# DOCUMENT TITLE PAGE

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| Program Project No. | # CR-0502-81-041 | (1) Master Info Center 50120 |
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| Test Project No. | Title: Thermal Survey of a Short Water Jacket Family I Phase 2 6T-590 Engine S/N 40531129 | (3) Info Center |
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| Date 8-27-81 | | (5)CCEP File |
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## SUMMARY


### Purpose

To determine how the short water jacket affects block temperatures and to understand phenomenon of piston seizing occuring on Family I engines. In addition, the valve bridge temperatures were also measured.

### Summary

Test work was done in T.C. 107. The engine used was a 6T-590 built to PPL-32-004 and equipped with 62 thermocouples in the block. Tests were run according to a proposal by N. F. Gale. All tests were carried out with piston cooling jets installed, 85$^{o}$C (185$^{o}$F) water out temperature and 110$^{o}$C (230$^{o}$F) oil pan temperature, except when noted otherwise.

### Results

1. No. 6 cylinder runs significantly hotter and No. 1 cylinder significantly cooler than all the other cylinders on the water pump side of the liners. The camshaft side of ~~the oil~~ all the liners show almost an identical temperature profile.

2. Feeding the cooling water through an external manifold and testing several different combinations had almost no impact to liner and valve bridge temperatures.

3. Varying the water flow rate from 10 GPM to 60 GPM did not influence the liner temperature profiles. Valve bridge temperatures also were not influenced by changing the water flow rate from 60-20 GPM; however, they did increase when the water flow rate was reduced to 10 GPM.

4. For every 1$^{o}$C both the water out and the oil pan temperature were increased, the liner temperatures raised 1$^{o}$C and the valve bridge temperatures ½$^{o}$C.

5. Blocking off piston cooling jets increased temperatures drastically (No. 2 thru 6 Cylinders) to a level of almost 180°C (356°F) at the bottom of the liners. Since No. 6 cylinder showed the same profile as the No. 2 through No. 5 cylinders, a piston cooling problem of No. 6 cylinder was suspected to be the cause for high temperatures found in test 1. Therefore, a modified Phase III main bearing was installed on No. 6 cylinder to increase the oil flow in the piston cooling jet.

6. Tests run with this modification show almost equal liner temperature profiles for No. 2 through No. 6 cylinders. The cooler No. 1 cylinder can be explained by the water pump discharging to the bottom of the liner.

7. An extensive test program with variable start of injection at different engine speeds was run to get correlation between temperatures measured and performance. Changing the start of injection from 0° to 24° BTDC in several steps did not alter liner temperature profiles. Both valve bridge temperatures and cylinder pressure are raising and BSFC is decreasing with advancing the start of injection.

Action

Liner temperatures with the modified No. 6 main bearing did not exceed 140°C under any test condition. This temperature seems to be safe from a standpoint of oil deterioration, but does not exclude any other problems with liner distortion.

Valve bridge temperatures are at an inacceptable high level especially at high engine speeds and advanced injection timing where it seems turbocharged Family I engines have a problem with combustion.

M. Thommen/bkg

Senior Engineer
Engine Projects

Attachments

Mark Thommen

Abbreviations:

SWJ = Short water jacket
LWJ = Long water jacket
VBI = Valve bridge temperatures
LIT = Liner temperatures
WPS = Water pump side
CSS = Camshaft side
ATT = Attachment

Discussion

A Family 1, 6 Cylinder, Phase 2 SWJ 6T-590 engine (S/N 40531129) was built to specification PPL-32-004 (ATT 1) and equipped with thermocouples on No. 1, No. 4 and No. 6 cylinders according to ATT 0. The cylinder head was instrumented with thermocouples in the valve bridge area. All the tests were carried out with $85^{\circ}$C ($185^{\circ}$F) water out and $110^{\circ}$C ($230^{\circ}$F) oil pan temperature and installed piston cooling jets, except where noted otherwise.

Break in of the engine took place early in March without any significant problems.

Initial Configuration:

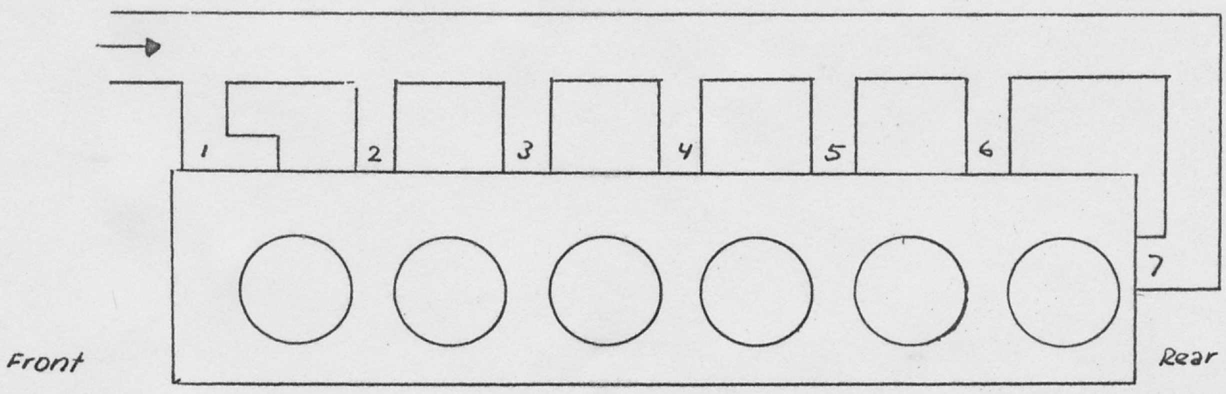
Tests were run at 2200 RPM - 326 ft.lb.
2000 RPM - 340 ft.lb.
1700 RPM - 363 ft.lb.
1400 RPM - 350 ft.lb.

Detailed liner temperature profiles (ATT 2 & 3) show liner No. 6 running much hotter than No. 4 and No. 1 running much cooler than No. 4 on the WPS. No. 6 cylinder running cooler can be explained by the water pump discharging onto the bottom of the liner. The LIT of the CSS show almost the same profile for each cylinder. VBT (ATT 4) indicate a problem with the thermocouple on No. 4 cylinder.

High blow-by and steam in the blow-by indicated a problem with the head. After removing the head from the engine, a crack in the valve bridge area of No. 4 cylinder was encountered. Therefore, a new head (#618) was mounted and the engine was rebuilt to specification PPL-32-013 (ATT 5).

External Water Manifold

An external water manifold was fitted to the engine to determine the influence of the water flow pattern.




Subsequent test work with valves 1-6 closed and only valve 7 open have shown that only liner No. 6 is influenced by this action. Its LIT decreases slightly with feeding all the water through the rear end of the engine. VBT were almost not influenced.

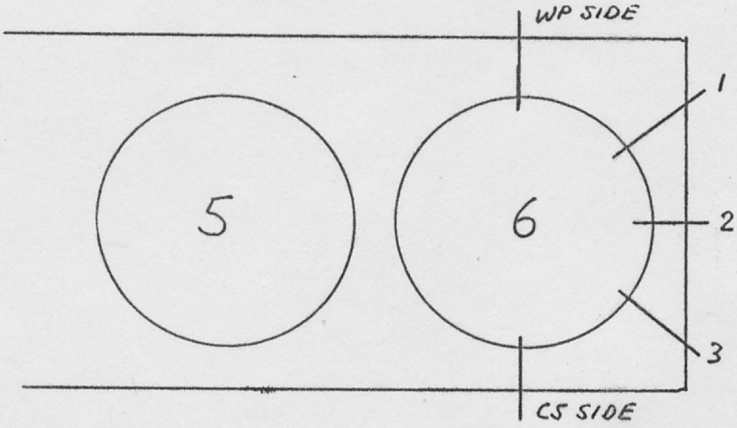
Changing Water Flow Rate

Further tests show the influence of the water flow rate to LIT and VBT (ATT 9-12). LIT stay constant within a range of 5$^{o}$C (9$^{o}$F) for all water flow rates from 10 GPM to 60 GPM. VBT remain almost at the same high level for flow rates from 20-60 GPM and increase for low water flow rates, such as 10 GPM by 20$^{o}$C (36$^{o}$F).

Top Tank and Oil Pan Temperatures

Increasing both water out and oil pan temperature by a certain amount in $^{o}$C caused liner temperatures to increase the same amount in $^{o}$C and valve bridge temperatures to increase only half the amount in $^{o}$C (ATT 15 & 16).

3 More Thermocouples Intalled on Cylinder No. 6




3 more thermocouples were installed in the flywheel housing area of the block. Readings of these thermocouples compared within 5°C (8°F) to the readings taken on the camshaft side of liner No. 6. The additional mass of iron behind cylinder No. 6 did not, therefore, change the thermal behavior of it, which does not exclude at all that it could affect the distortion of liner No. 6 under load conditions. There is still no explanation yet why cylinder No. 6 is running hotter on the WPS.

Constant Fuel Rate at Different Engine Speeds

Varying engine speed from 2200-2800 RPM with a constant fuel rate of 50.5 lb/h let LIT stay within about 5°C (8°F) and VBT within 10°C (18°F). The general trend seen is higher temperatures for higher speeds due to increased friction and less efficient combustion (ATT 17-20).

Blocked Piston Cooling Jets

New main bearing halfs were installed to block off the oil flow to the piston cooling jets. The effect of that were LIT, which topped 180°C (356°F).(ATT 21-22). From a standpoint of oil deterioration and liner lubrication, liner temperatures exceeding 160°C should be avoided. Therefore, the engine was brought back into the old configuration with unblocked piston cooling jets. Also, VBT increased by as much as 50°C (80°F). (ATT 23).

Since liner No. 4 and liner No. 6 showed almost the same profile on the WPS with cutoff piston cooling, inadequate oil flow to No. 6 cooling jet was suspected to be the cause for high LIT on No. 6 cylinder in all the previous tests.

Blocked Piston Cooling Jets (Cont'd)

A Phase III main bearing half was machined with restricted oil flow to the camshaft bushing to direct more oil to the cooling jet.

Modified No. 6 Main Bearing

All the tests were repeated similar to the initial configuration, but with modified No. 6 main bearing to supply adequate oil flow. LIT on both No. 4 and No. 6 cylinders are now within 5°C (8°F). (ATT 24-31). The maximum LIT on the bottom of the liner never did exceed 150°C (302°F) which means that liner temperatures with adequate piston cooling are safe; however, this does not exclude any problems of liner distortion which might be caused by the temperature.

VBT went up by almost 50°C (80°F) with the modification and read as high as 360°C (680°F). The explanation of this phenomenon might be that thermocouples were installed much closer to the gas face on head #618 compared to head #613 (ATT 32-33).

Anyway, the metal temperature on the gas side of the head will even be higher. Rough calculations by N. F. Gale, have shown that they are about 70°C (126°F) higher than read by the thermocouple. Therefore, metal temperatures of 430°C (806°F) are expected, which may cause cracking problems. This is an extrapolation of speed, water temperature and metal thickness.

Variable Start of Injection 0°-24° BTDC

A whole test series was run from 1400 RPM up to 2800 RPM in steps of 200 RPM. Each engine speed was tested in several steps from 0°-24° BTDC dynamic injection timing. ATT 34-57 show the detailed results. LIT seem not to respond to the timing and remain almost constant. VBT increase by advancing the injection timing. Temperatures as high as 430°C (788°F) are seen with advanced timing of 2800 RPM. (ATT 55). Also, cylinder pressures are too high at these advanced timings, running almost 2200 PSI. On the other hand, a good fuel consumption was only achieved at advanced timings. All these facts, together with high smoke levels and start of combustion of 15°-20° BTDC, show a severe problem in combustion and heat release characteristics with Family I turbocharged engines.

Summary

1. Cylinder No. 6 runs hotter because it gets less oil flow to the piston cooling jet than the remainder due to the design feeding both piston cooling jet and camshaft bushing through the main bearing groove.

2. Valve bridge temperatures are flow dependant. Flow should not be smaller than 20 GPM on Family I 6 Cylinder engines in any full load operation.

3. Liner temperatures seem to be acceptable with both sufficient piston cooling jet oil flow and 99°C (210°F) top tank temperature from a standpoint of oil deterioration and lubrication.

4. Valve bridge temperatures are unacceptably high under almost any running condition of all this test work. There are several approaches to this problem:

   a. reduce metal thickness in valve bridge area by scalloping.

   b. machine valve bridges by drilling to increase water flow through this portion of the head.

   c. reduce overall level of combustion temperature and therefore, reduce cylinder pressure by optimizing combustion.

   Points a and b really do not cure the real problem but alleviate it.

   The key issue for solving the problem is c.

   Combustion should start at about 5° BTDC normally. To get good BSFC and low smoke, Family I engines are operated at very advanced injection timings. This causes very advanced start of combustion, followed by sharp pressure raises, high cylinder pressures and high cylinder temperatures, because most of the heat is released before TDC.

   To get good performance at normal timings, research kind of work has to be done to optimize combustion.

5. A scalloped head which was installed on the engine showed lower VBT but also, lower performance, probably due to the increased dead volume. A report on that will be issued later.

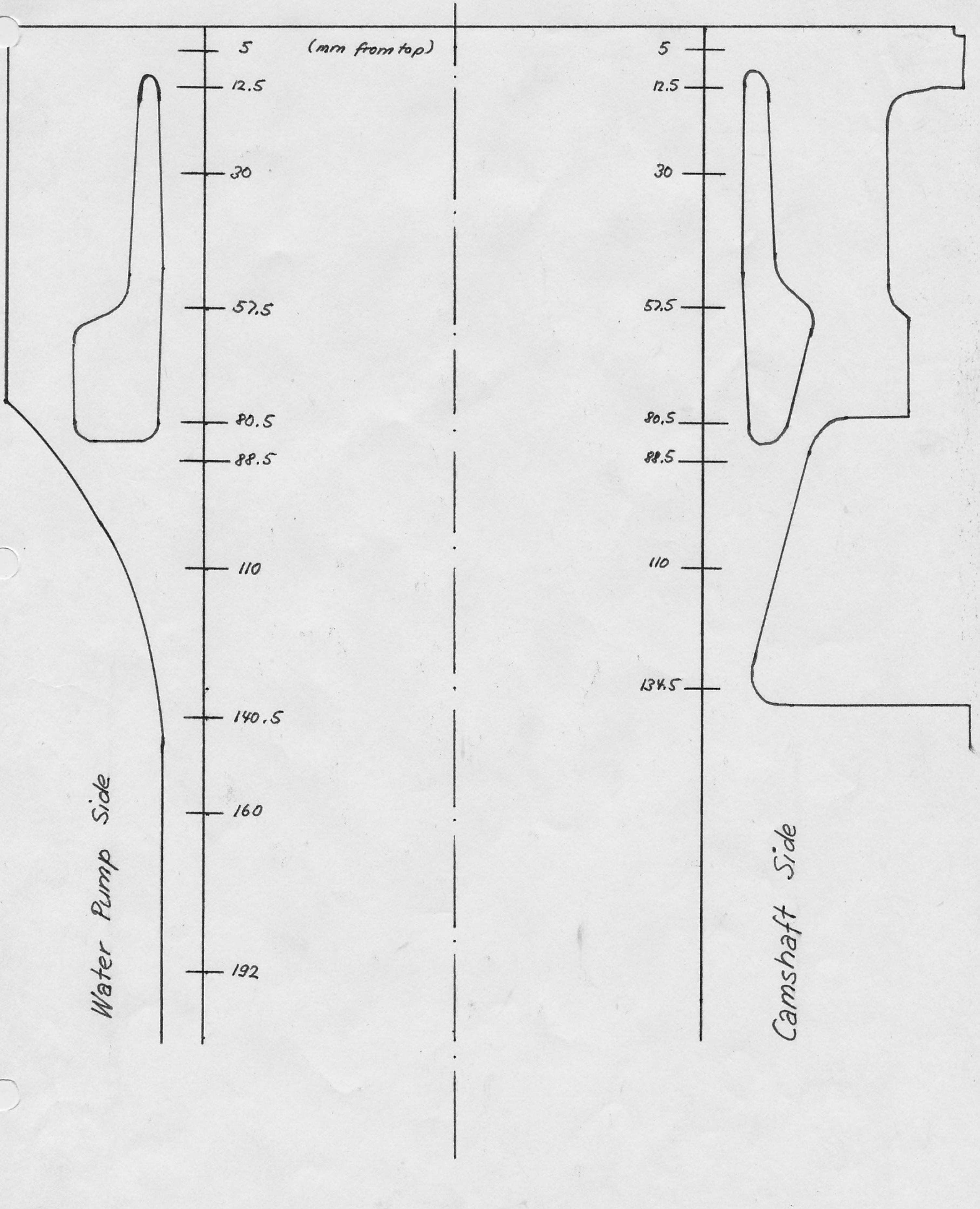
M.Thommen/bkg

Attachments

Senior Engineer
Engine Projects
Mark Thommen

Attachment 0

# Positions of Thermocouples



Attachment 1

# PERFORMANCE PARTS LIST PPL-32-004

ENGINEER: MORITZ THOMMEN ENGINE MODEL: 6T-590 S/N: 40531129 DATE: 27FEB81
TEST CELL: 107 TEST CELL HOURS [h]: 817.30 TOT ENGINE HOURS [h]: .00 AIR FLOW METER: Orifice dP
TITLE: FAMILY-1 PHASE-2 SHORT WATER JACKET THERMOCOUPLE ENGINE WITH PHASE-2 HEAD 1

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BLOCK P/N: SE-3900465 BLOCK S/N:
NO OF CYL: 6 BORE [mm]: 102.00 STROKE [mm]: 120.00 CONROD [mm]: 192.00 2

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HEAD P/N: SE-3900891 HEAD S/N: 613

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SWIRL RATIO: | 3.751 | 3.752 | 3.685 | 3.826 | 3.673 | 3.853 | 3.719 |
| PRESSURE LOSS [mbar]: | 259.9 | 254.2 | 260.5 | 260.6 | 259.3 | 259.0 | 266.0 |
| PREDICTED VOLUMETRIC EFF. [%]: | 88.50 | 88.90 | 88.30 | 88.30 | 88.40 | 88.50 | 88.60 |

3

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PISTON P/N: SE-3901325 BOWL DIAMETER [mm]: 58.00 BOWL DEPTH [mm]: 17.99 OFFSET [mm]/[mm]: 4.3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| BOWL VOLUME [cm3]: | 45.300 | 45.800 | 45.300 | 45.200 | 45.000 | 45.400 | 45.100 |
| PISTON-HEAD CLEARANCE [cm3]: | 7.145 | 7.110 | 7.526 | 7.007 | 7.007 | 7.007 | 7.214 |
| VALVE POCKETS IN PISTON [cm3]: | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| VALVE RECESSES IN HEAD [cm3]: | 5.483 | 5.100 | 5.400 | 6.000 | 5.300 | 5.600 | 5.500 |
| VOLUME OVER TOP RING [cm3]: | 3.400 | 3.400 | 3.400 | 3.400 | 3.400 | 3.400 | 3.400 |
| TOTAL DEAD VOLUME [cm3]: | 16.028 | 15.610 | 16.326 | 16.407 | 15.707 | 16.007 | 16.114 |
| COMPRESSION RATIO: | 16.989 | 16.967 | 16.911 | 16.916 | 17.152 | 16.968 | 17.018 |

4

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CAMSHAFT P/N: SE-3900850
INT OPEN [dCr bTDC]: 10.00 INT CLOSE [dCr aBDC]: 30.00 INT MAX LIFT [mm]: .000 INT VALVE LASH [mm]: .254
INT MAX ACCEL [mm/dCr2]: .000
EXH OPEN [dCr bBDC]: 58.00 EXH CLOSE [dCr aTDC]: 10.00 EXH MAX LIFT [mm]: .000 EXH VALVE LASH [mm]: .508
EXH MAX ACCEL [mm/dCr2]: .000 5

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INT MANIFOLD P/N: EXH MANIFOLD P/N: SE-3900515 6

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AFTERCOOLER P/N: MAKE: MODEL: 7

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TURBOCHARGER P/N: MAKE: AIRESEARCH MODEL: T04B COMPRESSOR TRIM: T-5
X-OVER DIAMETER [mm]: 47.63 TURBINE TRIM: 62 TURBINE NOZZLE A/R: 1.0 TURB IN DIAMETER [mm]: 53.85 8

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INJECTION PUMP P/N: MAKE: ROBERT BOSCH MODEL: VE6/12F1400RV7973 CODE: 7973
CAM P/N: SK3000 PLUNGER DIAMETER [mm]: 12.00 NO OF PLUNGERS: 1 SNUBBER DIAMETER [mm]: .45
NOM PUMP RATE [mm3/r]: .000 RETRACTION VOLUME OR PLUNGER RETRACTION ON DPA [mm3]: 40.000 9

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FUEL LINE LENGTH [mm]: 678.00 INSIDE DIAMETER [mm]: 1.600
P/N: SE-3900865 SE-3900866 SE-3900867 SE-3900868 SE-3900869 SE-3900870 10

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INJECTOR P/N: PxN 0567 MAKE: BOSCH MODEL: NOZZLE P/N:
OPENING PRESSURE [bar]: 245.00 NEEDLE DIFF RATIO: .000 MAJOR DIAMETER [mm]: .000 MINOR DIAMETER [mm]: .000
NO OF NOZZLE HOLES: 4 HOLE DIAMETER [mm]: .270 HOLE LENGTH [mm]: .000 NOZZLE SAC VOLUME [mm3]: .000
DISCHARGE COEFFICIENT: .700 NOM SPRAY CONE A [deg]: 155.00
NOZZLE PROTRUSION: 3.581 3.683 3.607 3.759 3.581 3.759 11

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STAT TIMING [dCr bTDC]: .00 ADV AMPLITUDE [dCr]: .00 ADVANCE BEGIN [r/min]: 0 ADVANCE END [r/min]: 0 12

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ENGINE FRICTION: FMEP = A + B * (r/min) + C * (r/min)2 A = .000000 B = .000000 C = .000000 13

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FAN P/N: ALTERNATOR P/N: SE-3901086 BELT P/N: SE-3900694
WATER PUMP P/N: SE-3900934 PULLEY P/N: PULLEY DIAMETER [mm]: 75
OIL PUMP ASS P/N: SE-3900479 OIL VISCOSITY: 30 PISTON COOLING NOZZLE P/N: 14

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