

| eTrent North American Natural Gas Specification | |
|---|------------------|
| Component: | Value (mol %) |
| Methane | 95.527 |
| Ethane | 2.064 |
| Propane | 0.117 |
| i-Butane | 0 |
| N-Butane | 0.01 |
| Nitrogen | 1.942 |
| Carbon Dioxide | 0.34 |
| Fuel Temperature | 373.15 K (212°F) |

| Diesel Fuel Specification | |
|---------------------------|----------|
| Component: | Value |
| Carbon Atoms | 12.9 |
| Hydrogen Atoms | 23.9 |
| Cp (BTU/lbF) | 0.4538 |
| LHV (BTU/lb) | 18315 |
| Fuel Temperature | 288.15 K |

NOx control:

| | |
|--------|------|
| Gas | 24.3 |
| Diesel | 42 |

Note: the reference temperature is 25°C, above the kink point, where the engine is operating on the T30 limiter.

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The results from the analysis of the factory test, shown in summary below, demonstrate that the engine meets PAT criteria.

| | GAS WET | | | | LIQUID WET | | | |
|---------------------------|---------------------|----------------|-------|-------------|---------------------|----------------|-------|-------------|
| | Engine 56 corrected | PAT acceptance | Diff. | STATUS | Engine 56 corrected | PAT acceptance | Diff. | STATUS |
| Shaft Power (kW) | 55283 | 53908 | 2.6% | PASS | 55007 | 53965 | 1.9% | PASS |
| Shaft Heat Rate (KJ/kWhr) | 8693 | 8975 | -3.1% | PASS | 8741 | 9107 | -4.0% | PASS |

Note : Negative heat rate margin means lower fuel consumption.

3.0 References

- | | |
|------------------------------------|---|
| 1. GTES 10760/2 H Ko, N Budeanu | Industrial Trent 60 WLE Dual Fuel – Customer Witness Test Procedure 4 September 2009 |
|------------------------------------|---|

4.0 Appendices

| | | | |
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Appendix A: Raw data used for analysis

| | GAS | DIESEL | |
|---------------------|------------|---------------|-------------------------------|
| SCAN | 22 | 37 | |
| WS PRES | 14.5764 | 14.5763 | Ambient pressure (PSI) |
| WS TEMP | 11.83 | 11.7283 | Ambient temperature (C) |
| WS HUM | 95.2654 | 95.4668 | Relative Humidity (%) |
| TCELL | 285.753 | 286.156 | Average inlet temperature (K) |
| UPOWERV | 58.0659 | 58.0751 | Generator power (MW) |
| NL | 3001.23 | 3001.47 | LP Speed (RPM) |
| NI | 6775.27 | 6776.82 | IP Speed (RPM) |
| NH | 10175.6 | 10175.4 | HP Speed (RPM) |
| UT30V | 589.676 | 591.414 | T30 average |
| LMETHANE | 96.4688 | - | Gas Composition (% vol) |
| LETHANE | 1.28687 | - | |
| LPROPANE | 0.081432 | - | |
| LIBUTANE | 0.005928 | - | |
| LNBTANE | 0.005616 | - | |
| LPENTANE | 0 | - | |
| LNPENTAN | 0 | - | |
| LC6PLUS | 0.00155 | - | |
| LNITRO | 1.61302 | - | |
| LCO2 | 0.537672 | - | |
| LFT_0101 | 23755.8 | - | Gas Fuel flow |
| LTE_0101 | 35.8818 | - | Gas Fuel Temperature |
| ULIQT1 | 23.2573 | 23.2129 | Diesel Temperature |
| FT0210 | - | 26538.9 | Diesel fuel flow |
| FT0314 | 29760.6 | 31236.4 | Water flow |
| UWIMSTI | 16.9955 | 17.0174 | Water temperature (C) |
| UTGTV | 740.765 | 752.962 | TGT average |
| NOx from lab (vppm) | 25.1 | 43 | |
| Diesel LCV from lab | - | 18498 | BTU/lb |
| Diesel LCV from lab | - | 43026 | kJ/kg |

| | | | |
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Appendix B

| 09/10/2009 RRC T87 ITRENT DF WLE 056 GAS WET PERF | | | | | | | | | | | PAGE 1 of 1 | | | | | |
|---|--------|---------------------|--------------------|--------|---------|--------|------------------------|----|----------|-----|---|--------|--------|-----|-------|-------|
| Emissions from jet pipe probes and cruciform rake (No.10) | | | | | | | | | | | Note: | | | | | |
| Measurements taken with M7000 CEMS | | | | | | | | | | | 1) Emissions calculations by: COEMISV1.DU (Version 1.0) | | | | | |
| Units: CO ₂ and O ₂ %; balance ppm | | | | | | | | | | | 2) Emissions data handling by: COEMIS 2.EXE (Version 2.0) | | | | | |
| Fuel analysis: Mole% | | | | | | | | | | | 3) Observe state changes in brackets | | | | | |
| Methane 95.247 Fuel net calorific value | | | | | | | | | | | 4) Analyst: GEORGE ZOHU (CEMS), KURT NORMANDIN (BE) | | | | | |
| Ethane 1.447 Fuel molecular weight | | | | | | | | | | | | | | | | |
| Propane 0.109 Relative humidity | | | | | | | | | | | | | | | | |
| Butane 0.021 Ambient temperature | | | | | | | | | | | 11.920 CHUMB | | | | | |
| Pentane 0.004 Barometric pressure | | | | | | | | | | | 16.64 g/mol | | | | | |
| Hexane 0.002 | | | | | | | | | | | 94.60 %RH | | | | | |
| Carbon dioxide 0.557 | | | | | | | | | | | 11.75 °C | | | | | |
| Nitrogen 1.613 | | | | | | | | | | | 15.60 psia | | | | | |
| Time | CO DRY | CO ₂ DRY | O ₂ DRY | HE WET | NOx DRY | NO DRY | O ₂ wet NOx | MW | SSS | T30 | Probe | AFR | Effy | P30 | FUEL | WATER |
| 11:53:50 | 32.9 | 1.302 | 18.72 | 5.3 | 27.2 | 0.0 | 73.7 | SI | 30310103 | 334 | 1 | 138.62 | 99.840 | 136 | 3975 | 0 |
| 11:54:46 | 29.4 | 1.303 | 18.70 | 4.0 | 27.5 | 0.0 | 73.7 | SI | 30310103 | 334 | 2 | 138.46 | 99.862 | 136 | 3975 | 0 |
| 11:55:42 | 30.9 | 1.300 | 18.59 | 4.1 | 29.2 | 0.0 | 74.6 | SI | 30310103 | 334 | 3 | 130.60 | 99.865 | 136 | 3975 | 0 |
| 11:56:38 | 30.4 | 1.326 | 18.68 | 4.3 | 28.5 | 0.0 | 75.8 | SI | 30310103 | 334 | 4 | 138.01 | 99.859 | 136 | 3975 | 0 |
| 11:57:35 | 32.0 | 1.333 | 18.67 | 4.8 | 28.6 | 0.0 | 75.7 | SI | 30310103 | 334 | 5 | 135.26 | 99.851 | 136 | 3975 | 0 |
| 11:58:31 | 32.9 | 1.320 | 18.69 | 4.5 | 27.8 | 0.0 | 74.2 | SI | 30310103 | 334 | 6 | 136.61 | 99.848 | 136 | 3975 | 0 |
| 11:59:27 | 32.3 | 1.312 | 18.70 | 6.1 | 27.7 | 0.0 | 74.3 | SI | 30310103 | 334 | 7 | 137.44 | 99.836 | 136 | 3975 | 0 |
| 12:00:24 | 32.2 | 1.287 | 18.74 | 5.1 | 26.7 | 0.0 | 72.8 | SI | 30310103 | 334 | 8 | 140.06 | 99.842 | 136 | 3975 | 0 |
| 12:02:16 | 36.3 | 1.518 | 18.39 | 3.7 | 32.1 | 22.8 | 75.4 | SI | 30310103 | 334 | 10 | 118.61 | 99.863 | 136 | 3975 | 0 |
| 12:26:40 | 53.2 | 3.083 | 15.55 | 11.6 | 21.8 | 13.1 | 24.0 | 45 | 30310105 | 553 | 10 | 58.69 | 99.879 | 441 | 19177 | 22331 |
| 12:41:03 | 47.0 | 3.168 | 15.40 | 8.9 | 23.2 | 14.7 | 24.8 | 50 | 30310107 | 567 | 10 | 57.17 | 99.900 | 471 | 20884 | 24780 |
| 12:55:30 | 46.0 | 3.214 | 15.32 | 8.0 | 23.1 | 15.0 | 24.4 | 55 | 30310109 | 580 | 10 | 56.37 | 99.906 | 501 | 22712 | 29058 |
| 13:09:10 | 39.9 | 3.135 | 15.48 | 6.9 | 21.0 | 0.0 | 25.0 | 56 | 30310111 | 588 | 1 | 57.77 | 99.917 | 518 | 23802 | 29831 |
| 13:10:06 | 52.9 | 3.132 | 15.44 | 11.1 | 22.7 | 0.0 | 24.5 | 58 | 30310111 | 588 | 2 | 57.79 | 99.883 | 519 | 23802 | 29831 |
| 13:11:03 | 46.7 | 3.404 | 14.99 | 7.9 | 24.8 | 0.0 | 24.8 | 58 | 30310111 | 588 | 3 | 53.30 | 99.913 | 519 | 23802 | 29831 |
| 13:11:59 | 44.7 | 3.328 | 15.12 | 6.8 | 24.5 | 0.0 | 25.0 | 58 | 30310111 | 588 | 4 | 54.49 | 99.915 | 519 | 23802 | 29831 |
| 13:12:55 | 44.3 | 3.367 | 15.07 | 6.8 | 25.7 | 0.0 | 26.0 | 58 | 30310111 | 588 | 5 | 53.87 | 99.917 | 519 | 23802 | 29831 |
| 13:13:52 | 43.1 | 3.369 | 15.05 | 6.6 | 24.5 | 0.0 | 24.7 | 58 | 30310111 | 588 | 6 | 53.84 | 99.919 | 519 | 23802 | 29831 |
| 13:14:48 | 45.6 | 3.428 | 14.95 | 7.3 | 24.9 | 0.0 | 24.7 | 58 | 30310111 | 588 | 7 | 52.94 | 99.915 | 519 | 23802 | 29831 |
| 13:15:44 | 44.6 | 3.318 | 15.15 | 7.4 | 25.4 | 0.0 | 26.1 | 58 | 30310111 | 588 | 8 | 54.65 | 99.915 | 519 | 23802 | 29831 |
| 13:17:36 | 43.0 | 3.161 | 15.41 | 6.9 | 23.6 | 15.1 | 25.3 | 58 | 30310111 | 588 | 10 | 57.31 | 99.913 | 519 | 23802 | 29831 |
| 13:24:28 | 44.1 | 3.257 | 15.24 | 7.0 | 23.8 | 15.6 | 24.8 | 58 | 10393101 | 588 | 10 | 55.64 | 99.913 | 519 | 23760 | 29844 |
| 13:34:35 | 44.8 | 3.306 | 15.16 | 7.1 | 23.7 | 15.9 | 24.4 | 58 | 10393102 | 588 | 10 | 54.85 | 99.914 | 519 | 23760 | 29844 |
| 13:44:19 | 44.5 | 3.315 | 15.14 | 7.1 | 24.5 | 15.9 | 25.1 | 58 | 10393103 | 588 | 10 | 54.70 | 99.914 | 519 | 23760 | 29844 |
| 13:55:31 | 44.7 | 3.337 | 15.09 | 7.0 | 24.6 | 16.1 | 25.0 | 58 | 10393104 | 588 | 10 | 54.34 | 99.915 | 519 | 23722 | 23820 |
| 14:04:21 | 44.5 | 3.335 | 15.10 | 6.9 | 24.5 | 16.0 | 24.9 | 58 | 10393105 | 588 | 10 | 54.38 | 99.915 | 519 | 23722 | 23820 |
| 14:14:03 | 44.6 | 3.330 | 15.11 | 7.1 | 24.6 | 16.0 | 25.0 | 58 | 10393106 | 588 | 10 | 54.46 | 99.915 | 520 | 23760 | 29820 |
| 14:19:24 | 44.2 | 3.330 | 15.11 | 7.0 | 24.6 | 16.1 | 25.1 | 58 | 10393107 | 588 | 10 | 54.46 | 99.915 | 520 | 23760 | 29820 |

Table 1: Gas Wet emissions

| | | | |
|---|---------------|-------|---------|
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|--|---------------------------------|---------------------|--------------------|--------|---------|--------|-------------------------|----|----------|---|-------|--------|--------|-----|-------|-------|
| Emissions from jet pipe probes and cruciform rake (No. 10) | | | | | | | | | | Note: | | | | | | |
| Measurements taken with M7000 CEMS | | | | | | | | | | 1) Emissions calculations by: COEMISV1.DLL (Version 1.0) | | | | | | |
| Units: CO ₂ and O ₂ % balance ppm | | | | | | | | | | 2) Emissions data handling by: COEMIS_2.EXE (Version 2.0) | | | | | | |
| Fuel analysis: Mole% | | | | | | | | | | 3) Observe scale changes in graphs | | | | | | |
| Methane | 96.247 Fuel net calorific value | | | | | | | | | 4) Analyst: GEORGE ZONI (CEMS), KURT NORMANDIN (CEMS, DE) | | | | | | |
| Ethane | 1.497 Fuel molecular weight | | | | | | | | | | | | | | | |
| Propane | 0.109 Relative humidity | | | | | | | | | 11420 CHU/lb | | | | | | |
| Butane | 0.021 Ambient temperature | | | | | | | | | 16.64 g/mol | | | | | | |
| Pentane | 0.004 Barometric pressure | | | | | | | | | 95.20 %RH | | | | | | |
| Hexane | 0.002 | | | | | | | | | 12.95 °C | | | | | | |
| Carbon dioxide | 0.557 | | | | | | | | | 14.58 psia | | | | | | |
| Nitrogen | 1.613 | | | | | | | | | | | | | | | |
| Time | CO DRY | CO ₂ DRY | O ₂ DRY | HC WET | NOx DRY | NO DRY | O ₂ adj. NOx | MW | SSS | T30 | Probe | AFR | Effy | P30 | FUEL | WATER |
| DIESEL/WET | | | | | | | | | | | | | | | | |
| 15:18:09 | 45.6 | 1.700 | 18.80 | 2.2 | 40.6 | 0.0 | 114.2 | SI | 30310118 | 338 | 1 | 105.86 | 99.961 | 136 | 4300 | 0 |
| 15:19:05 | 42.7 | 1.695 | 18.80 | 1.3 | 41.1 | 0.0 | 115.6 | SI | 30310118 | 338 | 2 | 106.20 | 99.874 | 136 | 4300 | 0 |
| 15:20:02 | 46.0 | 1.838 | 18.64 | 1.3 | 44.3 | 0.0 | 115.8 | SI | 30310118 | 338 | 3 | 97.92 | 99.076 | 136 | 4300 | 0 |
| 15:20:58 | 44.9 | 1.792 | 18.69 | 1.0 | 43.5 | 0.0 | 116.3 | SI | 30310118 | 338 | 4 | 100.45 | 99.077 | 136 | 4300 | 0 |
| 15:21:54 | 46.6 | 1.785 | 18.70 | 1.3 | 43.2 | 0.0 | 116.2 | SI | 30310118 | 338 | 5 | 100.64 | 99.870 | 136 | 4300 | 0 |
| 15:22:51 | 47.1 | 1.753 | 18.74 | 1.2 | 41.8 | 0.0 | 113.9 | SI | 30310118 | 338 | 6 | 102.69 | 99.867 | 136 | 4300 | 0 |
| 15:23:47 | 46.3 | 1.714 | 18.78 | 1.2 | 41.2 | 0.0 | 114.4 | SI | 30310118 | 338 | 7 | 104.99 | 99.866 | 136 | 4300 | 0 |
| 15:24:43 | 46.5 | 1.708 | 18.80 | 1.3 | 40.3 | 0.0 | 113.0 | SI | 30310118 | 338 | 8 | 105.36 | 99.865 | 136 | 4300 | 0 |
| 15:26:35 | 53.1 | 2.025 | 18.42 | 1.0 | 48.0 | 35.7 | 114.2 | SI | 30310118 | 338 | 10 | 88.90 | 99.872 | 136 | 4300 | 0 |
| 15:46:12 | 8.2 | 4.185 | 15.44 | 0.0 | 38.1 | 29.2 | 41.2 | 45 | 30310120 | 441 | 10 | 43.65 | 99.991 | 556 | 21462 | 23273 |
| 15:59:30 | 7.2 | 4.111 | 15.54 | 0.0 | 38.7 | 29.7 | 42.6 | 50 | 30310122 | 570 | 10 | 44.41 | 99.992 | 469 | 23375 | 25977 |
| 16:14:26 | 7.5 | 4.441 | 15.09 | 0.0 | 39.1 | 30.5 | 39.6 | 55 | 30310124 | 583 | 10 | 41.22 | 99.992 | 439 | 25323 | 30012 |
| 16:28:15 | 6.9 | 4.463 | 15.06 | 0.1 | 42.5 | 0.0 | 43.0 | 58 | 30310126 | 591 | 1 | 41.02 | 99.993 | 519 | 26480 | 31246 |
| 16:29:12 | 7.5 | 4.487 | 14.99 | 0.0 | 43.2 | 0.0 | 43.1 | 58 | 30310126 | 591 | 2 | 40.81 | 99.992 | 519 | 26480 | 31246 |
| 16:30:08 | 7.4 | 4.592 | 14.89 | 0.0 | 42.3 | 0.0 | 41.5 | 58 | 30310126 | 591 | 3 | 39.91 | 99.992 | 519 | 26480 | 31246 |
| 16:31:04 | 7.0 | 4.603 | 14.87 | 0.0 | 41.2 | 0.0 | 40.3 | 58 | 30310126 | 591 | 4 | 39.81 | 99.993 | 519 | 26480 | 31246 |
| 16:32:01 | 7.5 | 4.602 | 14.90 | 0.0 | 43.3 | 0.0 | 42.6 | 58 | 30310126 | 591 | 5 | 39.82 | 99.992 | 519 | 26480 | 31246 |
| 16:32:57 | 6.6 | 4.601 | 14.89 | 0.0 | 45.9 | 0.0 | 45.1 | 58 | 30310126 | 591 | 6 | 39.83 | 99.993 | 519 | 26480 | 31246 |
| 16:33:53 | 7.2 | 4.626 | 14.84 | 0.0 | 42.1 | 0.0 | 41.0 | 58 | 30310126 | 591 | 7 | 39.63 | 99.993 | 519 | 26480 | 31246 |
| 16:34:50 | 7.1 | 4.652 | 14.79 | 0.0 | 45.1 | 0.0 | 43.6 | 58 | 30310126 | 591 | 8 | 39.33 | 99.993 | 519 | 26480 | 31246 |
| 16:36:41 | 6.9 | 4.441 | 15.08 | 0.0 | 42.7 | 32.9 | 43.3 | 58 | 30310126 | 591 | 10 | 41.22 | 99.993 | 519 | 26480 | 31246 |

Table 2: Liquid Wet emissions

| | | | |
|---|---------------|-------|---------|
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Appendix C: Diesel analysis



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CERTIFICATE OF FUEL TESTING - DIESEL

TO: R. Inose, N. Budeanu

ENGINE: Ind. Trent Liquid Wet Performance Curve

ESN: 56

TEST DATE: October 9, 2009

This certifies that a representative fuel sample used in the performance testing of the above engine has been analyzed by the RRC Laboratory in accordance with the following ASTM methodology:

Calorific Value D 4809
 Specific Gravity D 1250 - 80
 Kinematic Viscosity D 445 - 96
 Dissolved Water Content D 6308

The following results were obtained:

LABORATORY I.D. **D26**
 TEST BED I.D. **RH-1 2009-F-016**
 SPECIFIC GRAVITY @ 60°F **0.8315** kg/L
 CALORIFIC VALUE **18498** BTU/lb
 VISCOSITY @ 0°C **5.41** cSt
 VISCOSITY @ 30°C **2.60** cSt
 WATER CONTENT **140** ppm

DATE OF FUEL ANALYSIS: October 15, 2009

Maryse Di Rosa

RRC Form No. 540-011 Rev. 5 2005

| | | | |
|---|---------------|-------|---------|
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Appendix D: Ratio method presentation



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**Trent 60 DF WLE
Method to correct to Guarantee
conditions or to PAT conditions**

Louise Leclerc

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Private - Rolls-Royce Data

Site data correction

- In field the engine runs to a limiter (Power, T30 or TGT) or a defined parameter, eg. Power, depending on ambient conditions and/or needs of customer.
- To properly assess the performance of the engine, the data need to be corrected for ambient conditions and if necessary for TGT and T30 margin.
- Rolls-Royce standard way to analyse the performance of DF WLE engines is to use the « ratio Method » and to refer the data to a specific condition, e.g. the guarantee point, cf. diagram.
- The « ratio method » is done using eTrent.
- The procedure is different if the referral point is above or below the kink point, i.e. limited by Power or T30.

Private - Rolls-Royce Data

Ratio Method presentation

Sheet 2

| | | | |
|---|--|------------------------|------------------------------|
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The "Ratio Method" to guarantee conditions (below kink point)

- 1 - Run eTrent at same conditions as engine on test
 - Guarantee Expected Limit Parameter, GELP (measured generator power)
 - Same ambient conditions
 - Same installation losses
 - Same fuel
- 2 - Calculate the ratios of actual power, TGT, T30 and heatrate to eTrent predictions (power ratio will be 1.0 as eTrent was run to test power)
- 3 - Run eTrent at guarantee conditions and GELP at the guarantee condition (power of 58MW gross)
- 4 - Multiply TGT and T30 (absolute temperatures) from 3. by ratios from 2.
- 5 - If both corrected TGT and T30 are below the control limits:
 - Achievement of guaranteed power assured
 - Calculate heatrate at guarantee condition by Multiplying heatrate ratio from 2. to heatrate from 3.
- 6 - If either corrected TGT or corrected T30 are above the control limits (meaning the engine fails guarantee on Power):
 - Repeat 1 to 5 using TGT or T30 as the GELP to determine heatrate at guarantee conditions, and also power shortfall.

The "Ratio Method" to PAT conditions (above kink point)

- 1 - Run eTrent at same conditions as engine on test
 - Guarantee Expected Limit Parameter, GELP (measured T30)
 - Same ambient conditions
 - Same installation losses
 - Same fuel
- 2 - Calculate the ratios of actual shaft power and Heat rate to eTrent predictions (T30 ratio will be 1.0 as eTrent was run to test T30)
- 3 - Run eTrent at reference conditions and GELP at the reference condition (T30 limit - 876K)
- 4 - Multiply Shaft Power and Heat Rate from 3 to ratios from
- 5 - Compare Corrected Shaft Power and Heat Rate to PAT acceptance values.

| | | | |
|--|---------------------------------|-----------------|-----------------------|
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Appendix E:

Trent 60 DFWE Engine Serial Number 056 Build 1
 Measured and Corrected Performance Data From Factory Test
 Rolls-Royce Canada, Montreal, Test Bed #7, October 8, 2009

| | |
|------------|----------|
| Experiment | 90158010 |
| Extract | 22 |
| Time | 2:18 PM |

| Standard_DFWE_ITRST606 | | Model at Test Conditions at test power | Engine Test Data | Ratio Engine to Model | Model at Guarantee Conditions (at Power Limit) | Engine Corrected to Guarantee Conditions | Project Guarantee | Difference to Project Guarantee |
|-------------------------------|-----------|--|------------------|-----------------------|--|--|-------------------|---------------------------------|
| Ambient Pressure | kPa | 100.50 | 100.50 | | 98.42 | | 98.42 | |
| Ambient Temperature | C | 12.60 | 12.60 | | 11 | | 11 | |
| Relative Humidity | % | 85.3 | 85.3 | | 80 | | 80 | |
| Inlet Loss | mmH2O | 27 | 27 | | 125 | | 125 | |
| Exhaust Loss | mmH2O | 305 | 305 | | 125 | | 125 | |
| LP Speed | rpm | 3000 | 3001 | | 3000 | | 3000 | |
| Shaft Power | kWe | 59640 | 59643 | 1.000 | 59003 | 59003 | 59003 | |
| Gross Electrical Power | kWe | | 58068 | | 58000 | 58000 | 58000 | 0.0% |
| Generator efficiency | | | 97.36% | | 98.3% | 98.3% | 98.3% | |
| Shaft Heatrate | kJ/kWh.hr | 8798 | 8648 | 0.983 | 8791 | 8614 | 8849 | |
| Gross Electrical Heatrate | kJ/kWh.hr | 8036 | 8883 | | 8673 | 8763 | 9002 | -2.7% |
| Fuel Composition | | | | | | | | |
| | vol% | Methane | 98.4658 | 98.4658 | 92.4 | | 92.4 | |
| | | Ethane | 1.2880 | 1.2880 | 5.3 | | 5.3 | |
| | | Propane | 0.0014 | 0.0014 | 1.8 | | 1.8 | |
| | | i-Butane | 0.0059 | 0.0059 | 0.5 | | 0.5 | |
| | | n-Butane | 0.0056 | 0.0056 | 0 | | 0 | |
| | | i-Pentane | 0 | 0 | 0 | | 0 | |
| | | n-Pentane | 0 | 0 | 0 | | 0 | |
| | | Hexane | 0.0016 | 0.0016 | 0 | | 0 | |
| | | Nitrogen | 1.8130 | 1.8130 | 0.2 | | 0.2 | |
| | | Carbon Dioxide | 0.5377 | 0.5377 | 0 | | 0 | |
| | LDV | 47865.4 | | | 49997 | | | |
| Fuel Temperature | C | 38.9 | 38.9 | | 50.0 | | | |
| LPT Entry Temperature (TGT) | C | 702.7 | 740.8 | 0.971 | 760.8 | 735.8 | LIMIT 762.6C | |
| HPC Exit Temperature (T30) | K | 881.0 | 882.8 | 1.002 | 858.8 | 803.8 | LIMIT 876K | |
| NOx (Corrected to 15% O2 dry) | ppm | 24.3 | 25.1 | | 24.3 | | | |
| Combustor Water Flow | kg/hr | 13662 | 13498 | 0.985 | 14085 | 13569.7 | | |
| Combustor Water Temperature | C | 17.0 | 17.0 | | 15 | | | |

Table 1: Gas Wet referred to Guarantees

| | | | |
|---|---------------|-------|---------|
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Trent 60 DPWLE Engine Serial Number 056 Build1
 Measured and Corrected Performance Data From Factory Test
 Rolls-Royce Canada, Montreal, Test Bed #7, October 9, 2009

| | |
|------------|----------|
| Experiment | 90156010 |
| Extract | 22 |
| Time | 2:18 PM |

| Standard_DPWLE_ITRST608 | | Model at Test Conditions at test T30 | Engine Test Data | Ratio Engine to Model | Model at PAT Conditions (at T30 Limit) | Engine Corrected to PAT Conditions | PAT Limits | Difference to PAT Limits |
|--------------------------------|-----------|--------------------------------------|------------------|-----------------------|--|------------------------------------|------------|--------------------------|
| Ambient Pressure | kPa | 100.50 | 100.50 | | 101.33 | | 101.325 | |
| Ambient Temperature | C | 12.60 | 12.60 | | 25.0 | | 25.0 | |
| Relative Humidity | % | 95.3 | 95.3 | | 60 | | 50 | |
| Inlet Loss | mmHgO | 28 | 28 | | 0 | | 0 | |
| Exhaust Loss | mmHgO | 309 | 309 | | 0 | | 0 | |
| LP Speed | rpm | 3000 | 3001 | | 3000 | | | |
| Shaft Power | MW | 60359 | 59540 | 0.988 | 59890 | 55283 | 53608 | 2.6% |
| Gross Electrical Power | MW | | 50086 | | 56026 | | | |
| Generator efficiency | | | 87.32% | | 86.35% | | | |
| Shaft Heatrate | kJ/MWh.hr | 8789 | 8648 | 0.984 | 8835 | 8693 | 8475 | -3.1% |
| Gross Electrical Heatrate | kJ/MWh.hr | 9027 | 8663 | | 8953 | | | |
| Fuel Composition | | | | | | | | |
| | vol% | 95.4688 | 95.4688 | | 95.527 | | 95.527 | |
| | | 1.2966 | 1.2966 | | 2.064 | | 2.064 | |
| | | 0.0614 | 0.0614 | | 0.117 | | 0.117 | |
| | | 0.0058 | 0.0058 | | 0.000 | | 0.000 | |
| | | 0.0056 | 0.0056 | | 0.010 | | 0.010 | |
| | | 0.0000 | 0.0000 | | 0.000 | | 0.000 | |
| | | 0.0000 | 0.0000 | | 0.000 | | 0.000 | |
| | | 0.0016 | 0.0016 | | 0.000 | | 0.000 | |
| | | 1.6130 | 1.6130 | | 1.942 | | 1.942 | |
| | | 0.6377 | 0.6377 | | 0.340 | | 0.340 | |
| | | 47865.4 | 47865.4 | | 47825 | | 47825 | |
| | 100.0 | 100.0 | | 100.0 | | 100.0 | | |
| Fuel Temperature | C | 35.0 | 35.0 | | | | | |
| LPT Entry Temperature (TGT) | C | 765.8 | 740.8 | 0.967 | 773.2 | 746.0 | | |
| HPC Exit Temperature (T30) | K | 862.8 | 862.8 | 1.000 | 876 | 876 | | |
| HCs (Corrected to 15% O2, dry) | ppm | 24.3 | 25.1 | | 24.3 | | | |
| Combustor Water Flow | kg/hr | 14218 | 13498 | 0.950 | 13484 | | | |
| Combustor Water Temperature | C | 17.0 | 17.0 | | 15 | | | |

Table 2: Gas Wet referred to PAT

| | | | |
|---|---------------|-------|---------|
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Trent 80 DFWE Engine Serial Number 056 Build1
 Measured and Corrected Performance Data From Factory Test
 Rolls-Royce Canada, Montreal, Test Bed #7, October 9, 2009

| | |
|------------|----------|
| Experiment | 90158010 |
| Extract | 37 |
| Time | 4:26 PM |

| Standard_DFWE_ITRST#06 | | Model at Test Conditions at test power | Engine Test Data | Ratio Engine to Model | Model at Guarantee Conditions (at Power Limit) | Engine Corrected to Guarantee Conditions | Project Guarantee | Difference to Project Guarantee |
|---|--------------------|--|------------------|-----------------------|--|--|-------------------|---------------------------------|
| Ambient Pressure | kPa | 100.50 | 100.50 | | 99.42 | | 99.42 | |
| Ambient Temperature | C | 13.01 | 13.01 | | 11 | | 11 | |
| Relative Humidity | % | 95.5 | 95.5 | | 80 | | 50 | |
| Inlet Loss | mmH ₂ O | 27 | 27 | | 125 | | 125 | |
| Exhaust Loss | mmH ₂ O | 306 | 306 | | 125 | | 125 | |
| LP Speed | rpm | 3000 | 3001 | | 3000 | | 3000 | |
| Shaft Power | MW | 59650 | 59649 | 1.000 | 59000 | 59002 | 59000 | |
| Gross Electrical Power | MW | | 58075 | | 58000 | 57999 | 58000 | 0.0% |
| Generator efficiency | | | 97.36% | | 98.30% | 98.30% | | |
| Shaft Heatrate | kJ/MWh.hr | 8917 | 8983 | 0.974 | 8822 | 8591 | 8109 | -4.1% |
| Gross Electrical Heatrate | kJ/MWh.hr | 9159 | 8919 | 0.974 | 8974 | 8719 | 9109 | |
| Fuel Composition | | | | | | | | |
| LCV | | 43026 | 43026 | | 41900 | | | |
| Fuel Temperature | C | 23.2 | 23.2 | | 15.0 | | | |
| LPT Entry Temperature (TGT) | C | 774.2 | 753.0 | 0.980 | 774.9 | 753.6 | LIMIT 762.0C | |
| HPC Exit Temperature (T30) | K | 881.7 | 864.8 | 1.003 | 858.4 | 861.3 | LIMIT 876K | |
| NOx (Corrected to 15% O ₂ , dry) | ppm | 42.0 | 43.0 | | 42.0 | | | |
| Compressor Water Flow | kg/hr | 14905 | 14169 | 0.951 | 13024 | 12380.7 | | |
| Compressor Water Temperature | C | 17.0 | 17.0 | | 15 | | | |

Table 3: Liquid Wet referred to Guarantees

| | | | |
|---|---------------|-------|---------|
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Trent 60 DPWLE Engine Serial Number 056 Build1
Measured and Corrected Performance Data From Factory Test
Rolls-Royce Canada, Montreal, Test Bed #7, October 9, 2009

| | |
|------------|----------|
| Experiment | 90156010 |
| Extract | 37 |
| Time | 4:26 PM |

| Standard_DPWLE_ITRST608 | | Model at Test Conditions at test T30 | Engine Test Data | Ratio Engine to Model | Model at PAT Conditions (at T30 Limit) | Engine Corrected to PAT Conditions | PAT Limits | Difference to PAT Limits |
|--------------------------------|-----------|--------------------------------------|------------------|-----------------------|--|------------------------------------|------------|--------------------------|
| Ambient Pressure | kPa | 100.50 | 100.50 | | 101.325 | | 101.325 | |
| Ambient Temperature | C | 13.01 | 13.01 | | 25.0 | | 25.0 | |
| Relative Humidity | % | 95.5 | 95.5 | | 60 | | 60 | |
| Inlet Loss | mmH2O | 28 | 27 | | 0 | | 0 | |
| Exhaust Loss | mmH2O | 312 | 306 | | 0 | | 0 | |
| LP Speed | rpm | 3000 | 3001 | | 3000 | | | |
| Shaft Power | kWs | 50738 | 50549 | 0.992 | 50011 | 55007 | 53905 | -1.8% |
| Gross Electrical Power | kWe | | 50075 | | 55007 | | | |
| Generator efficiency | | | 97.36% | | 98.36% | | | |
| Shaft Heatrate | kJ/kWh.hr | 8907 | 8863 | 0.975 | 8965 | 8741 | 9107 | -4.0% |
| Gross Electrical Heatrate | kJ/kWh.hr | 9145 | 8919 | | 9145 | | | |
| Fuel Composition | | | | | | | | |
| LCV | | 43026 | 43026 | | 42900 | | 42900 | |
| Fuel Temperature | C | 23.2 | 23.2 | | 15.0 | | 15.0 | |
| LPT Entry Temperature (TGT) | C | 779.2 | 753.0 | 0.9751 | 785.5 | 769.1 | | |
| HPC Exit Temperature (T30) | K | 864.6 | 864.6 | 1.000 | 878 | 878 | | |
| NOx (Corrected to 15% O2, dry) | ppm | 42.0 | 43.0 | | 42.0 | | | |
| Compressor Water Flow | kg/hr | 15290 | 14169 | 0.926 | 13796 | | | |
| Compressor Water Temperature | C | 17.0 | 17.0 | | 15 | | | |

Table 4: Liquid Wet referred to PAT

| | | | |
|---|---------------|-------|---------|
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