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Laboratory Memorandum (National Research Council Canada. Institute for Aerospace Research. Gas Turbine Laboratory); no. LM-GTL-2008-0018, 2008-05-20

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**REPORT
RAPPORT**

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AÉROSPATIALE

Pages: 27

Tables: 6

Figures: 14

GAS TURBINE
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LABORATOIRE DES
TURBINES A GAZ

Report No.: LM-GTL-2008-0018

Date: May 20, 2008

Classification: NRC Protected
Distribution: Limited

**DECLASSIFIED
DÉCLASSIFIÉ**

For: Rolls Royce Canada Limited
Pour:

Reference:
Référence:

LM-GTL-2008-0018

Rolls Royce Inlet Spray Bar Flow Testing

Submitted by:
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Director General/Directeur général

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1 Introduction

This report presents the data and results of testing performed for Rolls Royce Canada Limited in April 2008 as per Research Proposal RP-2008-0011. The objective of the tests was to determine the flow numbers for each lane of the inlet spray bars, originally reported in LTR-2007-0045, after operation in a Rolls Royce test cell and again after the bars were rebuilt. Based on observation in the Rolls Royce test cell it was expected that the spray bars had become clogged during operation. The flow numbers are required to quantify the amount of blockage each lane experienced. The flow numbers are checked after the bars are rebuilt to verify they have returned to their original condition. The flow number is defined below and although it quantifies the losses through the flow passage it is not a dimensionless value.

$$\text{Flow Number} = \frac{\text{Flow Rate}}{\sqrt{\text{Delivery Pressure}}}$$

2 Experimental Procedure

The procedure is given in Appendix A. Briefly, the system was brought to the desired delivery pressure, run for 30 seconds to ensure it was close to steady state, average values of pressures, flow rates and flow numbers were recorded over 30 seconds at a 10 Hz acquisition rate. Except during initial system commissioning, the flow number was determined at a typical operating pressure of 2200 PSIG.

The water supply system was comprised of a Danfoss PAH 10 pump, controlled by a variable frequency drive (VFD), supplying 3 flow lanes and a drain line. A simplified schematic of the water system is given in Figure 1. The water flow rate through the nozzles was determined from the difference between the inlet, and the combined drain and pressure relief valve (PRV) mass flows. The calibration sheets for the mass flow meters are included in Appendix B.

The Danfoss PAH 10 is a 9-piston positive displacement pump with a flow range of 8 to 22 L/min (125 to 350 GPH). To obtain lower flow rates the drain valve was opened to bleed off the excess. The VFD and all remote control valves were operated from the data acquisition and control computer located in the control room of Test Cell No. 5.

The nozzle delivery pressure was measured with Honeywell Precision Pressure Transducers – Ruggedized, Model PPTR3000GP2VB with a 0-3000 PSI range and a typical 0.12% full scale accuracy. Calibration sheets, produced at NRC for each lane, are included in Appendix B.

The average data was recorded in a text file, the structure of which is given in Appendix C.

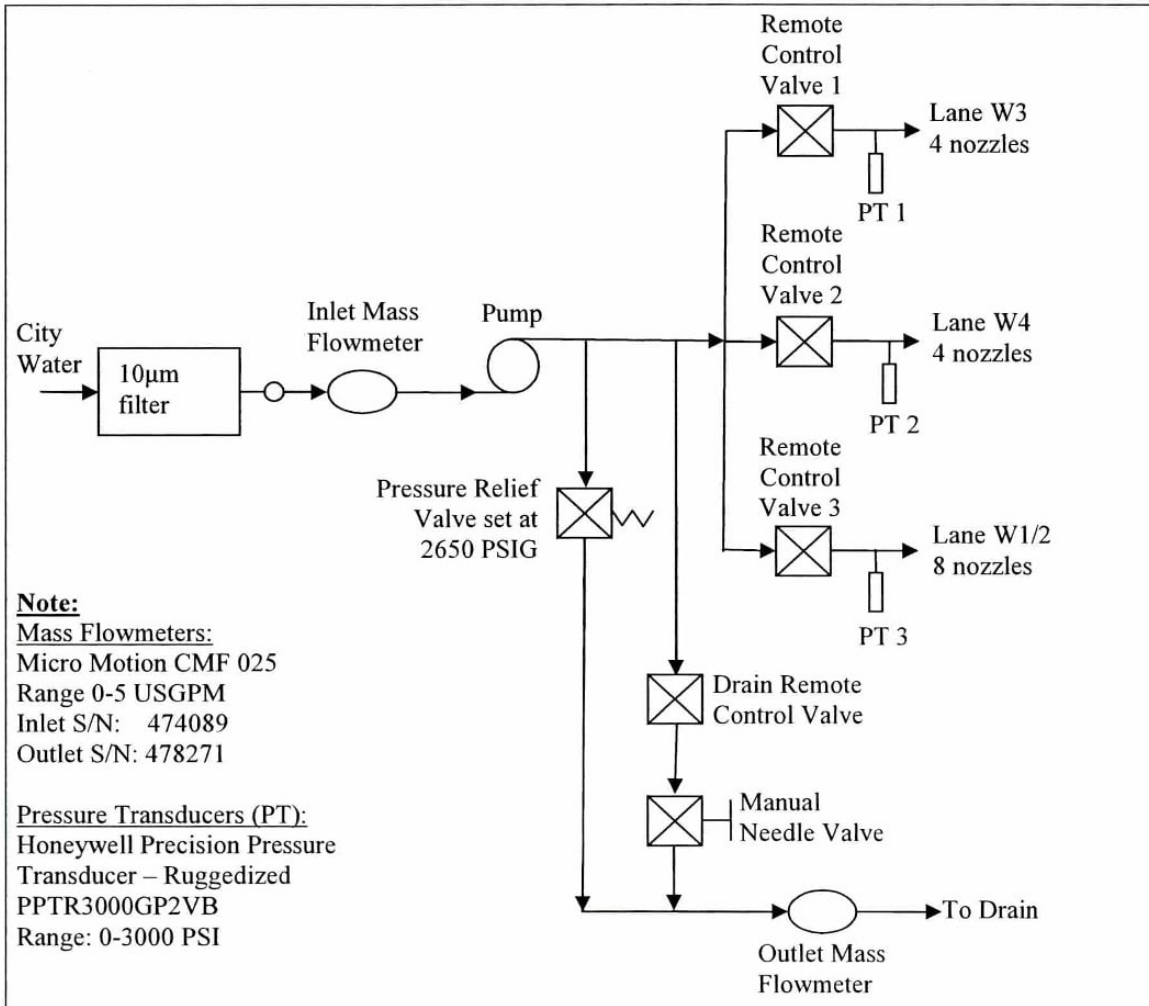


Figure 1: Test apparatus piping schematic

3 Results

3.1 Operational Spray Bars

The operational spray bars were received at NRC after being installed at Rolls Royce Canada's engine test cell. Flow numbers were determined for each of the spray bars before returning them to Rolls Royce personnel for rebuild in the M7 shop.

Figure 2 presents the measured flow numbers per nozzle for each lane at 2200PSIG nominal delivery pressure. These results are compared to the flow numbers originally determined. The pre-installation was originally presented in LTR-2007-0045. Of the 19 spray bars tested, ten were found to leak during testing. Three of the leaks were due to previous disassembly and inspection at Rolls Royce. The results from lanes which exhibited leakage are excluded from the figures. For the purpose of the lane identifier the lanes are numbered as follows:

W1/2 – 2

W3 – 3

W4 – 4

The lane identifier is then calculated:

$$\text{Lane Identifier} = 3 (\text{Bar}-1) + (\text{Lane}-1)$$

Figure 3 presents the flow numbers divided by the average flow number for all the bars, prior to use. Almost all showed a decrease in flow and the worst dropped by more than 70%. Figure 4 presents the comparative flow numbers by lane. It is clear that lane W1/2 was less susceptible to blockage than either lane W3 or W4. Appendix D provides the data that corresponds to the figures in this section and includes the results for the leaking spray bars.

Inspection of the disassembled spray bars by Rolls Royce personnel revealed clogging of the final filters prior to the nozzles. From the current data a cause cannot be determined; however, correlations of lane usage to running times and conditions, in the Rolls Royce test cell, may provide some indications.

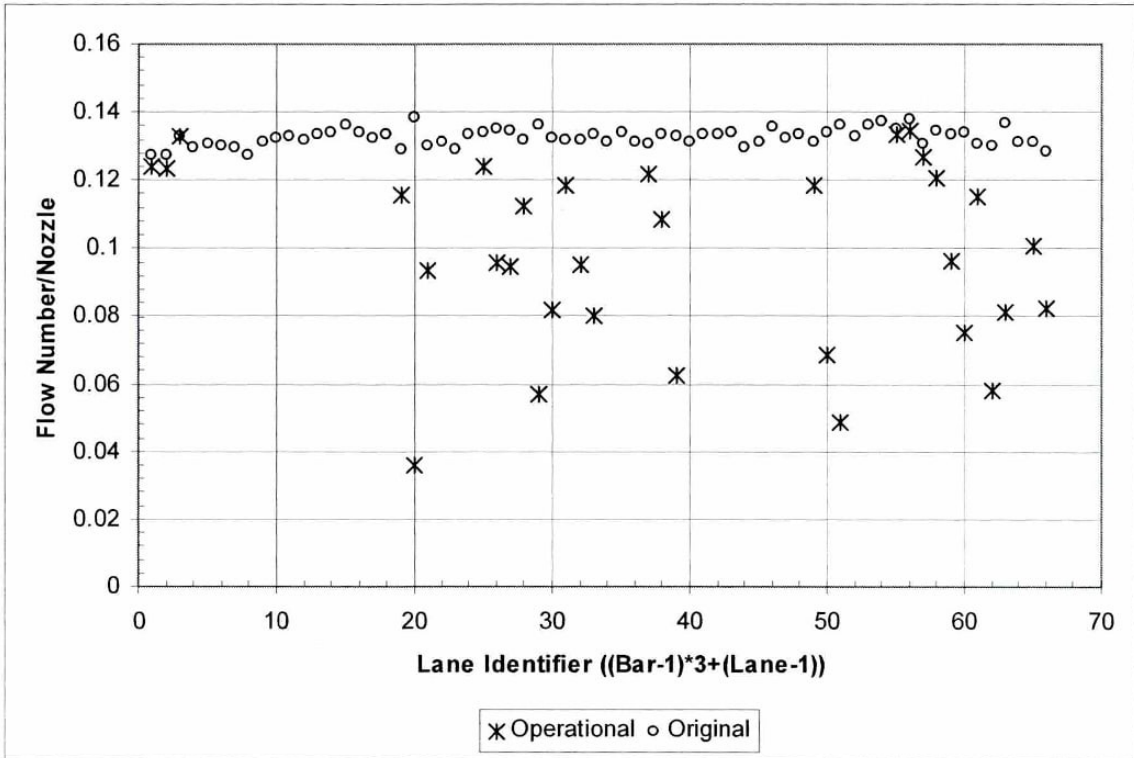


Figure 2: Spray bar flow numbers before and after use

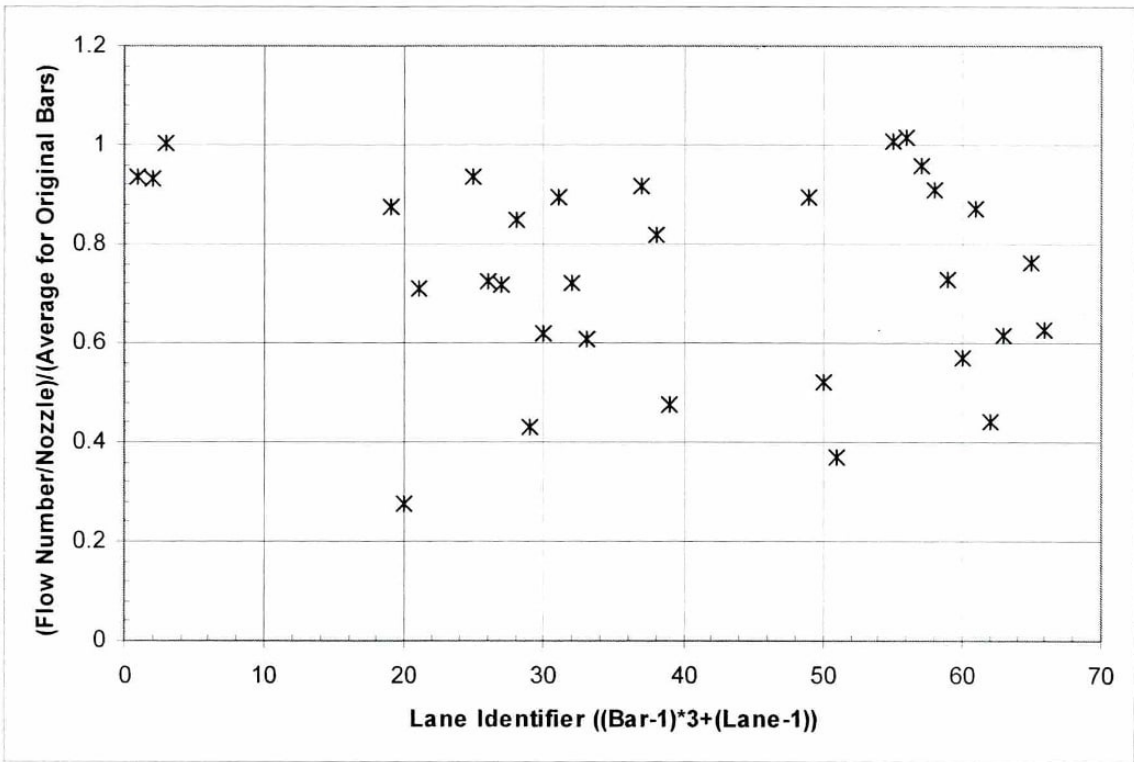


Figure 3: Nozzle flow numbers divided by average pre-use flow number

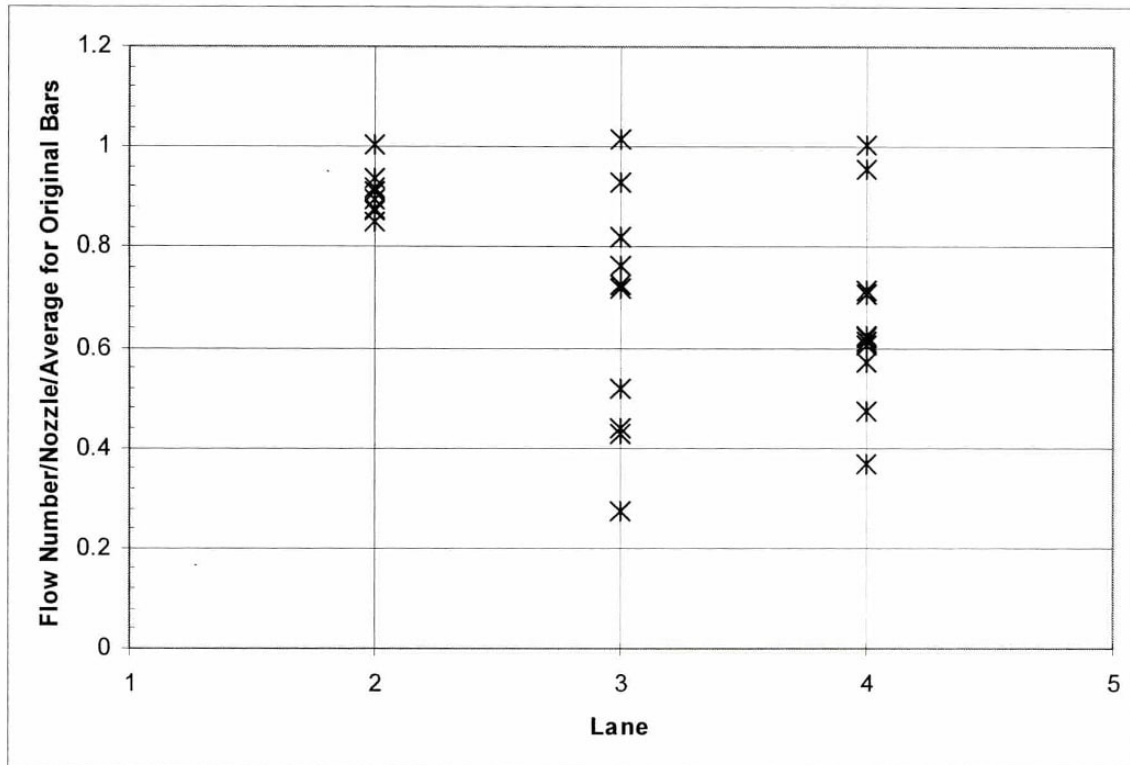


Figure 4: Nozzle flow numbers divided by average pre-use flow number by lane

3.2 Rebuilt Spray Bars

After testing Rolls Royce personnel disassembled the spray bars, replaced the clogged filters and reassembled them. Once reassembled the flow number for each lane was determined. Figure 5 gives both the original and rebuilt flow numbers for each lane. Figure 6 shows the change in flow number as a percentage of the original lane flow number. During assembly one lane was initially prepared without a filter. This lane is labelled on each figure and, as expected, had a noticeably higher flow number than the original, due to the reduced flow restriction. The rebuilt flow numbers fall within the scatter of the original flow numbers. Appendix E provides the data for the rebuilt flow numbers.

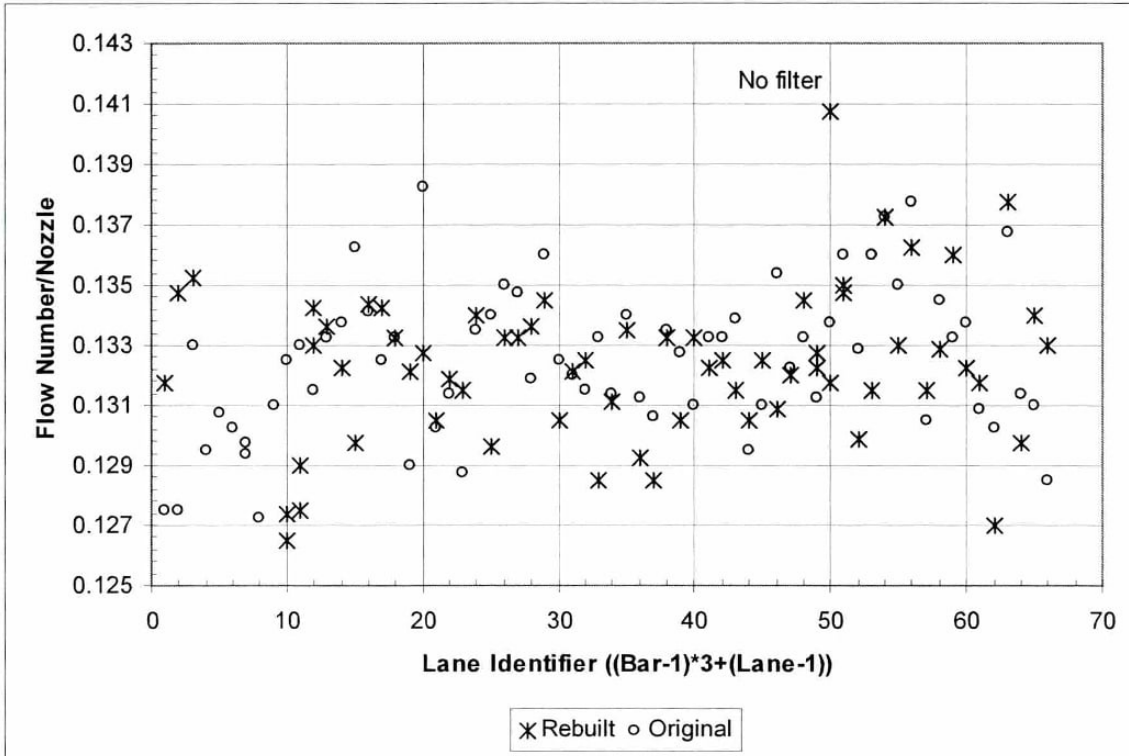


Figure 5: Spray bar flow numbers before use and after rebuild

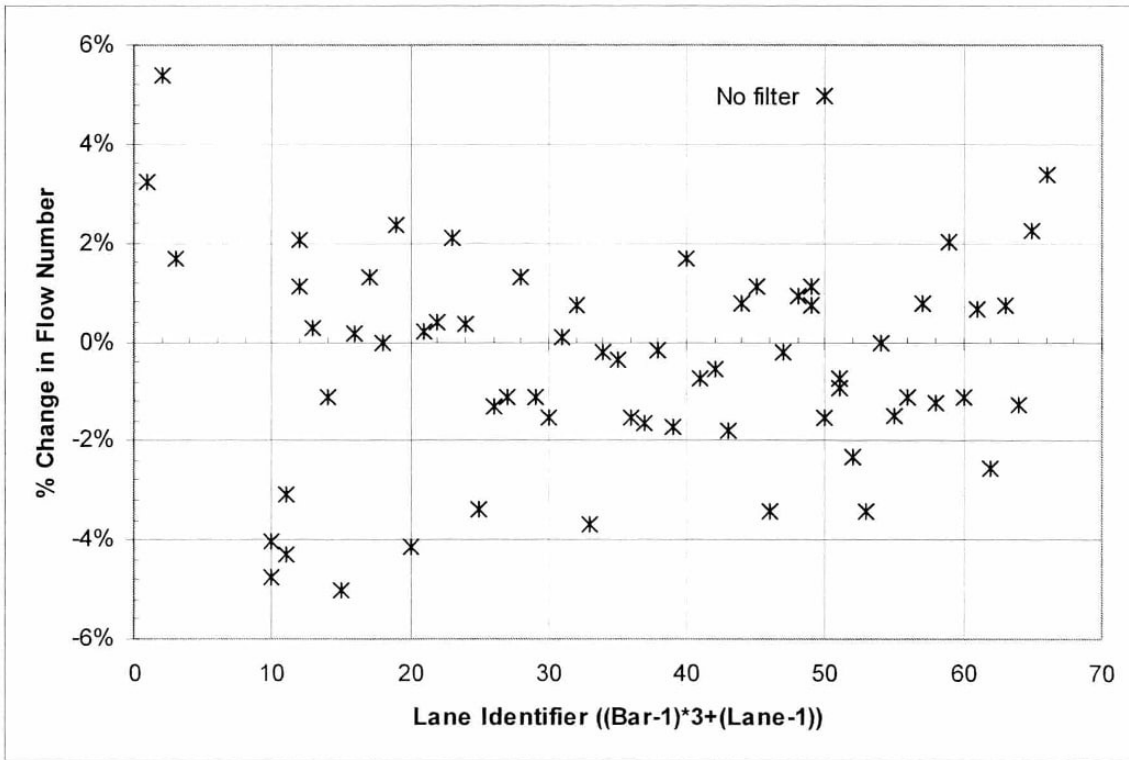


Figure 6: Change in flow number from original build to rebuilt condition

4 Conclusions

Flow numbers were determined for a set of 19 spray bars after installation in an engine test cell and again after rebuild. After operation the bars showed significant blockage and leakage, but after rebuild were returned to within 6% of the original flow number for each lane.

5 References

Davison, C., "Proposal for Flow Testing of Rolls Royce Inlet Spray Bars", RP-GTL-2008-0011, National Research Council of Canada, February 2008, Ottawa, Ontario.

Davison, C. and Benner, M., "Summary of Inlet Spray Testing for Rolls Royce Canada", LTR-GTL-2007-0045, National Research Council of Canada, May 2008, Ottawa, Ontario.

6 Appendix A – Flow Testing Procedure

Procedure:

1. Open valve required nozzle group
2. Adjust pressure to 1800PSIG ±10PSI
3. Spray for minimum of 30 seconds or until steady state is achieved.
4. Record average flow rate (USGPH), delivery pressure (PSI) and flow number (USGPH/PSIG^{0.5}) over 30 seconds at 10Hz sample rate.

$$FlowNumber_i = \frac{FlowRate_i}{\sqrt{DeliveryPressure_i}} \left[\frac{USGPH}{\sqrt{PSIG}} \right]$$

$$FlowNumber_{Ave} = \frac{\sum_{i=1}^n FlowNumber_i}{n} \left[\frac{USGPH}{\sqrt{PSIG}} \right]$$

5. Repeat steps 2, 3 and 4 for pressures of 2200PSIG and 2400PSIG.
6. Repeat steps 1, 2, 3, 4 and 5 for the 2 lanes (W3 & W4) containing 4 nozzles each.
7. Repeat steps 1, 2, 3, 4 and 5 for the lane (W1/2) containing 8 nozzles.

Test Set-Up:

2 individually controlled lanes consisting of 4 nozzles each.

1 individually controlled lane consisting of 8 nozzles each.

Minimum pump flow is 8 L/min at 700RPM.

Maximum pump flow is 21.6 L/min

The flow number for each nozzle will be assumed to be the flow number for the group divided by the number of nozzles in the group.

Flow configuration:

The following tables describe the flow distribution and associated errors based on the installed flow meters. The nozzle flow is determined from the Parker Aerospace Macrospray SP-1.5-N specifications.

Table 1: Water flow and associated error at 1800PSIG delivery pressure

Qty. of Nozzles	Flow (L/min)			Error (± fraction of flow)			Error in flow (± L/min)		
	Pump	Bleed	Total Nozzle	Pump	Bleed	Total Nozzle	Pump	Bleed	Total Nozzle
4	8.0	6.4	1.6	0.15%	0.05%	0.76%	0.012	0.003	0.012
8	8.0	4.8	3.2	0.15%	0.05%	0.37%	0.012	0.002	0.012
16	8.0	1.5	6.5	0.15%	0.05%	0.18%	0.012	0.001	0.012
32	12.9	0.0	12.9	0.15%	0.05%	0.15%	0.019	0.000	0.019

Table 2: Water flow and associated error at 2200PSIG delivery pressure

Qty. of Nozzles	Flow (L/min)			Error (± fraction of flow)			Error in flow (± L/min)		
	Pump	Bleed	Total Nozzle	Pump	Bleed	Total Nozzle	Pump	Bleed	Total Nozzle
4	8.0	6.2	1.8	0.15%	0.05%	0.69%	0.012	0.003	0.012
8	8.0	4.5	3.5	0.15%	0.05%	0.34%	0.012	0.002	0.012
16	8.0	0.9	7.1	0.15%	0.05%	0.17%	0.012	0.000	0.012
32	14.2	0.0	14.2	0.15%	0.05%	0.15%	0.021	0.000	0.021

Table 3: Water flow and associated error at 2400PSIG delivery pressure

Qty. of Nozzles	Flow (L/min)			Error (± fraction of flow)			Error in flow (± L/min)		
	Pump	Bleed	Total Nozzle	Pump	Bleed	Total Nozzle	Pump	Bleed	Total Nozzle
4	8.0	6.1	1.9	0.15%	0.05%	0.66%	0.012	0.003	0.012
8	8.0	4.3	3.7	0.15%	0.05%	0.32%	0.012	0.002	0.012
16	9.0	1.6	7.4	0.15%	0.05%	0.18%	0.013	0.001	0.013
32	14.8	0.0	14.8	0.15%	0.05%	0.15%	0.022	0.000	0.022

Sample calculation for 4 nozzles at 2200PSIG:

Flow number at 2000PSI is:

$$\text{Flow Number} = \frac{6.7 \text{ USGPH}}{\sqrt{2000 \text{ PSI}}} = 0.150 \text{ USGPH} / \sqrt{\text{PSI}}$$

Use this flow number to calculate flow per nozzle at 2200 PSI:

$$\text{Flow} = \text{Flow Number} \sqrt{\text{Pressure}} = 0.150 \sqrt{2200} = 7.03 \text{ USGPH} = 0.44 \text{ L/min}$$

$$\text{For 4 nozzles} = 7.03 * 4 = 28.1 \text{ USGPH} (1.77 \text{ L/min})$$

Minimum pumped flow is 8 L/min with excess flow bled off.

Therefore for 4 nozzles bleed is:

$$8 - 1.77 = 6.23 \text{ L/min}$$

Flow error is combination of inlet and bleed flow meter errors:

Inlet flow meter error is ±0.148% of reading at minimum pump flow of 8 L/min

$$\text{Inlet flow meter error} = \pm 0.148\% (8 \text{ L/min}) = \pm 0.012 \text{ L/min}$$

Bleed flow meter error is ±0.05% of reading.

$$\text{Bleed flow meter error} = \pm 0.05\% (6.23 \text{ L/min}) = \pm 0.003 \text{ L/min}$$

$$\text{Nozzle Flow Error} = \sqrt{0.003^2 + 0.012^2} = 0.012 \text{ L/min}$$

$$\% \text{ of flow} = 0.012 / 1.77 = 0.69\%$$

Figure 7: Inlet mass flow meter calibration sheet (page 1)

Micro Motion, Inc.		Transmitter Configuration Report				225 353	
Product Code	Serial ID	Order ID	Line	Item	Customer Tag		
CMF025M313NABCEZZZ	474089	RMA306796	1	1			
1700R11ABCEZZZ	2257653	RMA306796	2	1			
CORE PROCESSOR SN: 030-01235							
Process							
Process ID:1.18411280							
Process Time:2004.08.30 13:32:06							
Process Stand:SSCB-CONFIG1@SSCB							
Sensor			Units				
D1:0			Special Volume Conv Factor:1				
D2:1			Special Volume Flow Text:NONE				
DFQ1:0			Special Volume Time Unit:SEC				
DFQ2:0			Special Volume Total Text:NONE				
DT:4.44			Temperature Unit:DEGC				
DTG:0			Volume Flow Unit:L/MIN				
Density Meter Factor:1			Assignments				
Density Press Comp Factor:0			Frequency Scaling Method:FREQUENCY/FLOW				
FD:424.98			mA1 Variable:MASS FLOW RATE				
FFQ:0			Ranges				
FTG:0			Frequency Active State:ACTIVE HIGH				
Flow Cal Pressure PSI:0			Frequency Hertz:10000				
Flow Press Comp Factor:0			Frequency Pulses/Unit:15000				
FlowCal:4.14164.75			Frequency Rate:2400				
K1:6368.148			Frequency Units/Pulse:6.666667E-5				
K2:7556.102			mA1 LRV:-6574.1				
Mass Flow Meter Factor:1			mA1 URV:6574.112				
Temperature Cal Factor:1.00000T.00000			Faults				
Volume Flow Meter Factor:1			Frequency Fault Behavior:DOWNSCALE				
Units			Frequency Fault Value:15000				
Density Unit:G/CUCM			RS485 Fault Behavior:NONE				
Mass Flow Unit:LB/HR			mA1 Fault Behavior:DOWNSCALE				
Pressure Unit:PSI			mA1 Fault Value:2				
Special Mass Base Unit:GRAM			Other				
Special Mass Conv Factor:1			Calibration Process ID:1.18411081				
Special Mass Flow Text:NONE			Core Software Rev:23				
Special Mass Time Unit:SEC			Density Cutoff:0.2				
Special Mass Total Text:NONE			Density Damping:0.8				
Special Volume Base Unit:LITER			Density High Limit:5				

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Figure 8: Inlet mass flow meter calibration sheet (page 2)

Micro Motion, Inc.				Mass Flowmeter Calibration Certificate		474089																														
Product Code	Serial ID	Order ID	Line	Item	Customer Tag																															
CMF025M313NABCEZZZ	474089	RMA306796	1	1																																
FLOW VERIFICATION - FLOW CAL FACTORS SAME AS PRIOR CAL																																				
Process			Detail																																	
Process ID: 1.18411081 Process Time: 2004.08.30 12:35:08 Process Stand: TSM1C@SSCB Stand Uncertainty: +/- 0.03% Fluid: H2O 100% Rate: 40 LB/MIN Pickoff: 1 100% P/T: 36.13 PSIG/25 C																																				
Results																																				
Status: PASS D1: 0 D2: 1 K1: 6368.148 K2: 7556.102 DT: 4.44 FD: 424.98 DTG: 0 DFQ1: 0 DFQ2: 0 FlowCal: 4.14164.75 FFQ: 0 FTG: 0 DensCal: 06368075564.44 FCF: 4.1416 FT: 4.75			<table border="1" style="width: 100%; border-collapse: collapse; margin: 0 auto;"> <thead> <tr style="background-color: #333; color: white;"> <th style="text-align: center;">Flow (%)</th> <th style="text-align: center;">Nominal Flow Rate (kg/min)</th> <th style="text-align: center;">Meter Total (kg)</th> <th style="text-align: center;">Reference Total (kg)</th> <th style="text-align: center;">Error (%)</th> <th style="text-align: center;">Specification (±%)</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">100.0</td> <td style="text-align: center;">18.1437</td> <td style="text-align: center;">7.576419</td> <td style="text-align: center;">7.575336</td> <td style="text-align: center;">0.014</td> <td style="text-align: center;">0.100</td> </tr> <tr> <td style="text-align: center;">10.0</td> <td style="text-align: center;">1.81437</td> <td style="text-align: center;">0.7367303</td> <td style="text-align: center;">0.7367781</td> <td style="text-align: center;">-0.006</td> <td style="text-align: center;">0.100</td> </tr> <tr> <td style="text-align: center;">50.0</td> <td style="text-align: center;">9.07185</td> <td style="text-align: center;">3.322738</td> <td style="text-align: center;">3.319661</td> <td style="text-align: center;">0.093</td> <td style="text-align: center;">0.100</td> </tr> <tr> <td style="text-align: center;">100.0</td> <td style="text-align: center;">18.1437</td> <td style="text-align: center;">7.470111</td> <td style="text-align: center;">7.470684</td> <td style="text-align: center;">-0.008</td> <td style="text-align: center;">0.100</td> </tr> </tbody> </table>				Flow (%)	Nominal Flow Rate (kg/min)	Meter Total (kg)	Reference Total (kg)	Error (%)	Specification (±%)	100.0	18.1437	7.576419	7.575336	0.014	0.100	10.0	1.81437	0.7367303	0.7367781	-0.006	0.100	50.0	9.07185	3.322738	3.319661	0.093	0.100	100.0	18.1437	7.470111	7.470684	-0.008	0.100
Flow (%)	Nominal Flow Rate (kg/min)	Meter Total (kg)	Reference Total (kg)	Error (%)	Specification (±%)																															
100.0	18.1437	7.576419	7.575336	0.014	0.100																															
10.0	1.81437	0.7367303	0.7367781	-0.006	0.100																															
50.0	9.07185	3.322738	3.319661	0.093	0.100																															
100.0	18.1437	7.470111	7.470684	-0.008	0.100																															
_____ N. WILSON Technician			ORIGINAL																																	
Traceable to International Standards. Meter total based on pulse out;		Details at www.micromotion.com .		2004.08.30 13:13		3 / 1																														

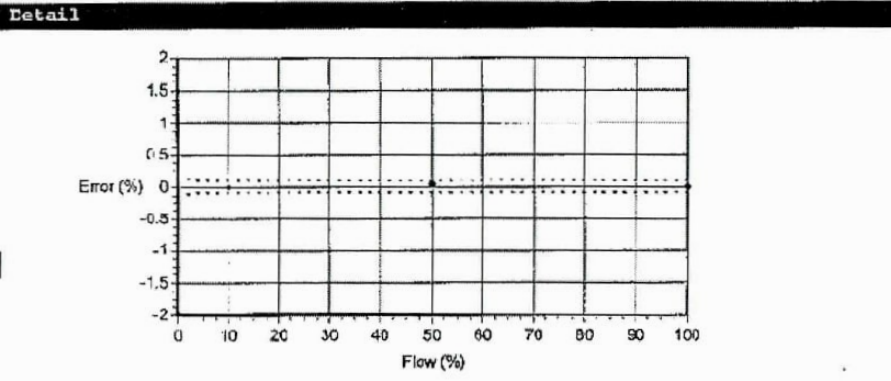
Figure 9: Outlet mass flow meter calibration sheet (page 1)

Micro Motion, Inc.					Mass Flowmeter Calibration Certificate		47 71	
Product Code	Serial ID	Order ID	Line	Item	Customer Tag			
CMF02SM313NABCEZZZ	478271	5J004684	1	1	478271			

FLOW CALIBRATION - CORE PROCESSOR SN: 012-00360

Process

Process ID: 1.22553786
 Process Time: 2007.10.11 20:18:18
 Process Stand: SSFLA@SSCB
 Stand Uncertainty: +/- 0.03%
 Fluid: H2O
 100% Rate: 40 LB/MIN
 Pickoff: 1
 100% P/T: 56.65 PSIG/24.8 C



Results

Status: PASS

D1: 0
 D2: 1
 K1: 6361.011
 K2: 7558.056
 DT: 4.44
 FD: 408.23
 DTG: 0
 DFQ1: 0
 DFQ2: 0
 FlowCal: 4.09654.75
 FFC: 0
 FTG: 0
 DensCal: 0.0361075584.44
 FCF: 4.0965
 ET: 4.75


Flow (%)	Flow Rate (kg/min)	Meter Total (kg)	Reference Total (kg)	Error (%)	Specification (±%)
100.0	16.1437	12.81317	12.81309	0.001	0.100
10.0	1.81437	1.32592	1.325747	0.013	0.100
50.0	9.07185	6.4232	6.420555	0.041	0.100
100.0	16.1437	12.78149	12.78206	-0.004	0.100

DUONG HUONG
 Technician

MASS FLOWMETER CALIBRATION REPORT
 OCT 11 2007 - 5 CELL RR CRAIG
 Dec 08 2007 - 1 cell FUEL FLOW - PIT
 MAR 25 2008 - 2 CELL H2O FLOW RR

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Figure 10: Outlet mass flow meter calibration sheet (page 2)

Micro Motion, Inc.		Transmitter Configuration Report			300 303	
Product Code	Serial ID	Order ID	Line	Item	Customer Tag	
CMF025M313NABCEZZZ	478271	50004684	1	1	3006903	
1700R11ABCEZZZ	3006903	50004684	3	1		
CORE PROCESSOR SN: 032-00360						
Process						
Process ID:1.22554113				TRANSMITTER CONFIGURATION REPORT		
Process Time:2007.10.11 22:04:54						
Process Stand:S3CB-CONFIG1@S3CB						
Sensor						
D1:0			Special Volume Base Unit:LITER			
D2:1			Special Volume Conv Factor:1			
DFQ1:0			Special Volume Flow Text:NONE			
DFQ2:0			Special Volume Time Unit:SEC			
DT:4.44			Special Volume Total Text:NONE			
DTS:0			Temperature Unit:DEGC			
Density Meter Factor:1			Volume Flow Unit:L/MIN			
Density Press Comp Factor:0			Assignments			
FCF:4.0965			Frequency Scaling Method:FREQUENCY/FLCW			
FD:406.23			Frequency Variable:MASS FLOW RATE			
FFQ:0			mAl Variable:MASS FLOW RATE			
FT:4.75			Ranges			
FTS:0			Frequency Active State:ACTIVE HIGH			
Flow Cal Pressure PSI:0			Frequency Hertz:10000			
Flow Press Comp Factor:0			Frequency Pulses/Unit:15000			
K1:6361.011			Frequency Rate:2400			
K2:7058.056			Frequency Units/Pulse:6.6665E-5			
Mass Flow Meter Factor:1			mAl LRV:0			
Temperature Cal Factor:1.000000.00000			mAl URV:1990			
Volume Flow Meter Factor:1			Faults			
Units			Frequency Fault Behavior: DOWNSCALE			
Density Unit:LB/CUFT			Frequency Fault Value:15000			
Mass Flow Unit:LB/HR			RS485 Fault Behavior:NONE			
Pressure Unit:PSI			mAl Fault Behavior: DOWNSCALE			
Special Mass Base Unit:GRAM			mAl Fault Value:2			
Special Mass Conv Factor:1			Other			
Special Mass Flow Text:NONE			Calibration Process ID:1.22553786			
Special Mass Time Unit:SEC			Core Software Rev:25			
Special Mass Total Text:NONE			Density Cutoff:12.48559			

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Figure 11: Outlet mass flow meter calibration sheet (page 3)

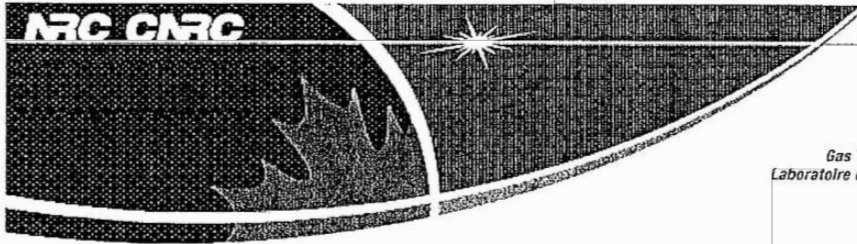
Other

300 6903

Density Damping:0.8
 Density High Limit:5
 Density Low Limit:0
 Direction:FORWARD
 Fault Dwell Time:0
 Feature Key:2
 Flow Damping:0.8
 HART Device ID:12780266
 Mass Flow Cutoff:6.85726
 Pressure Comp Line Pressure:0
 Pressure Compensation State:OFF
 RS485 Baud:1200
 RS485 Parity:ODD
 RS485 Protocol:NONE
 Slug Duration:0
 Tag:
 Temperature Damping:2.4
 Transmitter Software Rev:51
 Volume Flow Cutoff:0.05184

TRANSMITTER CONFIGURATION REPORT

**COPY
ORIGINAL**

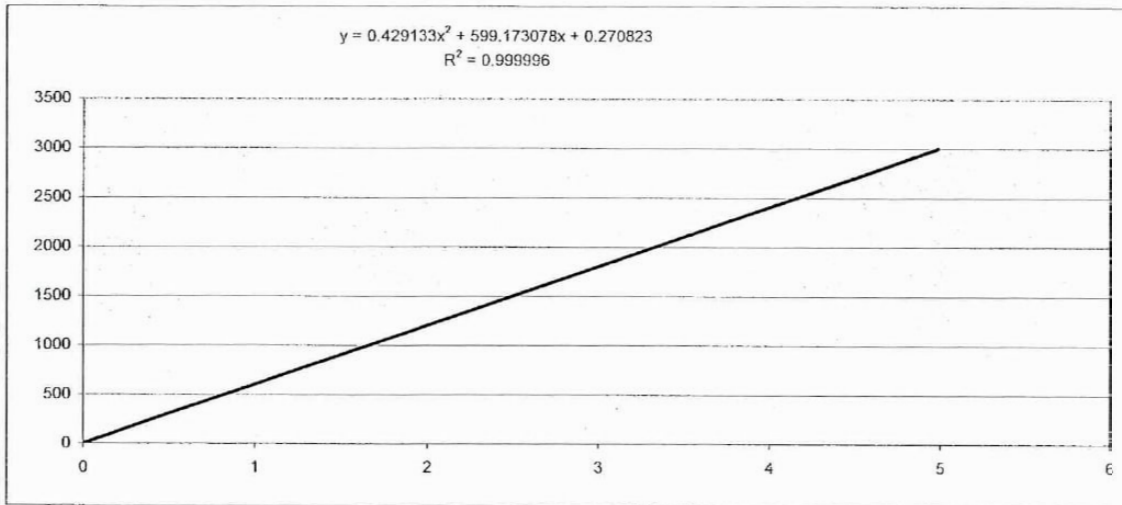


DAS ANALOG CALIBRATION

Project: RR Spray Bars
 Channel: PW1-2
 Model (SN): Honeyweall
 Range: 3000
 Eng. Unit: PSIG

VOLTS	Expected PSIG	Calculated PSIG	%FS Error
0.000656	0.000000	0.663881	-0.022129
1.249231	750.000000	749.446102	0.018463
2.494683	1500.000000	1497.688400	0.077053
3.750753	2250.000000	2253.658149	-0.121938
4.986211	3000.000000	2998.543449	0.048552

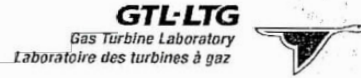
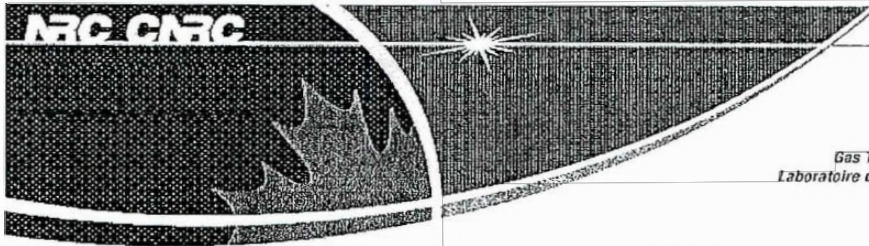
A = 0.429133
 B = 599.173078
 C = 0.270823
 R2 = 0.999996



Calibration Standard:	Serial Number	Calibration due date	Performed by
XHG-V-0000	1000-4722		

Calibrated by:	Signature	Location	Date
J. WILLIAMS	J. Williams	TEST CELL 5.	14-Apr-08

Figure 12: Lane 1/2 pressure transducer (including data acquisition system) calibration sheet

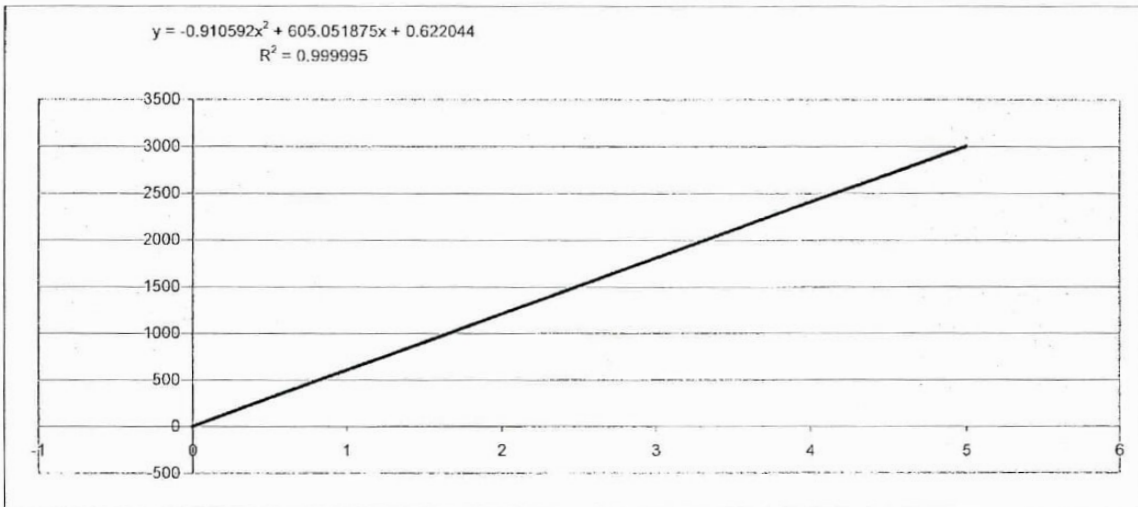


DAS ANALOG CALIBRATION

Project: RR Spray Bars
 Channel: PW3
 Model (SN): Honeyweall
 Range: 3000
 Eng. Unit: PSIG

VOLTS	Expected PSIG	Calculated PSIG	%FS Error
-0.003737	0.000000	-1.639048	0.054635
1.246201	750.000000	753.224131	-0.107471
2.487705	1500.000000	1500.177260	-0.005909
3.732958	2250.000000	2246.566204	0.114460
4.997575	3000.000000	3001.671445	-0.055715

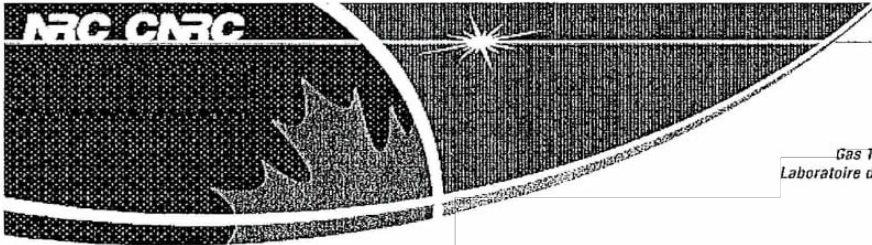
A = -0.910592
 B = 605.051875
 C = 0.622044
 R2 = 0.999995



Calibration Standard:	Serial Number	Calibration due date	Performed by
XH GV-0000	1000-4722		

Calibrated by:	Signature	Location	Date
<i>J. Williams</i>	<i>J. Williams</i>	TEST CELL 5	14-Apr-08

Figure 13: Lane 3 pressure transducer (including data acquisition system) calibration sheet

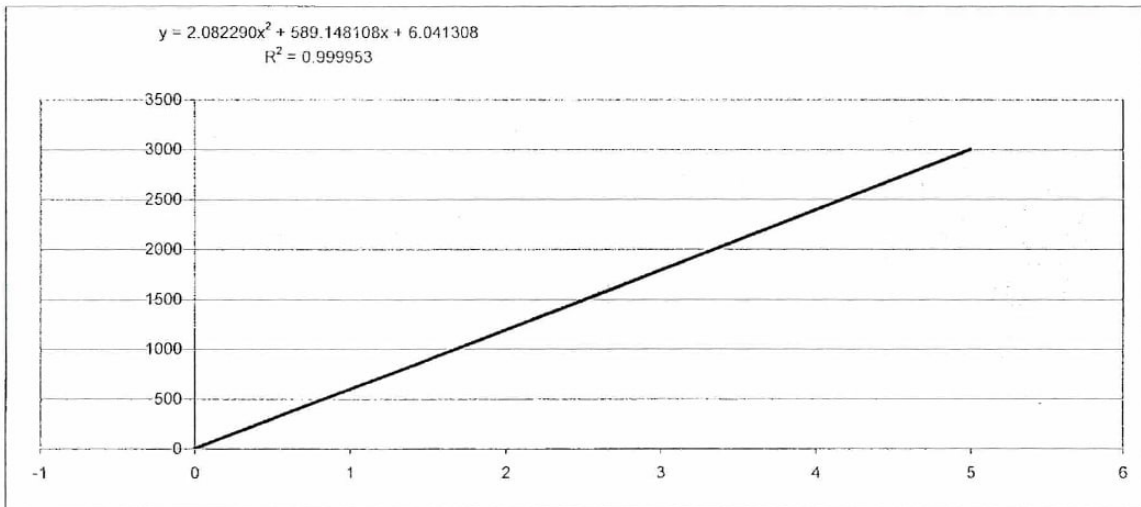


DAS ANALOG CALIBRATION

Project: RR Spray Bars
 Channel: PW4
 Model (SN): Honeywell
 Range: 3000
 Eng. Unit: Psig

VOLTS	Expected Psig	Calculated Psig	%FS Error
-0.004331	0.000000	3.489747	-0.116325
1.239577	750.000000	739.535297	0.348823
2.531891	1500.000000	1511.048562	-0.368285
3.751751	2250.000000	2245.687867	0.143738
4.994097	3000.000000	3000.238512	-0.007950

A = 2.082290
 B = 589.148108
 C = 6.041308
 R2 = 0.999953



Calibration Standard:	Serial Number	Calibration due date	Performed by
XHG-V-0000	1000-4722		

Calibrated by:	Signature	Location	Date
J WILLIAMS	J Williams	TEST CELL 5.	18-Apr-08

Figure 14: Lane 4 pressure transducer (including data acquisition system) calibration sheet

Appendix C: Data File Structure

The raw data is presented in a text file summarising the average over 30 seconds acquired at 10Hz.

The file names are: "TUNNELSSxxx.dat"

Where the xxx is replaced with a sequential number.

The first two rows of the data file contain the data description and units for the column. The file then has four rows containing the mean, minimum, maximum and standard deviation for the time period recorded. Table 4 explains each of the relevant columns in the data file.

Table 4: Data file fields

Column	Description	Units	Notes
1	READ	Date	The units row contains the date and time. Contains the number of scans used in the average.
2	Looptime	ms	Length of time for each scan
3	ScanFreq	Hz	Frequency of scans
4	Scan	#	File number ie xxx given in file names above
5	DTIME	sec	Time elapsed during scan
9	WF3NUM3	NA	Lane W3 flow number (GPH/PSIG ^{0.5})
10	WF3NUM4	NA	Lane W4 flow number (GPH/PSIG ^{0.5})
11	WF3NUM1/2	NA	Lane W1/2 flow number (GPH/PSIG ^{0.5})
23	BARO	PSIA	Absolute pressure in test cell 5
25	PWATER	PSIG	Pressure at pump inlet
26	PW3	PSIG	Water pressure at lane W3 inlet
27	PW4	PSIG	Water pressure at lane W4 inlet
28	PW1/2	PSIG	Water pressure at lane W1/2 inlet
29	TWATER	DEGC	Water delivery temperature
58	WFBLEED	USGPH	Water drain flow rate
59	WH2O	USGPH	Water inlet flow rate

8 Appendix D: Operational spray bar data

Table 5 provides the data for each lane of the spray bars tested after use but prior to rebuild. Flow numbers are normalised by the original flow number average at 2200 PSI.

Table 5: Spray bar nozzle flow number results after use

ID	File No.	Bar	Lane	Desired Press. (PSIG)	Pressure (PSIG)		Flow (GPH)	Flow Number (USGPH/PSIG ^{0.5})		Flow Number /Nozzle	Normalised Flow Number	Note
					Mean	Std. Dev.		Mean	Std. Dev.			
1	1142	1	2	2200	2207	3	46.7	0.992	0.005	0.124	0.005	
2	1143	1	3	2200	2202	7	23.2	0.493	0.006	0.123	0.005	
3	1144	1	4	2200	2210	7	25.1	0.532	0.005	0.133	0.006	
10	1121	4	2	2200	2201	2	46.6	0.991	0.005	0.124	0.006	Leak
11	1122	4	3	2200	2208	5	25.9	0.550	0.006	0.138	0.007	Leak
12	1123	4	4	2200	2206	6	21.0	0.446	0.016	0.112	0.005	Leak
13	1127	5	2	2200	2203	2	47.3	1.005	0.007	0.126	0.005	Leak
14	1128	5	3	2200	2213	6	17.7	0.376	0.006	0.094	0.004	Leak
15	1129	5	4	2200	2210	10	10.7	0.227	0.006	0.057	0.004	Leak
16	1172	6	2	2200	2204	3	48.6	1.031	0.005	0.129	0.005	Leak
17	1173	6	3	2200	2206	8	23.0	0.488	0.005	0.122	0.006	Leak
18	1174	6	4	2200	2215	11	17.6	0.373	0.004	0.093	0.005	Leak
19	1115	7	2	2200	2211	2	43.7	0.927	0.005	0.116	0.006	
20	1116	7	3	2200	2211	9	6.8	0.145	0.005	0.036	0.006	
21	1117	7	4	2200	2207	6	17.7	0.375	0.005	0.094	0.006	
22	1130	8	2	2200	2100	6	108.8	2.368	0.014	0.296	0.016	Leak
23	1131	8	3	2200	2197	2	55.8	1.187	0.005	0.297	0.005	Leak
24	1132	8	4	2200	2206	13	10.4	0.220	0.004	0.055	0.005	Leak
25	1124	9	2	2200	2210	2	46.8	0.992	0.007	0.124	0.007	
26	1125	9	3	2200	2214	6	18.1	0.384	0.006	0.096	0.005	
27	1126	9	4	2200	2213	6	17.9	0.379	0.005	0.095	0.005	
28	1112	10	2	2200	2206	2	42.4	0.900	0.005	0.113	0.006	
29	1113	10	3	2200	2225	9	10.7	0.227	0.005	0.057	0.007	
30	1114	10	4	2200	2222	7	15.5	0.328	0.007	0.082	0.006	
31	1157	11	2	2200	2214	4	44.8	0.949	0.004	0.119	0.006	
32	1158	11	3	2200	2210	9	18.0	0.381	0.006	0.095	0.005	
33	1159	11	4	2200	2210	12	15.2	0.321	0.006	0.080	0.006	
34	1103	12	2	2200	2202	7	44.0	0.935	0.005	0.117	0.005	Leak
35	1104	12	3	2200	2209	5	17.6	0.373	0.005	0.093	0.004	Leak
36	1105	12	4	2200	2226	2	13.3	0.281	0.007	0.070	0.005	Leak
37	1139	13	2	1800	1808	4	41.2	0.967	0.005	0.121	0.005	
37	1106	13	2	2400	2389	7	47.7	0.973	0.005	0.122	0.003	
37	1107	13	2	2200	2222	6	46.0	0.973	0.003	0.122	0.004	
38	1108	13	3	1800	1804	4	18.2	0.427	0.004	0.107	0.005	
38	1140	13	3	2400	2393	10	21.4	0.436	0.005	0.109	0.005	
38	1109	13	3	2200	2193	6	20.4	0.434	0.005	0.109	0.005	

ID	File No.	Bar	Lane	Desired Press. (PSIG)	Pressure (PSIG)		Flow (GPH)	Flow Number (USGPH/PSIG ^{0.5})		Flow Number /Nozzle	Normalised Flow Number	Note
					Mean	Std. Dev.		Mean	Std. Dev.			
39	1110	13	4	2400	2393	10	12.6	0.256	0.006	0.064	0.004	
39	1111	13	4	1800	1860	8	10.6	0.244	0.008	0.061	0.004	
39	1141	13	4	2200	2208	12	11.8	0.251	0.006	0.063	0.005	
40	1145	14	2	2200	2203	3	47.0	0.998	0.006	0.125	0.005	Leak
41	1146	14	3	2200	2198	9	19.2	0.408	0.005	0.102	0.005	Leak
42	1147	14	4	2200	2211	11	15.8	0.335	0.005	0.084	0.006	Leak
43	1160	15	2	2200	2205	3	45.8	0.973	0.005	0.122	0.005	Leak
44	1161	15	3	2200	2206	9	19.8	0.419	0.005	0.105	0.006	Leak
45	1162	15	4	2200	2211	10	18.8	0.398	0.006	0.100	0.006	Leak
46	1148	16	2	2200	1885	6	125.1	2.873	0.005	0.359	0.014	Leak
47	1149	16	3	2200	2173	3	53.5	1.144	0.004	0.286	0.008	Leak
48	1150	16	4	2200	2185	8	25.2	0.538	0.005	0.135	0.005	Leak
49	1136	17	2	2200	2204	4	44.7	0.949	0.006	0.119	0.005	
50	1137	17	3	2200	2208	11	13.0	0.275	0.005	0.069	0.006	
51	1138	17	4	2200	2212	13	9.2	0.195	0.005	0.049	0.005	
52	1175	18	2	2200	2207	5	40.8	0.866	0.006	0.108	0.004	Leak
53	1176	18	3	2200	2201	9	19.5	0.415	0.006	0.104	0.006	Leak
54	1177	18	4	2200	2210	10	18.9	0.400	0.005	0.100	0.006	Leak
55	1133	19	2	2200	2205	3	50.2	1.066	0.005	0.133	0.007	
56	1134	19	3	2200	2201	7	25.3	0.538	0.004	0.135	0.005	
57	1135	19	4	2200	2201	8	23.9	0.507	0.004	0.127	0.005	
58	1118	20	2	2200	2211	2	45.5	0.964	0.006	0.121	0.006	
59	1119	20	3	2200	2204	5	18.1	0.385	0.006	0.096	0.005	
60	1120	20	4	2200	2212	6	14.2	0.302	0.005	0.076	0.006	
61	1169	21	2	2200	2206	4	43.5	0.923	0.005	0.115	0.005	
62	1170	21	3	2200	2206	10	11.0	0.233	0.006	0.058	0.005	
63	1171	21	4	2200	2210	11	15.3	0.325	0.005	0.081	0.005	
64	1178	22	2	2200	2200	4	40.8	0.867	0.006	0.108	0.005	Leak
65	1179	22	3	2200	2206	9	19.0	0.404	0.005	0.101	0.005	
66	1180	22	4	2200	2204	12	15.6	0.331	0.006	0.083	0.006	

9 Appendix E: Rebuilt spray bar data

Table 5 provides the data for each lane tested of the spray bars after rebuild. Flow numbers are normalised by the original flow number average at 2200 PSI.

Table 6: Spray bar nozzle flow number results after rebuild

ID	File No.	Bar	Lane	Desired Press. (PSIG)	Pressure (PSIG)		Flow (GPH)	Flow Number (USGPH/PSIG ^{0.5})		Flow Number /Nozzle	Normalised Flow Number	Note
					Mean	Std. Dev.		Mean	Std. Dev.			
1	1246	1	2	2200	2203	3	49.6	1.054	0.005	0.132	0.995	
2	1247	1	3	2200	2199	7	25.4	0.539	0.006	0.135	1.017	
3	1248	1	4	2200	2201	7	25.4	0.541	0.006	0.135	1.021	
10	1154	4	2	2200	2207	3	47.7	1.012	0.005	0.127	0.955	
10	1237	4	2	2200	2208	3	48.0	1.019	0.006	0.127	0.962	
11	1155	4	3	2200	2200	7	24.3	0.516	0.005	0.129	0.974	
11	1238	4	3	2200	2206	6	24.0	0.51	0.005	0.128	0.963	
12	1156	4	4	2200	2201	8	25.3	0.537	0.005	0.134	1.014	
12	1239	4	4	2200	2206	7	25.1	0.532	0.005	0.133	1.004	
13	1220	5	2	2200	2202	2	50.3	1.069	0.007	0.134	1.009	
14	1221	5	3	2200	2200	7	24.9	0.529	0.005	0.132	0.998	
15	1222	5	4	2200	2202	7	24.4	0.519	0.005	0.130	0.980	
16	1211	6	2	2200	2214	2	50.7	1.075	0.007	0.134	1.014	
17	1212	6	3	2200	2201	6	25.3	0.537	0.005	0.134	1.014	
18	1213	6	4	2200	2209	8	25.1	0.533	0.005	0.133	1.006	
19	1217	7	2	2200	2193	4	49.7	1.057	0.008	0.132	0.997	
20	1218	7	3	2200	2208	7	25.0	0.531	0.006	0.133	1.002	
21	1219	7	4	2200	2197	7	24.6	0.522	0.006	0.131	0.985	
22	1196	8	2	2200	2200	3	49.6	1.055	0.005	0.132	0.996	
23	1197	8	3	2200	2200	7	24.8	0.526	0.006	0.132	0.993	
24	1198	8	4	2200	2198	8	25.2	0.536	0.006	0.134	1.012	
25	1214	9	2	2200	2203	3	48.8	1.037	0.005	0.130	0.979	
26	1215	9	3	2200	2200	7	25.1	0.533	0.007	0.133	1.006	
27	1216	9	4	2200	2197	8	25.1	0.533	0.005	0.133	1.006	
28	1199	10	2	2200	2203	2	50.3	1.069	0.007	0.134	1.009	
29	1200	10	3	2200	2213	7	25.4	0.538	0.005	0.135	1.015	
30	1201	10	4	2200	2209	8	24.6	0.522	0.007	0.131	0.985	
31	1240	11	2	2200	2201	3	49.7	1.057	0.005	0.132	0.997	
32	1241	11	3	2200	2205	7	25.0	0.53	0.006	0.133	1.000	
33	1242	11	4	2200	2204	8	24.2	0.514	0.005	0.129	0.970	
34	1151	12	2	2200	2203	3	49.4	1.049	0.005	0.131	0.990	
35	1152	12	3	2200	2203	7	25.1	0.534	0.005	0.134	1.008	
36	1153	12	4	2200	2206	8	24.4	0.517	0.006	0.129	0.976	
37	1205	13	2	2200	2201	2	48.4	1.028	0.008	0.129	0.970	
38	1206	13	3	2200	2213	7	25.2	0.533	0.004	0.133	1.006	
39	1207	13	4	2200	2205	9	24.6	0.522	0.006	0.131	0.985	

ID	File No.	Bar	Lane	Desired Press. (PSIG)	Pressure (PSIG)		Flow (GPH)	Flow Number (USGPH/PSIG ^{0.5})		Flow Number /Nozzle	Normalised Flow Number	Note
					Mean	Std. Dev.		Mean	Std. Dev.			
40	1202	14	2	2200	2203	3	50.2	1.066	0.007	0.133	1.006	
41	1203	14	3	2200	2202	7	24.9	0.529	0.006	0.132	0.998	
42	1204	14	4	2200	2197	8	24.9	0.53	0.005	0.133	1.000	
43	1187	15	2	2200	2201	3	49.5	1.052	0.006	0.132	0.993	
44	1188	15	3	2200	2206	8	24.6	0.522	0.004	0.131	0.985	
45	1189	15	4	2200	2203	9	25.0	0.53	0.006	0.133	1.000	
46	1243	16	2	2200	2199	3	49.2	1.047	0.007	0.131	0.988	
47	1244	16	3	2200	2202	7	24.8	0.528	0.006	0.132	0.997	
48	1245	16	4	2200	2195	8	25.3	0.538	0.005	0.135	1.015	
49	1166	17	2	2200	2201	3	49.8	1.058	0.005	0.132	0.998	
49	1181	17	2	2200	2207	2	50.0	1.062	0.006	0.133	1.002	
50	1167	17	3	2200	2206	7	26.5	0.563	0.005	0.141	1.063	No filter
50	1182	17	3	2200	2213	6	24.9	0.527	0.006	0.132	0.995	
51	1168	17	4	2200	2204	8	25.4	0.54	0.005	0.135	1.019	
51	1183	17	4	2200	2207	6	25.4	0.539	0.006	0.135	1.017	
52	1190	18	2	2200	2206	3	48.9	1.039	0.006	0.130	0.980	
53	1191	18	3	2200	2205	8	24.8	0.526	0.004	0.132	0.993	
54	1192	18	4	2200	2192	8	25.8	0.549	0.006	0.137	1.036	
55	1184	19	2	2200	2206	2	50.1	1.064	0.006	0.133	1.004	
56	1185	19	3	2200	2210	7	25.7	0.545	0.006	0.136	1.029	
57	1186	19	4	2200	2202	8	24.8	0.526	0.005	0.132	0.993	
58	1163	20	2	2200	2205	3	50.1	1.063	0.005	0.133	1.003	
59	1164	20	3	2200	2199	7	25.6	0.544	0.004	0.136	1.027	
60	1165	20	4	2200	2204	10	24.9	0.529	0.005	0.132	0.998	
61	1193	21	2	2200	2199	3	49.6	1.054	0.007	0.132	0.995	
62	1194	21	3	2200	2208	7	23.9	0.508	0.005	0.127	0.959	
63	1195	21	4	2200	2204	8	26.0	0.551	0.006	0.138	1.040	
64	1208	22	2	2200	2204	3	48.9	1.038	0.007	0.130	0.980	
65	1209	22	3	2200	2197	7	25.2	0.536	0.007	0.134	1.012	
66	1210	22	4	2200	2202	8	25.1	0.532	0.005	0.133	1.004	