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C-130J BREATHING RESISTANCE STUDY

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May 2016
Final Report

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14. ABSTRACT

C-130J Program Office requested a study to determine if long breathing hoses (18 feet, 24 feet, and 30 feet) would meet the breathing resistance standards noted in Air Standardization Coordinating Committee (ASCC) Air Standard 61/101/6A, "Minimum Physiological Requirements for Aircrew Demand Breathing Systems." The aircraft oxygen system, including CRU-73 oxygen regulator and MBU-20/P oxygen mask, was setup at the On-Board Oxygen Generating System (OBOGS) Laboratory, Wright-Patterson AFB OH. The mask pressure data were compared to the mask pressure requirements for breathing resistance in the Air Standard. The study revealed the long breathing hose configurations did not provide acceptable breathing resistance in a significant majority of test conditions.

15. SUBJECT TERMS
Aircraft Breathing System; Aircraft Oxygen System; Breathing Hoses; Aircrew Oxygen Regulator; CRU-73; C-130J

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ACKNOWLEDGEMENTS

The author wishes to recognize the individuals listed below for their dedication, expertise, and professional support during the testing. Further, laboratory automation software and "on-the-fly" data reduction software developed by Mr. Doug Coppess reduced the planned testing time by about 50%. The effort was supported by USAF Contract No. FA8650-14-D-6500 Task Order 0004 with Infoscitex Corporation.

Doug Coppess (Infoscitex Corp.)

Jerry Terrell (Infoscitex Corp.)

1.0 EXECUTIVE SUMMARY

The C-130J Program Office requested 711 HPW/RHCPT to conduct a study to determine if the aircrew breathing regulator connected to long breathing hoses (18 feet, 24 feet, and 30 feet) would meet the breathing resistance standards noted in Air Standardization Coordinating Committee (ASCC) Air Standard 61/101/6A, "Minimum Physiological Requirements for Aircrew Demand Breathing Systems," Paragraph 10d. Long breathing hose lengths were under consideration for a specific aircrew station. The aircraft oxygen system, CRU-73 aircrew oxygen regulator and MBU-20/P oxygen mask, was supplied gaseous Aviators' Breathing Oxygen (ABO). The regulator was operated in various operating modes, at several altitudes, and at several breathing simulator settings. During this unmanned testing mask pressure data were compared with mask pressure requirements in the Air Standard. In general, breathing resistance of the system with the long breathing hoses did not meet the Air Standard requirements.

2.0 INTRODUCTION

This study compared the breathing resistance of the CRU-73 aircrew oxygen regulator when using long breathing hoses (18 feet, 24 feet, and 30 feet) to the Air Standard requirements. The oxygen system equipment was setup in altitude chamber PV2, On-Board Oxygen Generating System (OBOGS) Laboratory, Area B, Wright-Patterson AFB OH. The CRU-73 oxygen regulator was supplied with 50 pounds/square inch of gaseous Aviators' Breathing Oxygen (ABO). The regulator was tested in the operating modes of 1) Normal-Normal-On, 2) EMER-Normal-On, 3) EMER-100%-On, and 4) Normal-100%-On. However, the C-130 Program Office stated the aircrew would use the regulator operating mode of Normal-Normal-On. It was decided to test the system in all operating modes because it was convenient to do so. The C-130J Program Office stated oxygen would sometimes be used below a cabin altitude of 10,000 feet and always be used at and above a cabin altitude of 10,000 feet. This breathing resistance assessment was based on system performance with the oxygen regulator in the operating mode of Normal-Normal-On and at altitudes from Ground Level to 25,000 feet. Long breathing hoses have been used by aircrew but aircrew have questioned whether long breathing hoses provide adequate breathing performance. This effort provided an opportunity to collect actual performance data.

3.0 METHODS

Test items supplied by the C-130J Program Office were 2 ea. CRU-73 breathing regulators (S/N 701890 and S/N 008366). Regulator S/N 701890 was used during the testing. The regulators were overhauled and acceptance tested by the manufacturer prior to the study. Breathing hoses in the lengths of 6 feet were supplied. Stock number for the hoses was 4720-00-810-7351. These hoses had an inner diameter of 0.780". In-line connectors (Part No. G002-1660-1) were used to connect multiple hoses together to achieve the appropriate lengths.

Equipment supplied by 711 HPW/RHCPT was: 1) CRU-60 integrated terminal block; 2) MBU-20/P oxygen mask; 3) breathing simulator; 4) oxygen mask pressure transducer; 5) regulator outlet pressure transducer; 6) regulator inlet pressure transducer; 7) mass spectrometer; and 8) breathing gas flow meter.

Test matrix for the long hose study is noted in Table 1. A 6 foot hose was tested as a baseline case for informational purposes only. The long hoses were installed between the breathing gas flow meter

outlet and the CRU-60 mask oxygen connector. An additional length of about 4 feet existed between the regulator outlet and the breathing gas flow meter outlet. This additional length was needed to incorporate the breathing gas flow meter into the test setup and would have negligible impact on the breathing resistance data. During the testing the long breathing hoses were generally coiled in a circle with a diameter of approximately 17" (see Photograph 1). The CRU-73 oxygen regulator inlet was supplied with Aviators' Breathing Oxygen (ABO) at a pressure of 50 pounds/square inch. A computer controlled breathing machine was used to control the breathing flow (Photograph 2). Altitude chamber PV2 used for this effort is shown in Photograph 3. Laboratory automation software and "on-the-fly" data reduction software was developed for this effort and it reduced the testing time by 50% (2 weeks vs. 4 weeks). Photograph 4 shows the general equipment layout in the altitude chamber PV2.

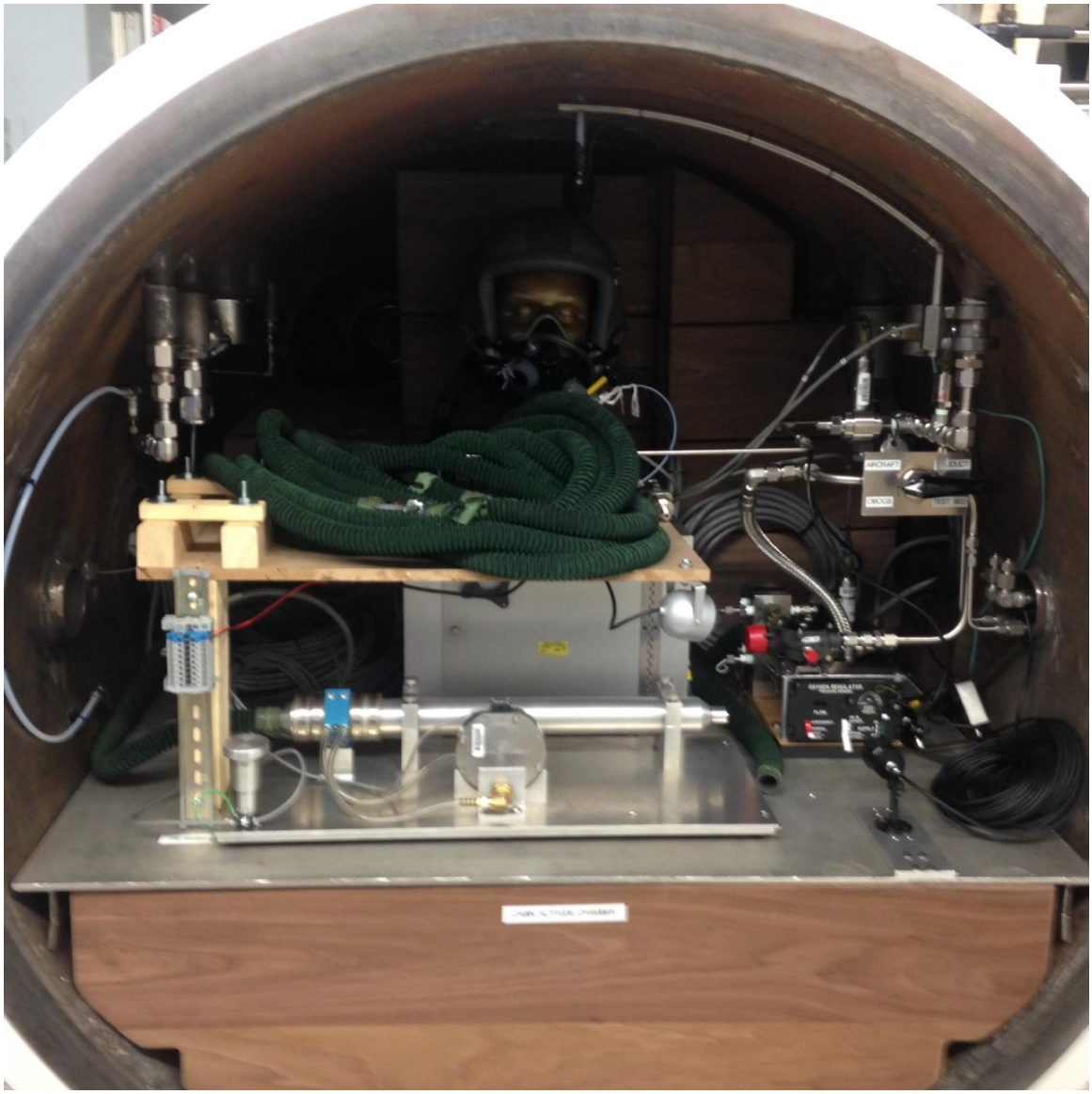
Photograph 1. 30 foot hose configuration shown inside the altitude chamber. The coiled hose configuration had a diameter of about 17"

Table 1. Test conditions for C-130J long breathing hose study

Altitude (Kft)	**Hose Lengths (feet)**	**Breathing Machine Settings: Peak Flow (Ambient Liters/Minute)/ (Breaths/Minute)**	**CRU-73 Regulator Settings**
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	60 ALPM/12 BPM	NORM, NORM, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	90 ALPM/50 BPM	NORM, NORM, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	125 ALPM/40 BPM	NORM, NORM, ON
Ground Level, 10, 14, 20 and 25	6, 18, 24, 30	150 ALPM/25 BPM	NORM, NORM, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	60 ALPM/12 BPM	EMER, NORM, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	90 ALPM/50 BPM	EMER, NORM, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	125 ALPM/40 BPM	EMER, NORM, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	150 ALPM/25 BPM	EMER, NORM, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	60 ALPM/12 BPM	EMER, 100%, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	90 ALPM/50 BPM	EMER, 100%, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	125 ALPM/40 BPM	EMER, 100%, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	150 ALPM/25 BPM	EMER, 100%, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	60 ALPM/12 BPM	NORM, 100%, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	90 ALPM/50 BPM	NORM, 100%, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	125 ALPM/40 BPM	NORM, 100%, ON
Ground Level, 10, 14, 20, and 25	6, 18, 24, 30	150 ALPM/25 BPM	NORM, 100%, ON

Photograph 2. Computer controlled breathing machine is shown

Photograph 3. On-Board Oxygen Generating System Laboratory is shown. The door to Altitude Chamber PV2 is open.



Photograph 4. C-130J equipment setup in altitude chamber PV2

Success criteria are noted in Tables 2 and 3 below. Compliance with the Air Standard requires the mask pressure data to fall within or on the curves defined by the Air Standard (upper curve for exhalation and lower curve for inhalation).

Table 2. Mask pressure success criteria for regulator settings of 1) NORM, NORM, ON; and 2) NORM, 100%, ON. (ASCC Air Standard 61/101/6A, Para. 10d)

Peak Inspiratory and Expiratory Flow (Ambient Liters/Minute)	Minimum Mask Cavity Pressure inches of Water gauge (mm Hg)	Maximum Mask Cavity Pressure inches of Water gauge (mm Hg)
30	-1.5 (-2.8)	+1.5 (+2.8)
90	-2.2 (-4.1)	+2.6 (+4.9)
150	-4.5 (-8.4)	+4.0 (+7.5)

Table 3. Mask pressure success criteria for regulator settings of 1) EMER, NORM, ON; and 2) EMER, 100%, ON. (ASCC Air Standard 61/101/6A, Para. 10d)

Peak Inspiratory and Expiratory Flow (Ambient Liters/Minute)	Minimum Mask Cavity Pressure inches of Water gauge (mm Hg)	Maximum Mask Cavity Pressure inches of Water gauge (mm Hg)
30	+0.1 (+0.2)	+3.0 (+5.6)
90	-0.8 (-1.5)	+3.8 (+7.1)
150	-3.5 (-6.5)	+5.0 (+9.3)

4.0 RESULTS

Mask pressure data and the Air Standard requirements (i.e. the basis for determining breathing resistance) are presented in Figures 1-5 for the CRU-73 aircrew regulator operating in Normal-Normal-On operating mode and hose lengths of 6 feet, 18 feet, 24 feet, and 30 feet. The data are also found in Appendices A-D. To achieve the Air Standard performance for breathing resistance the mask pressure data should lie between or on the Air Standard curves. Mask pressures of -20 mm Hg or lower are essentially considered "dry mask" conditions. The C-130J SPO reported the aircrew will use the operating mode of Normal-Normal-On. Further, the SPO reported the aircrew will sometimes use oxygen below a cabin altitude of 10,000 feet and always use oxygen at a cabin altitude of 10,000 feet and above. Tables 4-7 summarize the success criteria pass/fail results. Success criteria passing percentages for the study test conditions were: 1) 6 foot hose: 75% (For Informational Purposes Only); 2) 18 foot hose: 15%; 3) 24 foot hose: 5%; and 4) 30 foot hose: 0%. ASCC Air Standard 61/10B, "Developmental Test and Evaluation of Aircraft Oxygen Delivery Systems," Table 2, "Workloads" notes the relative workloads for the peak flows used in the study. The simulated workloads were: 1) 60 ALPM: Rest; 2) 90 ALPM: Light Work; 3) 125 ALPM: Moderate Work; and 4) 150 ALPM: Moderate Work.

In general, the data in Figures 1-5 and Tables 5-7 show the breathing resistances for the CRU-73 regulator and long breathing hoses (18 feet, 24 feet, and 30 feet) do not meet the Air Standard. Breathing resistance of any system is a function of regulator performance, oxygen mask performance, breathing hose length, and altitude. In general, as altitude increases, breathing resistance will decrease due to the lower density of the breathing gas at altitude.

Figure 1. Breathing resistance data for the CRU-73 regulator in Normal-Normal-On mode at Ground Level with various hose lengths (6 feet, 18 feet, 24 feet, and 30 feet)

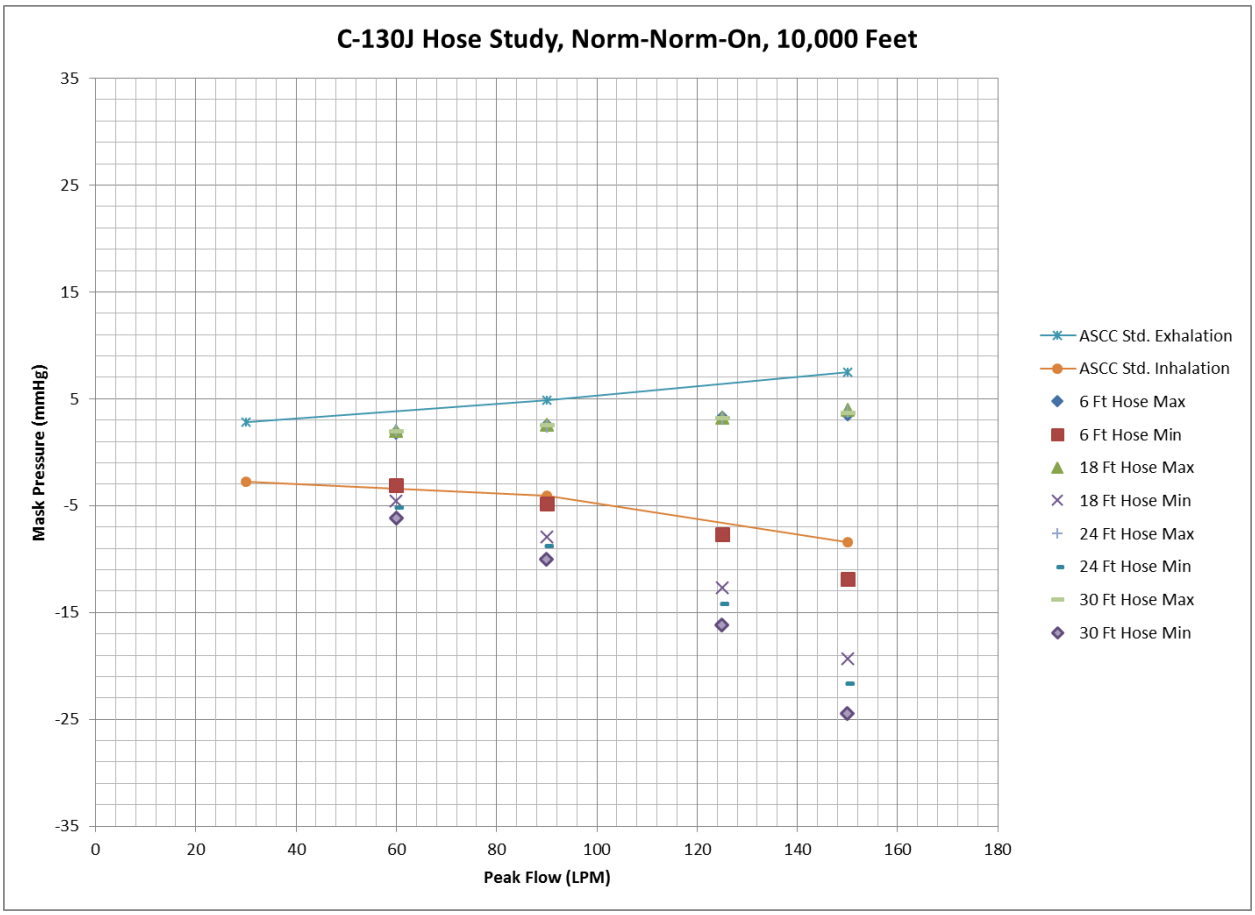


Figure 2. Breathing resistance data for the CRU-73 regulator in Normal-Normal-On mode at 10,000 feet with various hose lengths (6 feet, 18 feet, 24 feet, and 30 feet)

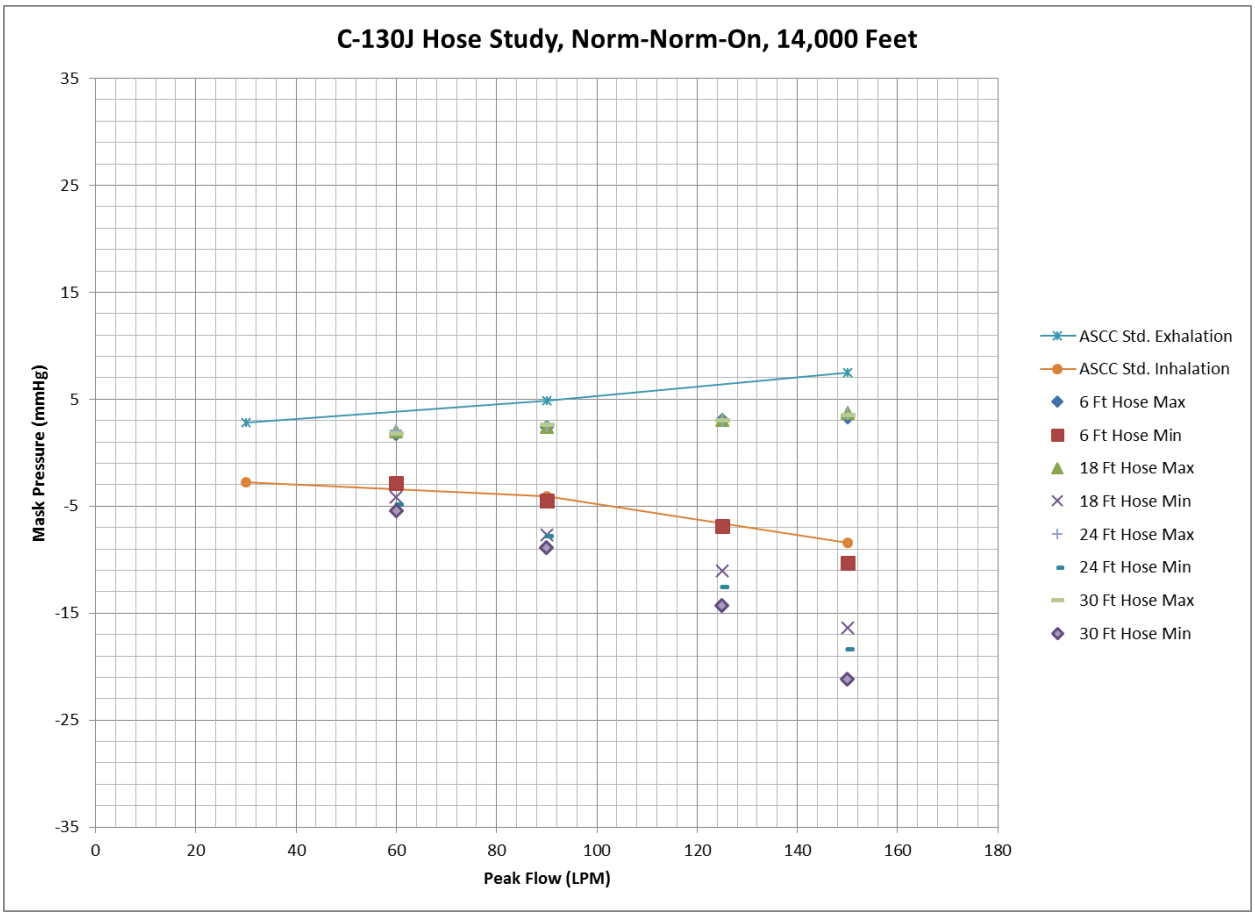


Figure 3. Breathing resistance data for the CRU-73 regulator in Normal-Normal-On mode at 14,000 feet with various hose lengths (6 feet, 18 feet, 24 feet, and 30 feet)

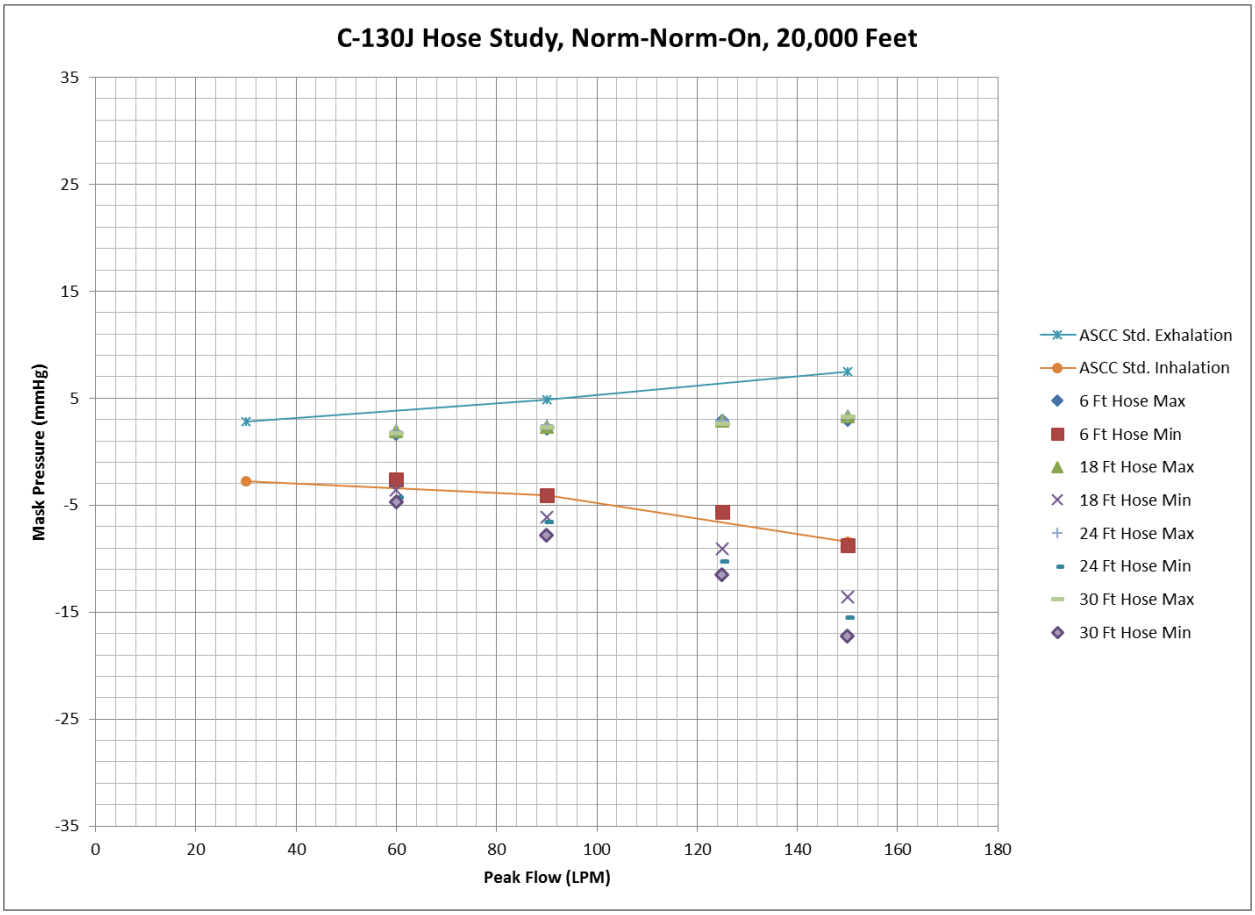


Figure 4. Breathing resistance data for the CRU-73 regulator in Normal-Normal-On mode at 20,000 feet with various hose lengths (6 feet, 18 feet, 24 feet, and 30 feet)

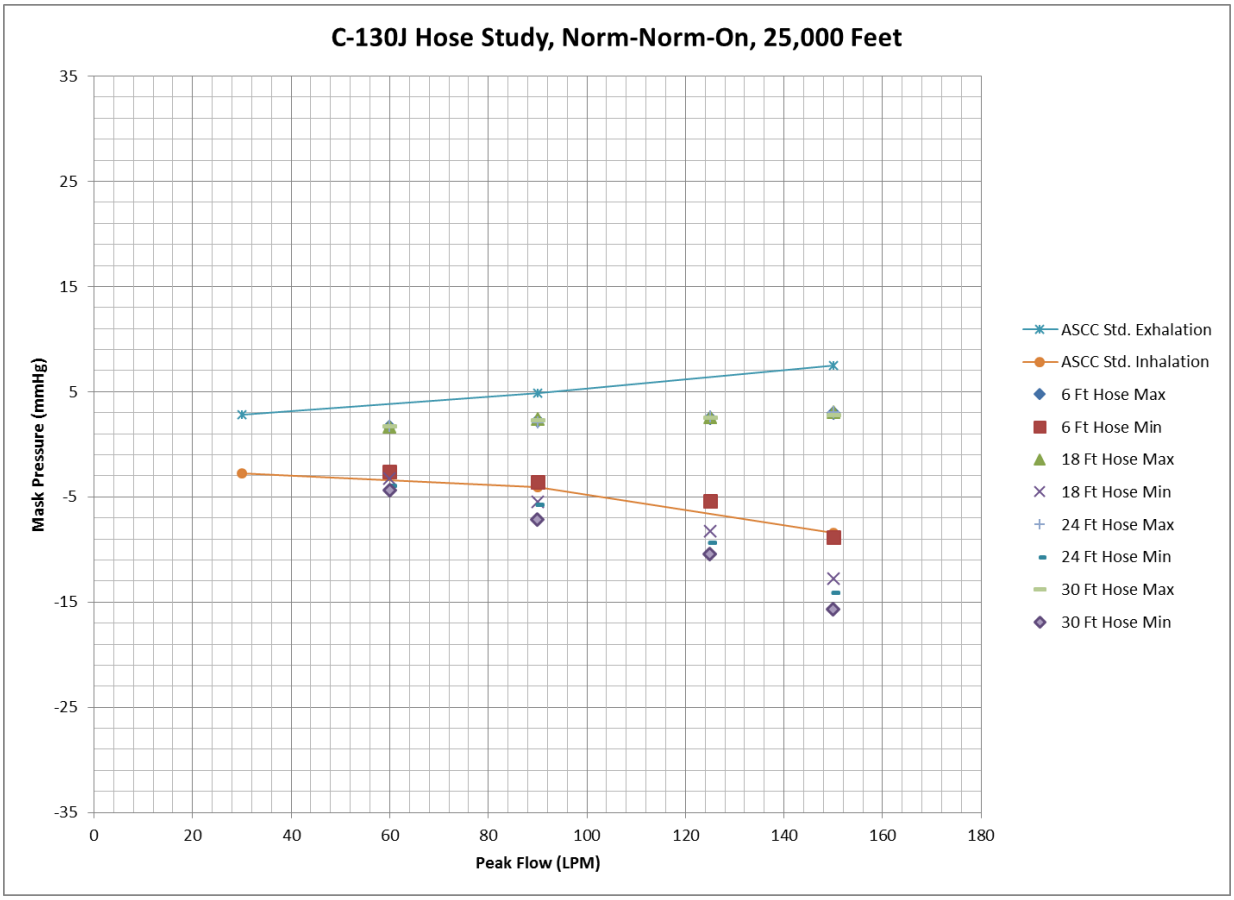


Figure 5. Breathing resistance data for the CRU-73 regulator in Normal-Normal-On mode at 25,000 feet with various hose lengths (6 feet, 18 feet, 24 feet, and 30 feet)

Table 4. Breathing Resistance Pass/Fail Results for the CRU-73 Oxygen Regulator in Normal-Normal-On and 6 Feet of Breathing Hose. (For Informational Purposes Only)

Peak Flow (ALPM)	Ground Level	10,000 feet	14,000 feet	20,000 feet	25,000 feet
60 (Rest)	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**
90 (Light Work)	Fail	**Pass**	**Pass**	**Pass**	**Pass**
125 (Moderate Work)	Fail	**Pass**	**Pass**	**Pass**	**Pass**
150 (Moderate Work)	Fail	Fail	Marginal	**Pass**	**Pass**

Table 5. Breathing Resistance Pass/Fail Results for the CRU-73 Oxygen Regulator in Normal-Normal-On and 18 Feet of Breathing Hose

Peak Flow (ALPM)	Ground Level	10,000 feet	14,000 feet	20,000 feet	25,000 feet
60 (Rest)	Fail	Marginal	**Pass**	**Pass**	**Pass**
90 (Light Work)	Fail	Fail	Fail	Fail	Marginal
125 (Moderate Work)	Fail	Fail	Fail	Fail	Fail
150 (Moderate Work)	Fail	Fail	Fail	Fail	Fail

Table 6. Breathing Resistance Pass/Fail Results for the CRU-73 Oxygen Regulator in Normal-Normal-On and 24 Feet of Breathing Hose

Peak Flow (ALPM)	Ground Level	10,000 feet	14,000 feet	20,000 feet	25,000 feet
60 (Rest)	Fail	Fail	Marginal	Marginal	**Pass**
90 (Light Work)	Fail	Fail	Fail	Fail	Marginal
125 (Moderate Work)	Fail	Fail	Fail	Fail	Fail
150 (Moderate Work)	Fail	Fail	Fail	Fail	Fail

Table 7. Breathing Resistance Pass/Fail Results for the CRU-73 Oxygen Regulator in Normal-Normal-On and 30 Feet of Breathing Hose

Peak Flow (ALPM)	Ground Level	10,000 feet	14,000 feet	20,000 feet	25,000 feet
60 (Rest)	Fail	Fail	Fail	Marginal	Marginal
90 (Light Work)	Fail	Fail	Fail	Fail	Fail
125 (Moderate Work)	Fail	Fail	Fail	Fail	Fail
150 (Moderate Work)	Fail	Fail	Fail	Fail	Fail

5.0 CONCLUSION

The C-130J oxygen system with CRU-73 breathing regulator and MBU-20/P mask when operated with long breathing hoses (18 feet, 24 feet, and 30 feet) does not meet the breathing resistance standards stated in ASCC Air Standard 61/101/6A, Para. 10d under a significant majority of test conditions.

LIST OF ABBREVIATIONS AND ACRONYMS

ABO	Aviators' Breathing Oxygen
ALPM	Ambient Liters/Minute
ASCC	Air Standardization Coordinating Committee
BPM	Breaths/Minute
EMER	Regulator Emergency Operating Mode
NORM	Regulator Normal Operating Mode
OBOGS	On-Board Oxygen Generating System

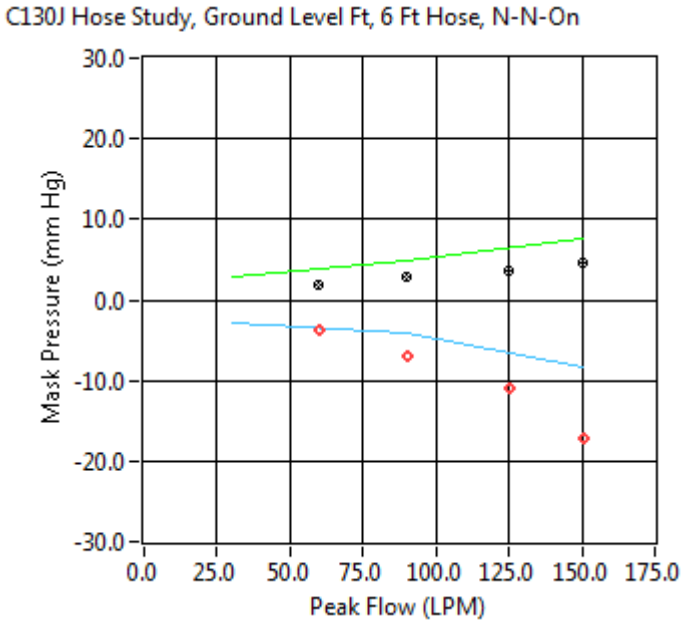
REFERENCES

1. Air Standardization Coordinating Committee (ASCC) Air Standard 61/101/6A, "Minimum Physiological Requirements for Aircrew Demand Breathing Systems," 16 February 2000.

2. ASCC Air Standard 61/10B, "Developmental Test and Evaluation of Aircraft Oxygen Delivery Systems," 18 August 1982.

Appendix A
CRU-73 Breathing Resistance Data: 6’ Hose Length

Figure A-1



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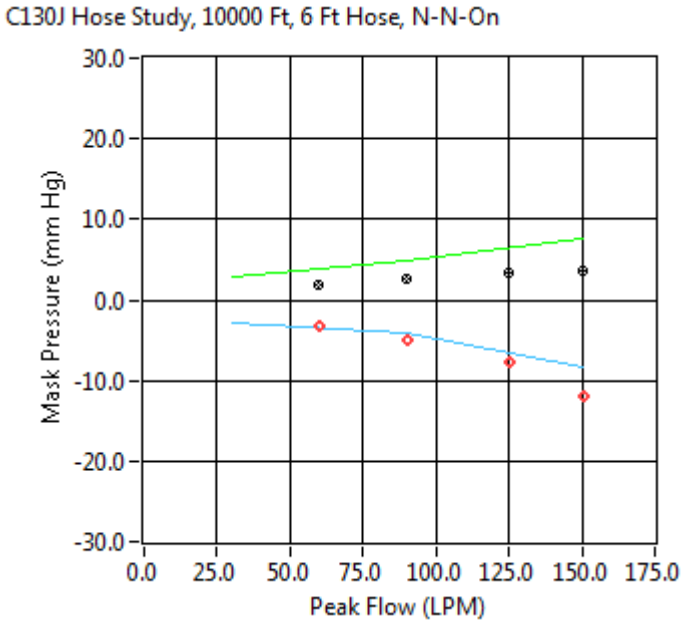

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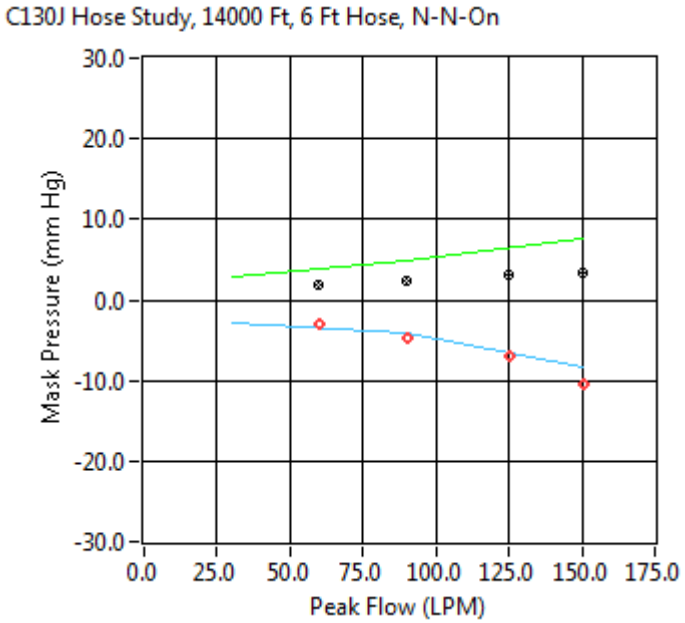

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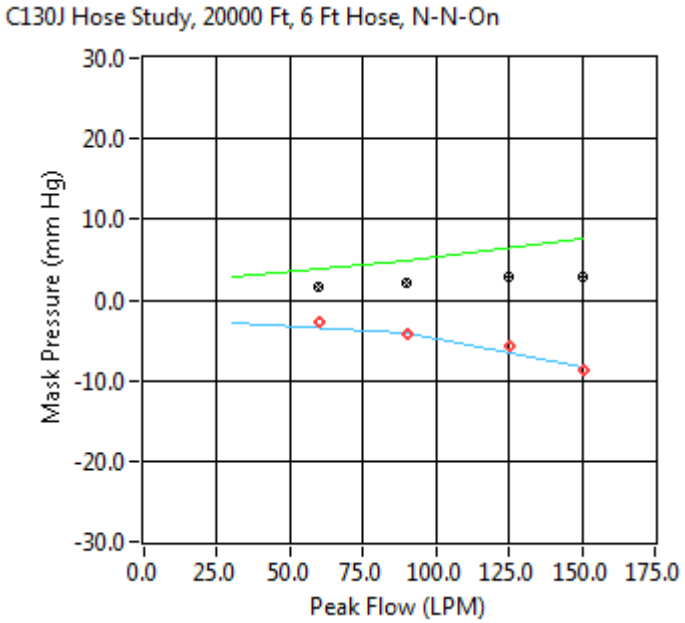

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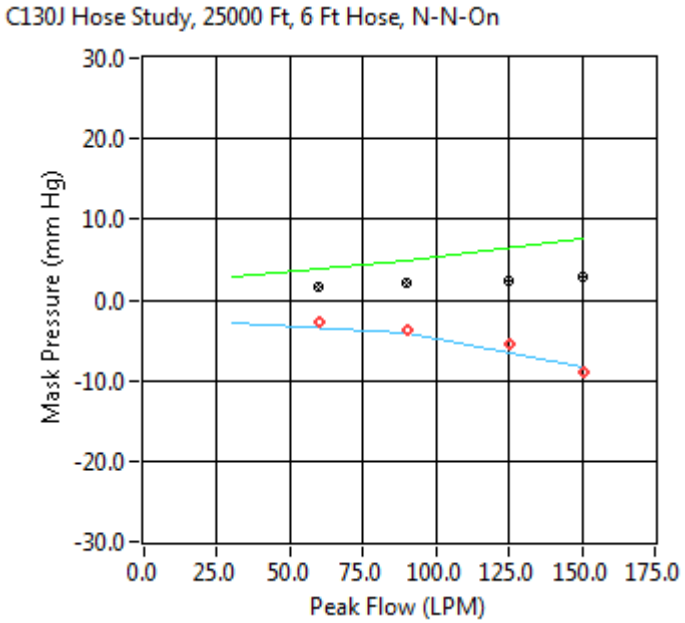

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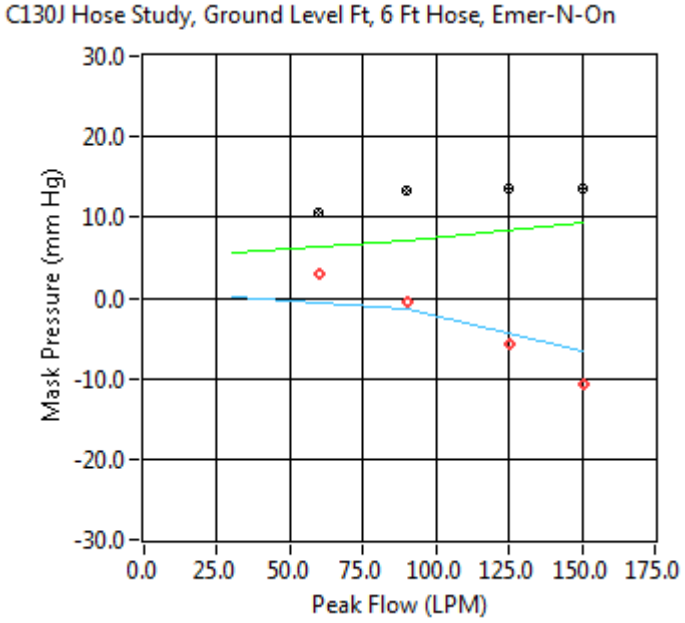

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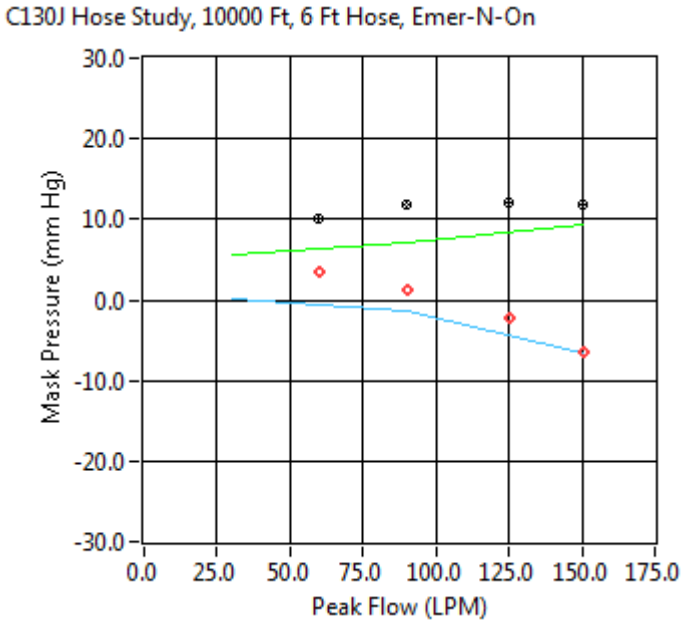

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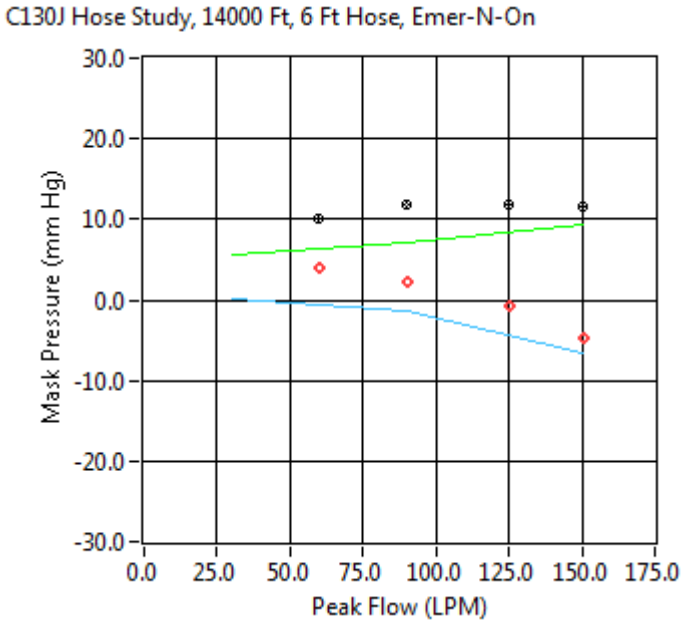

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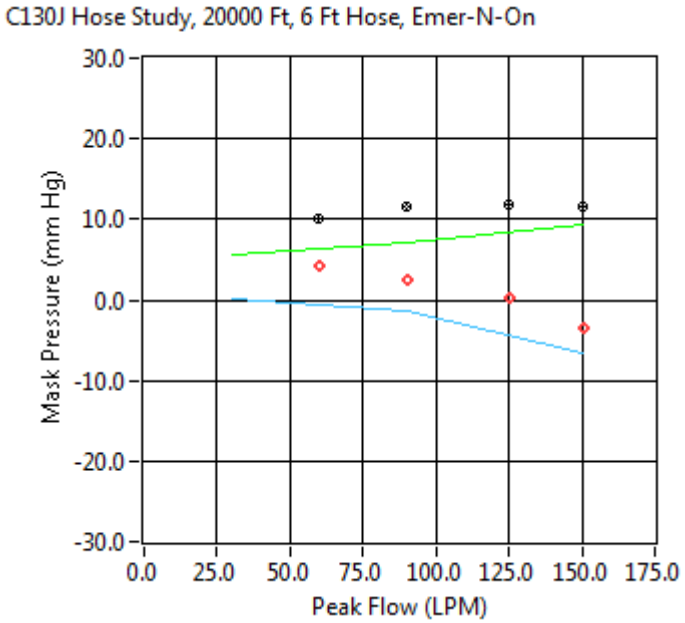

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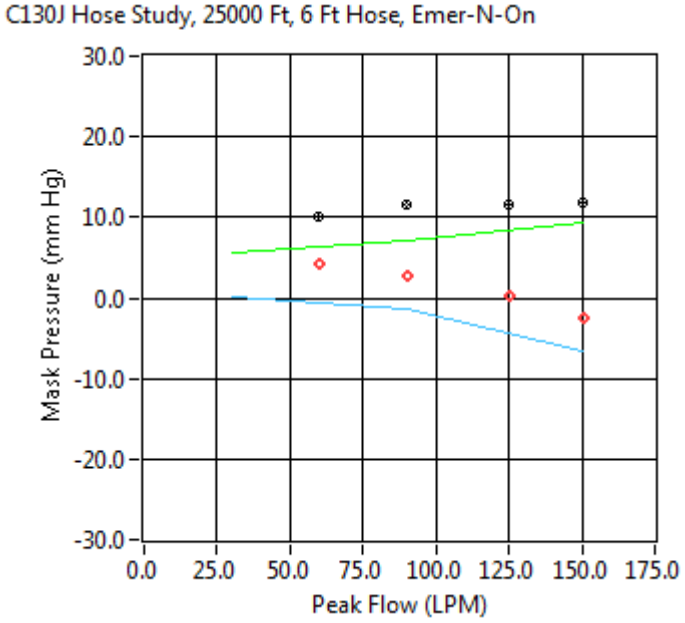

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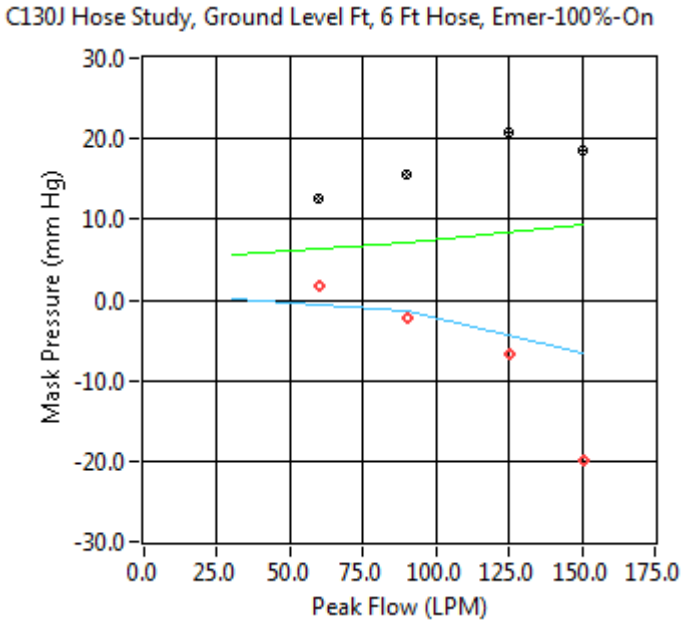

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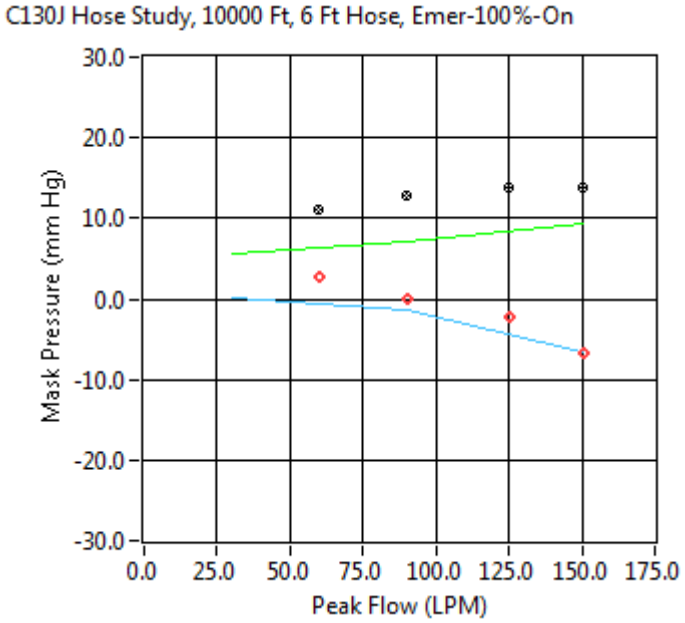

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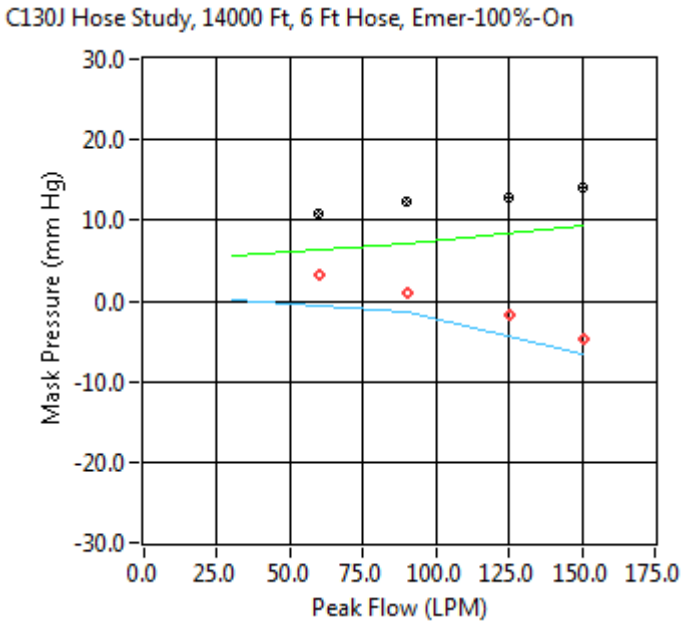

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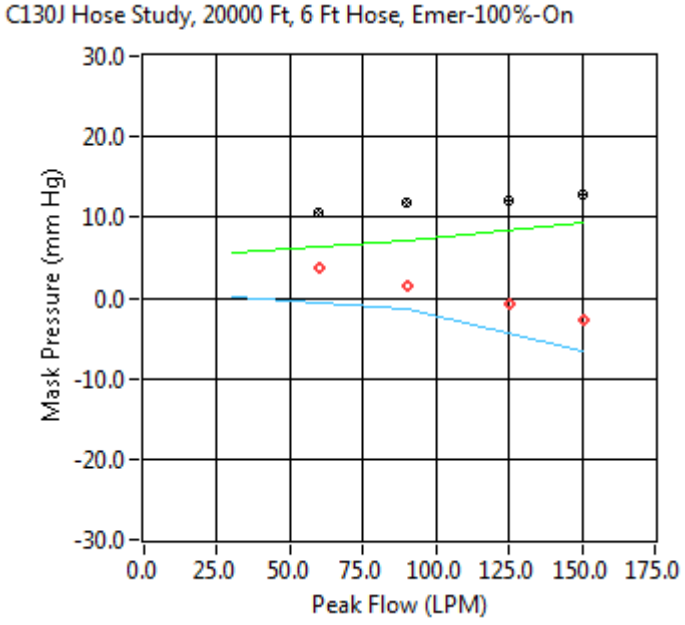

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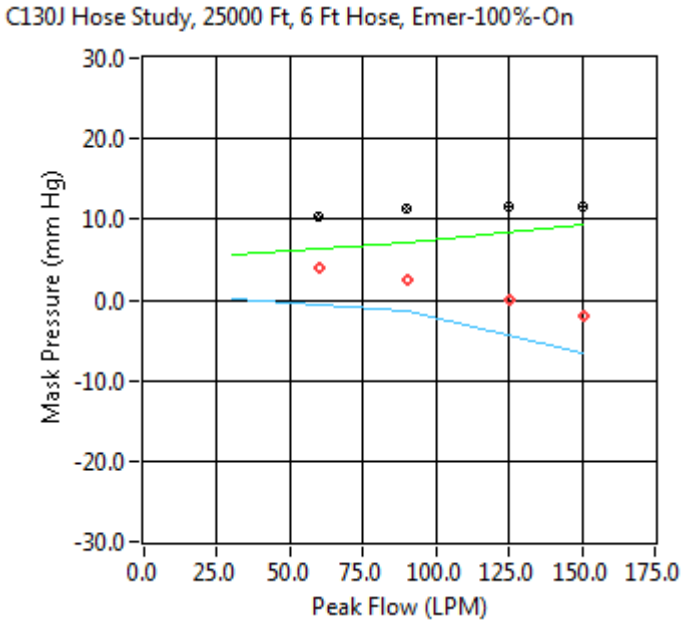

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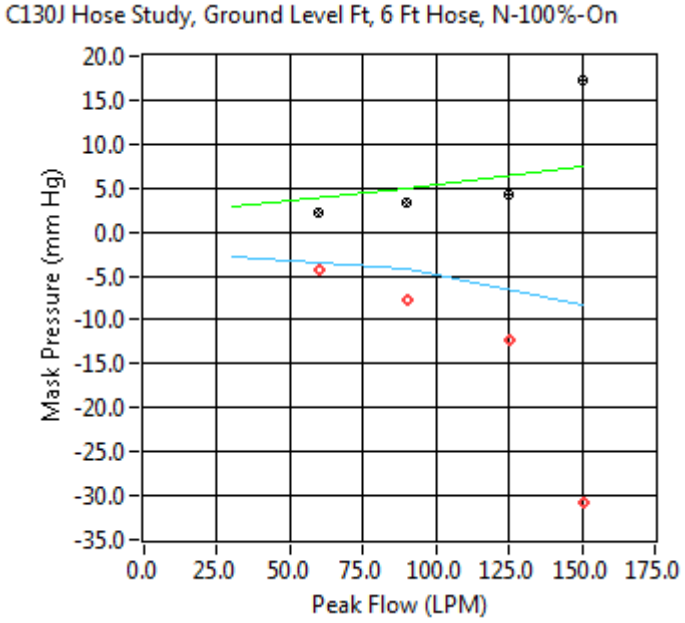

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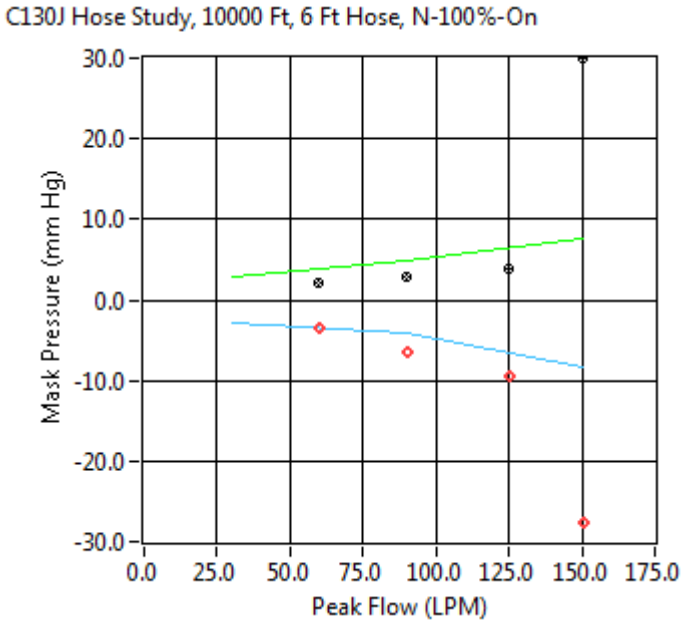

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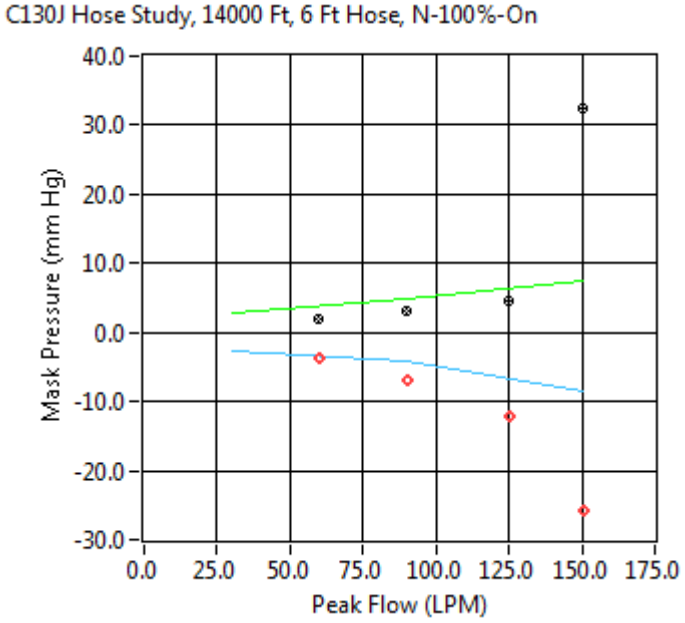


Figure A-19

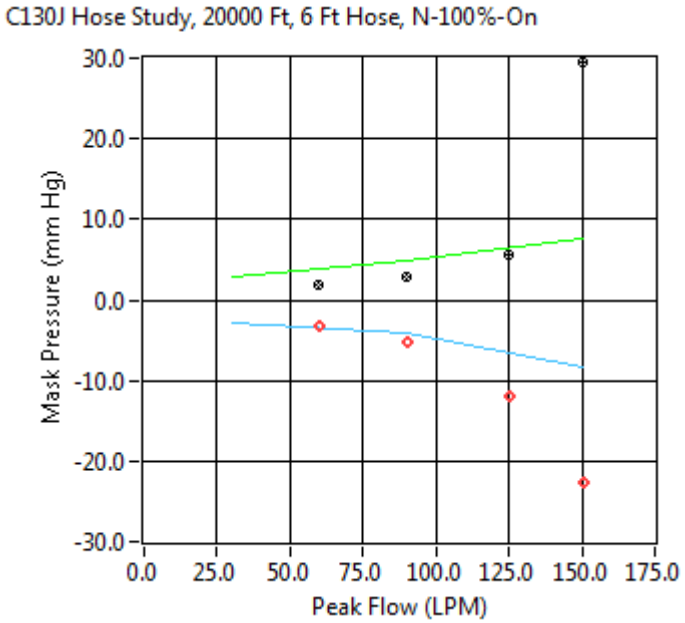
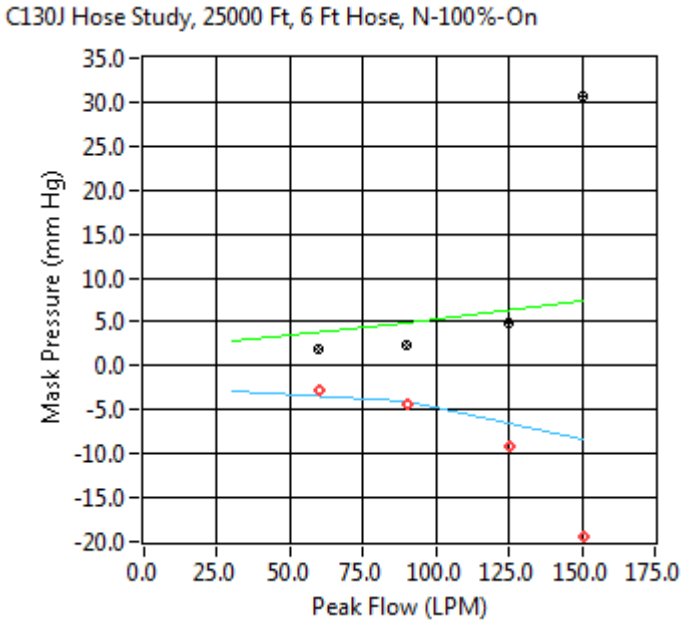


Figure A-20



Appendix B
CRU-73 Breathing Resistance Data: 18’ Hose Length

Figure B-1

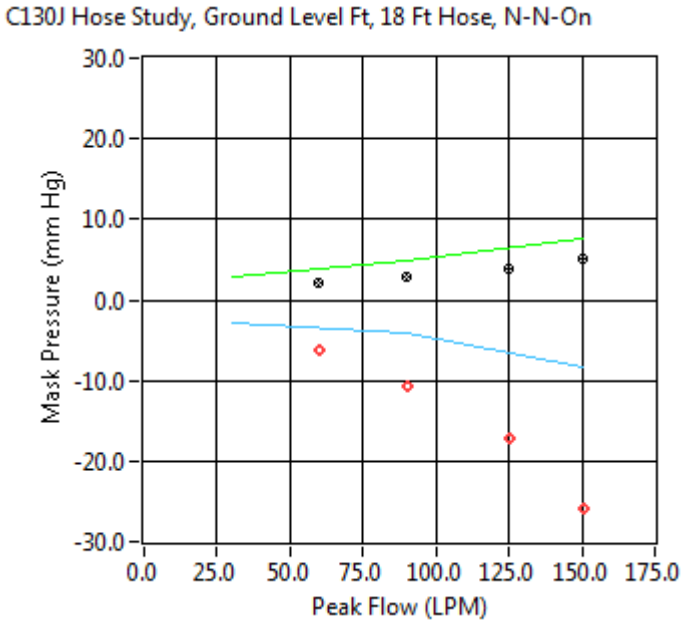


Figure B-2

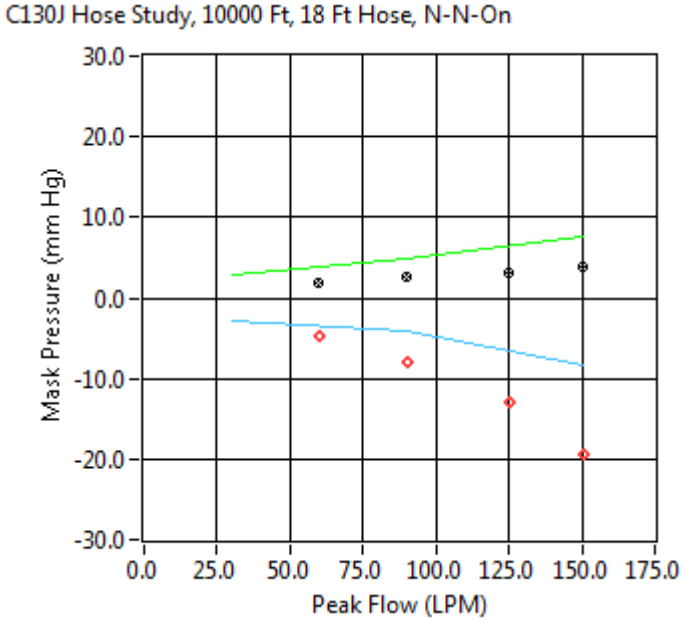
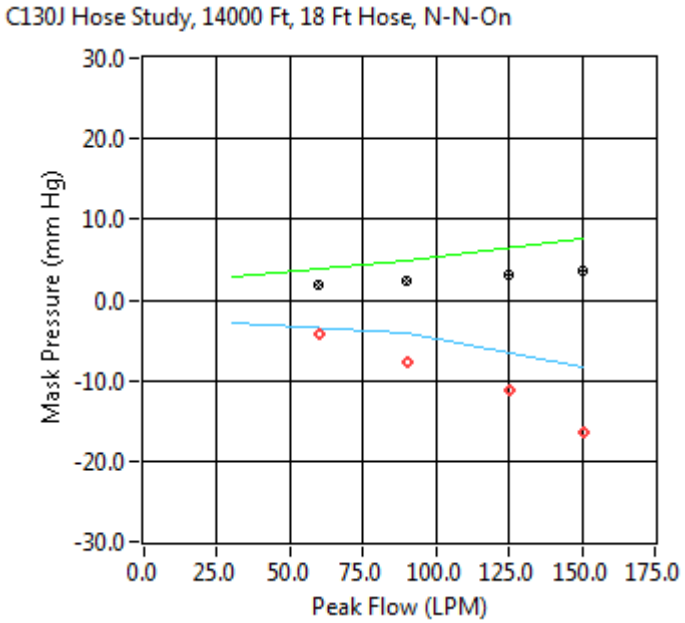


Figure B-3



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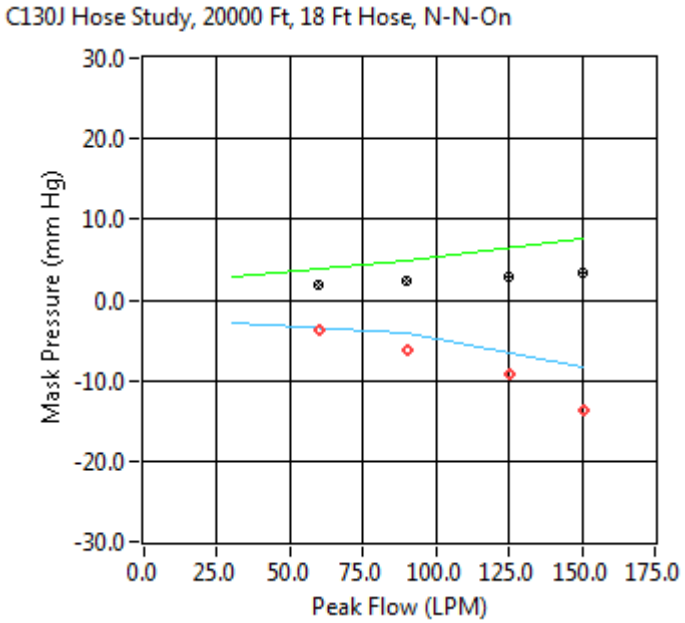

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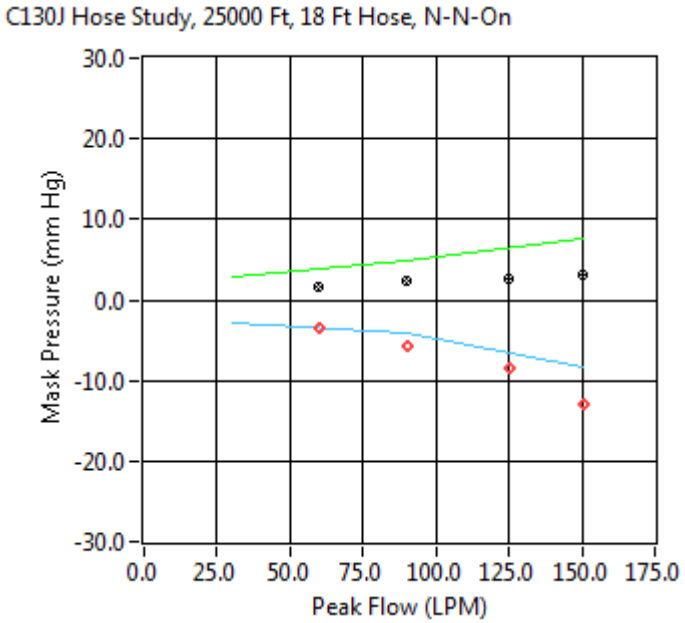


Figure B-6

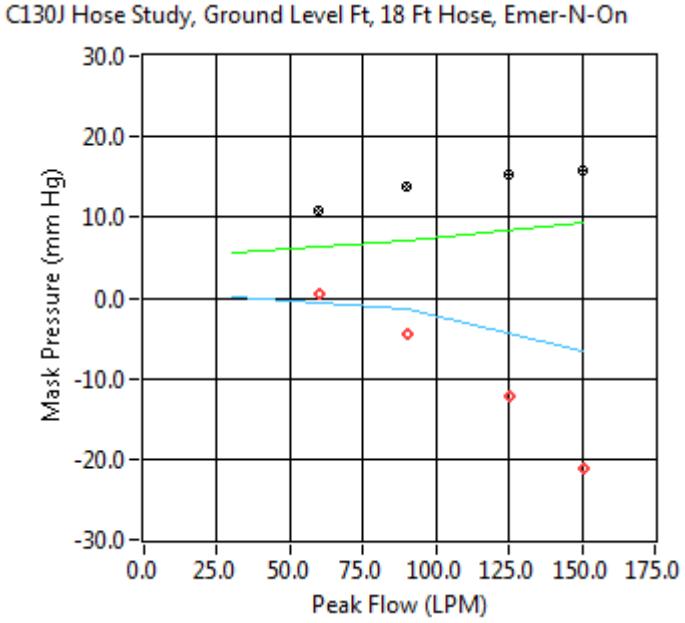


Figure B-7

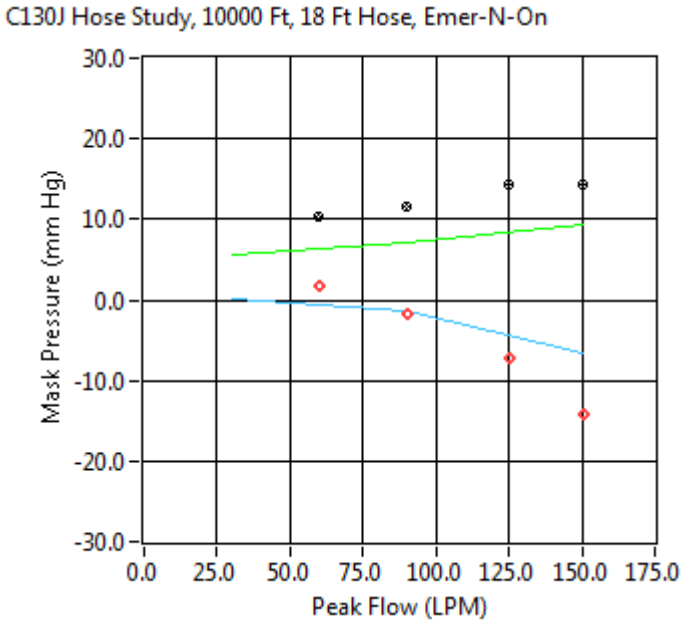


Figure B-8

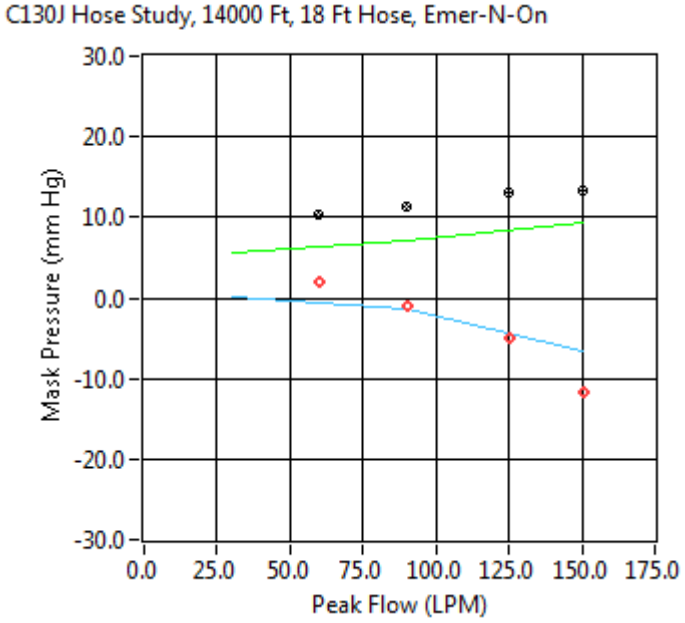
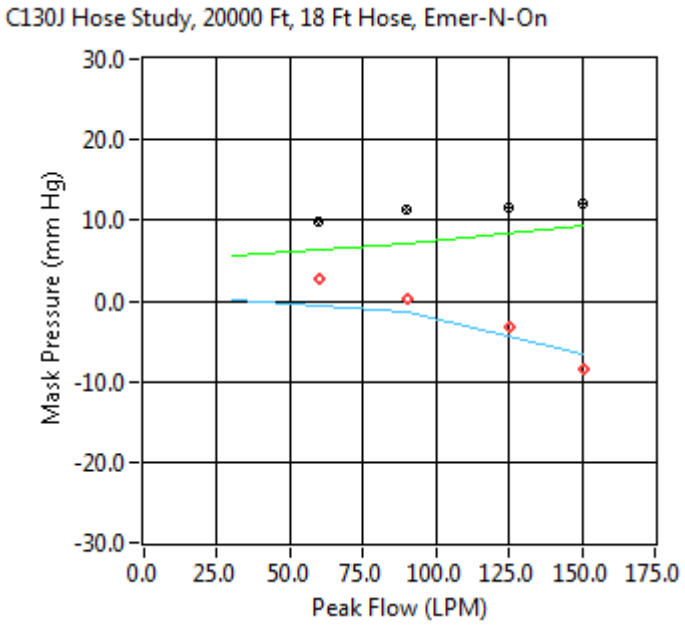


Figure B-9



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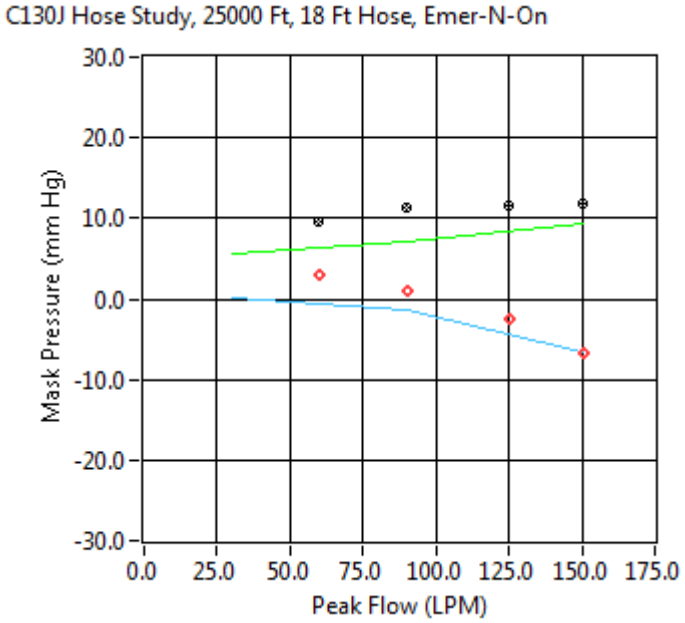
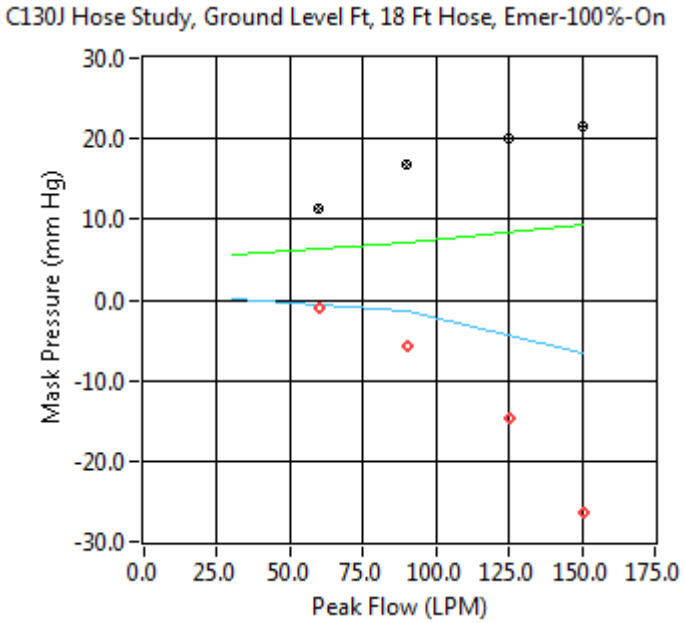


Figure B-11



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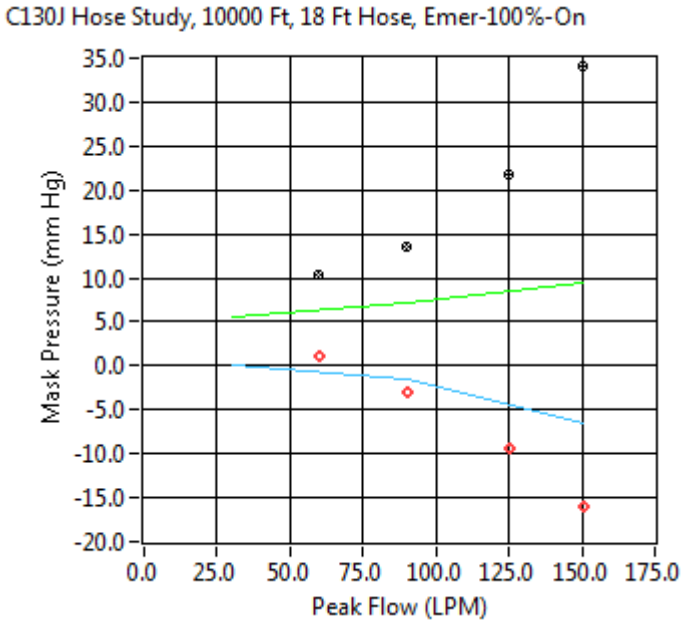
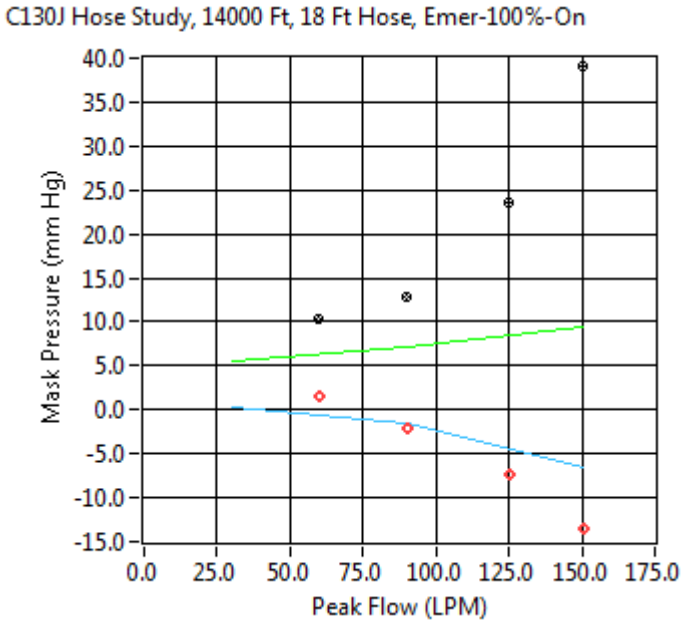


Figure B-13



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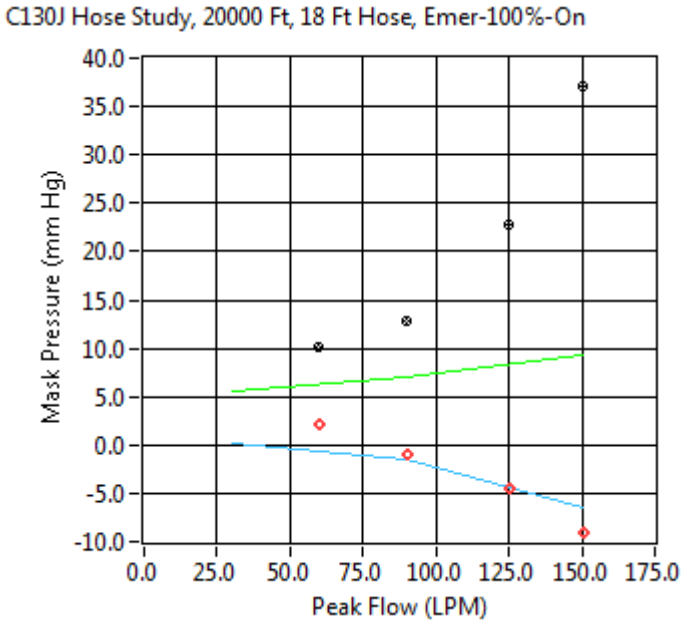


Figure B-15

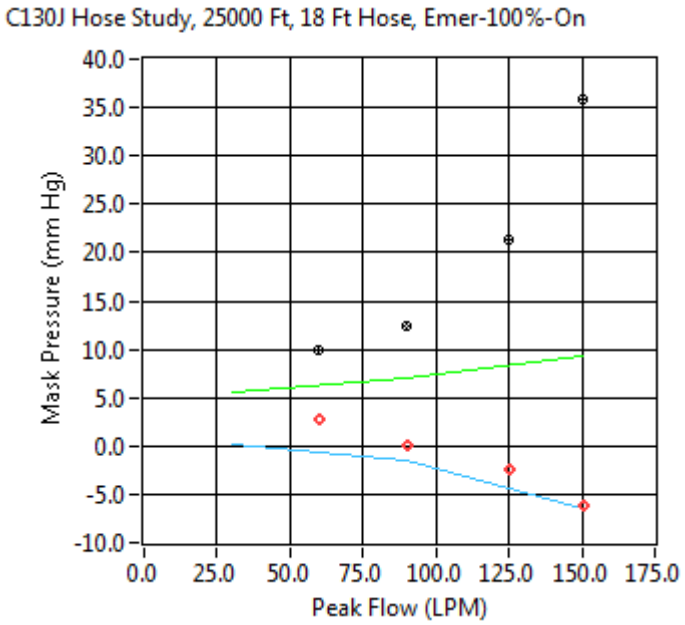


Figure B-16

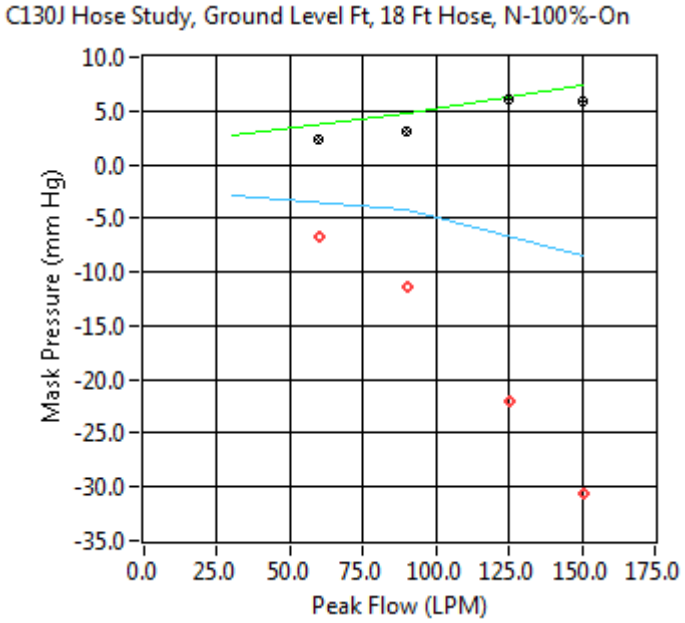


Figure B-17

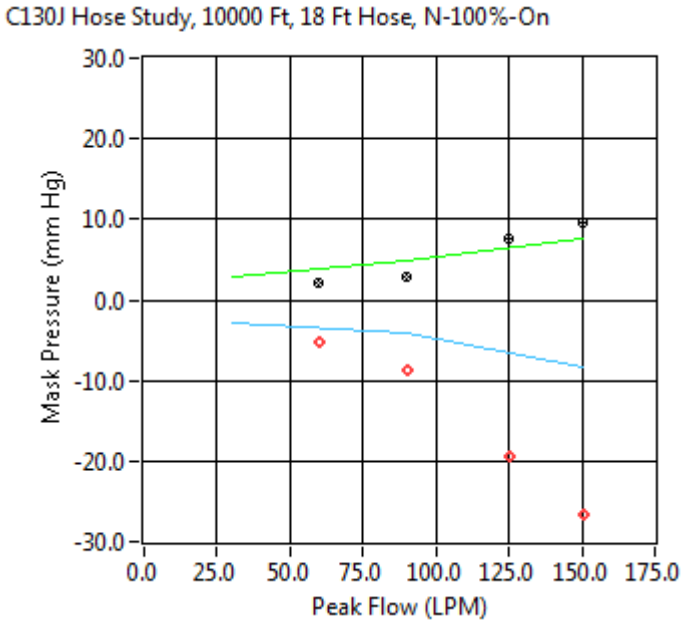


Figure B-18

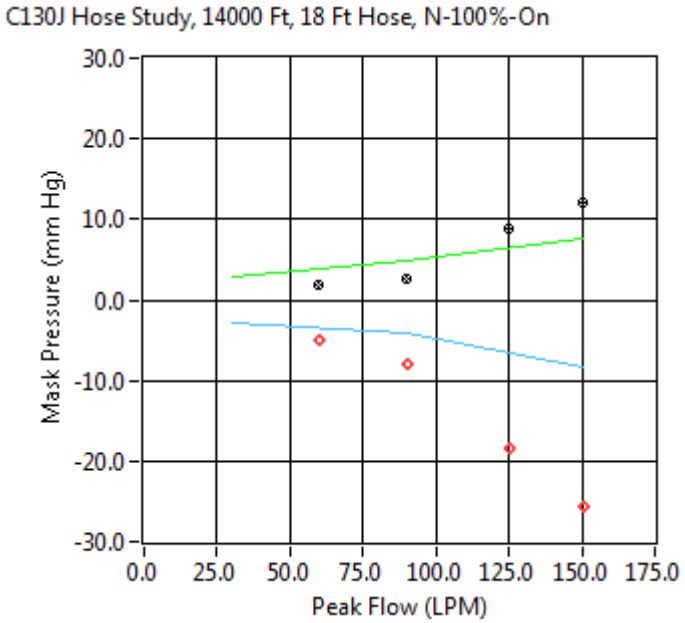


Figure B-19

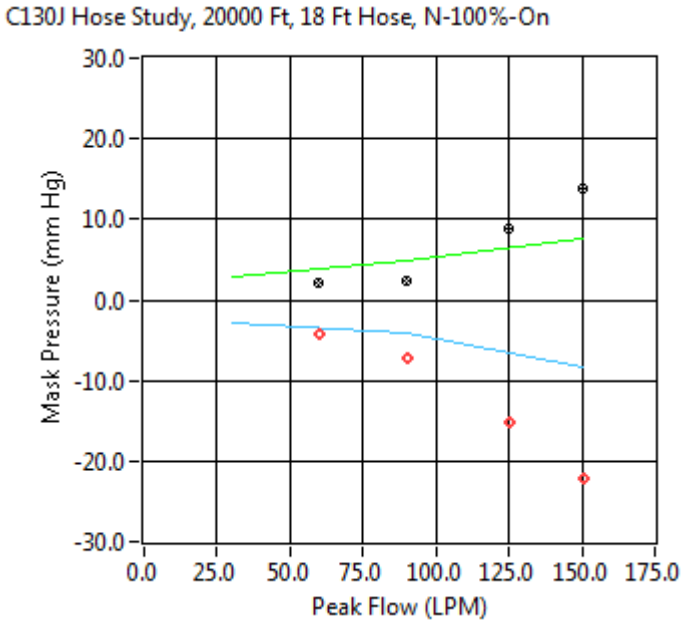
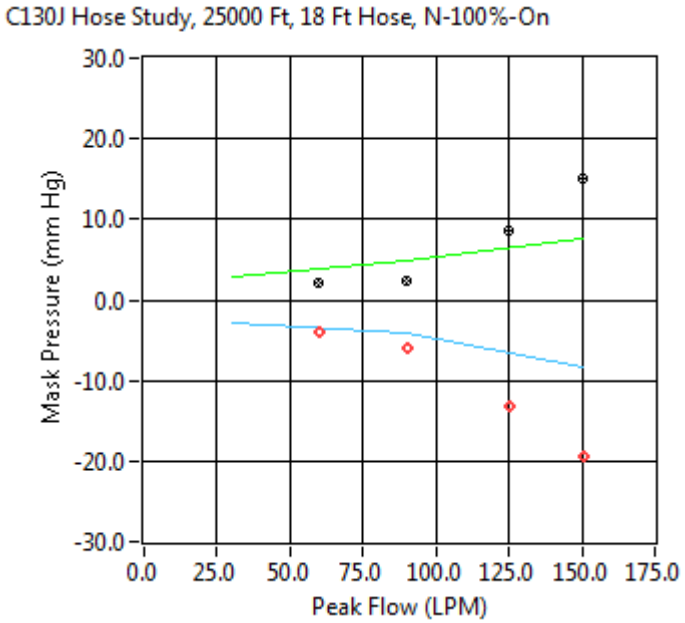


Figure B-20



Appendix C
CRU-73 Breathing Resistance Data: 24’ Hose Length

Figure C-1

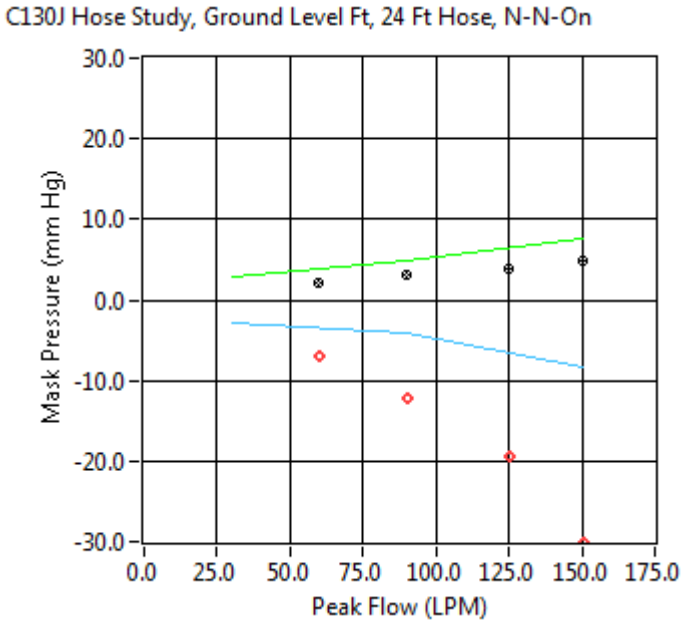


Figure C-2

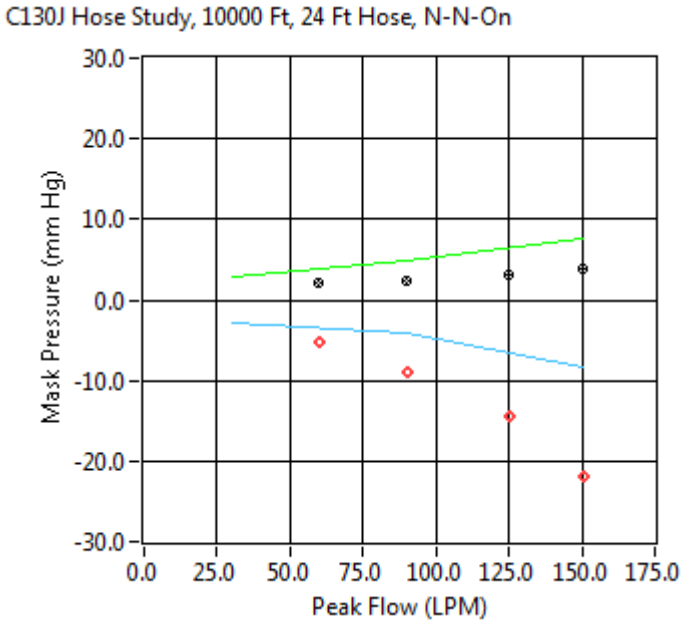


Figure C-3

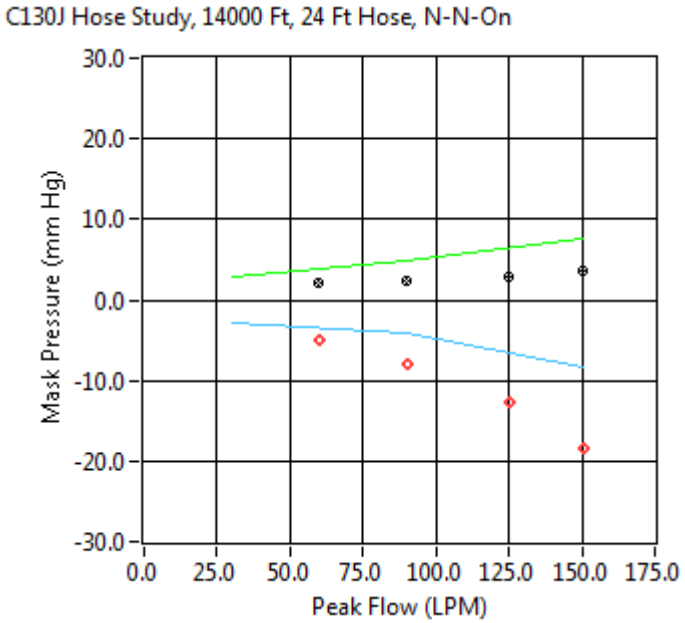


Figure C-4

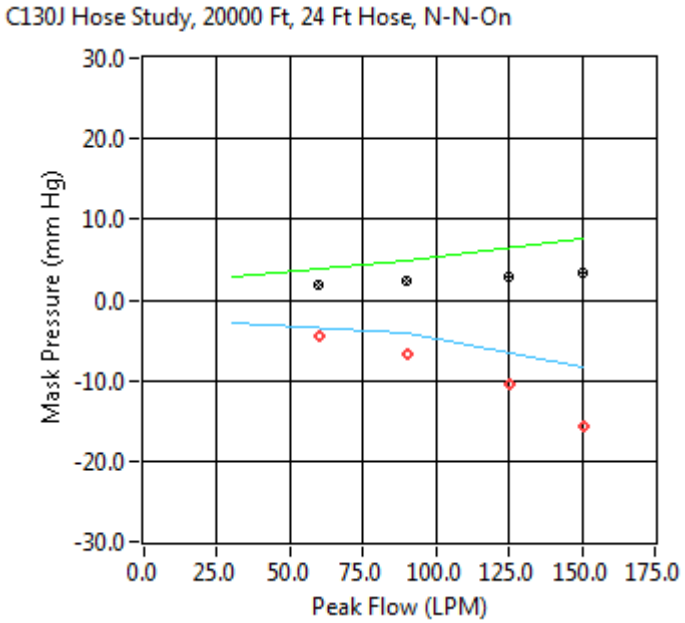


Figure C-5

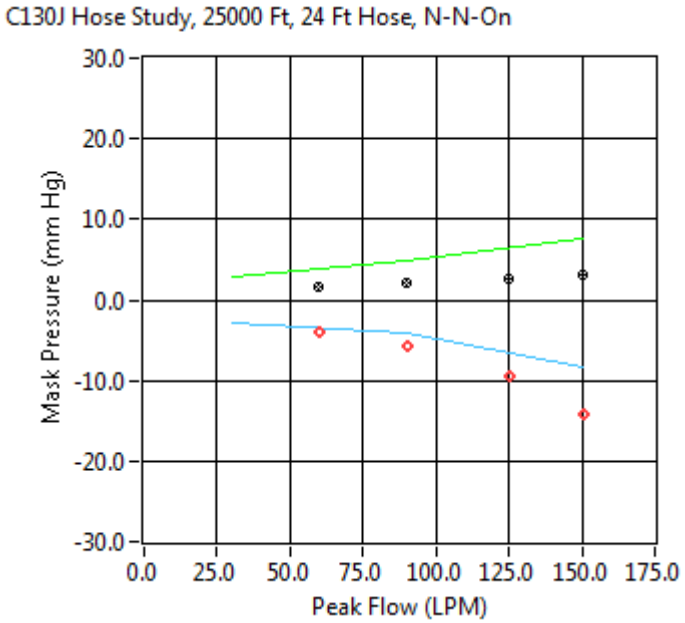


Figure C-6

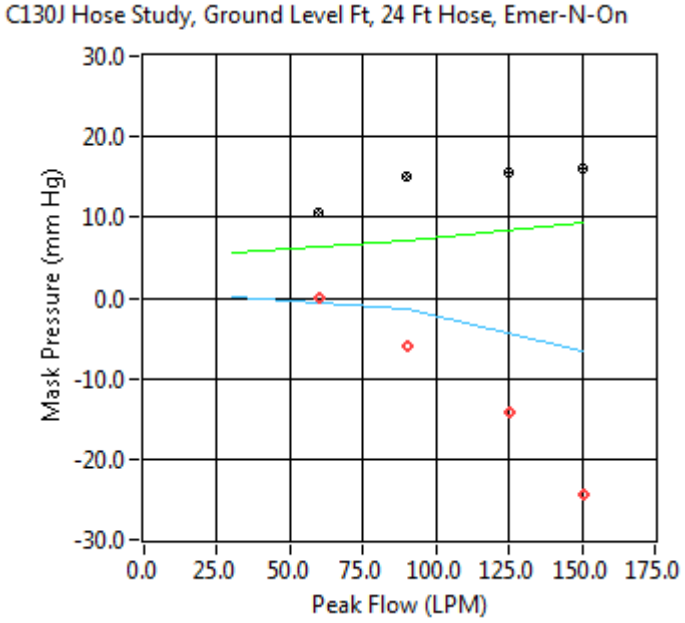


Figure C-7

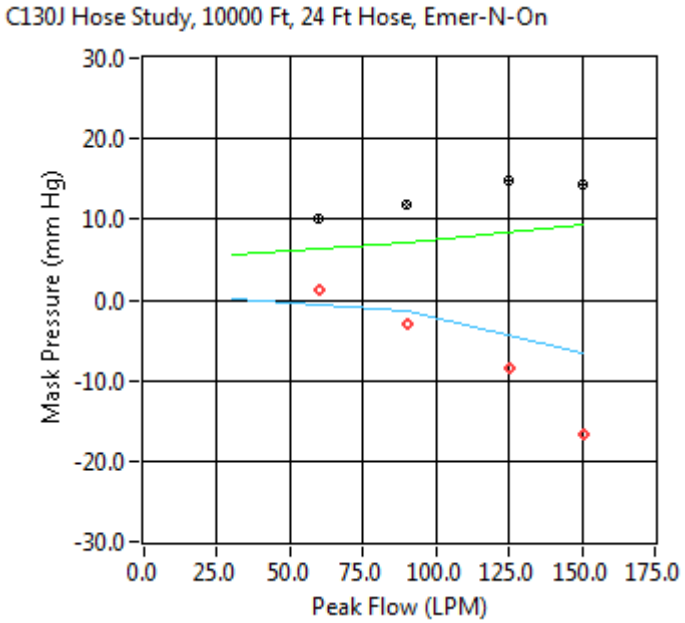


Figure C-8

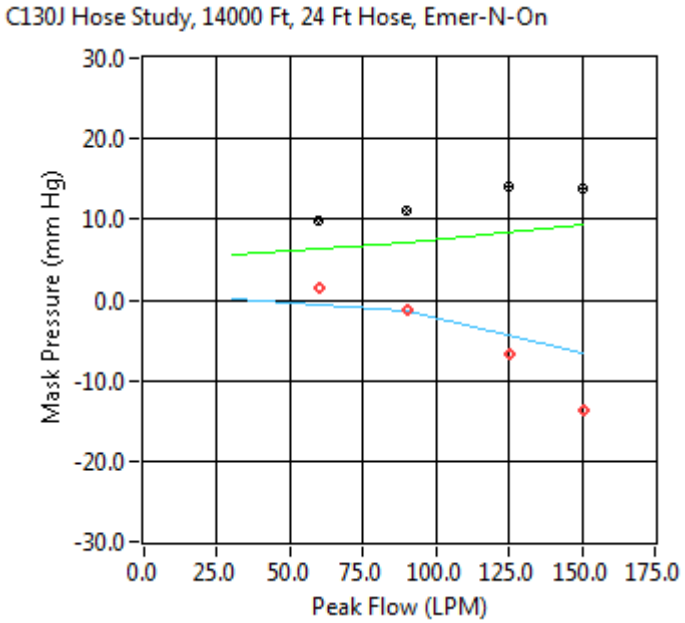


Figure C-9

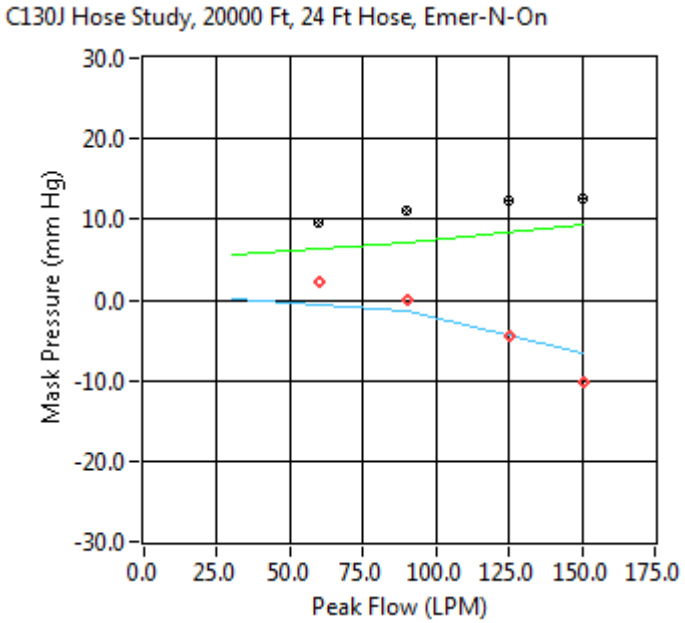
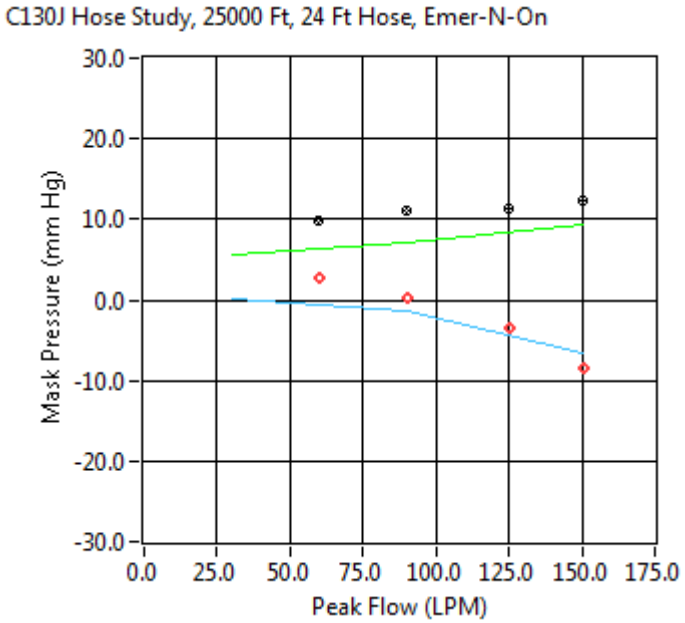


Figure C-10



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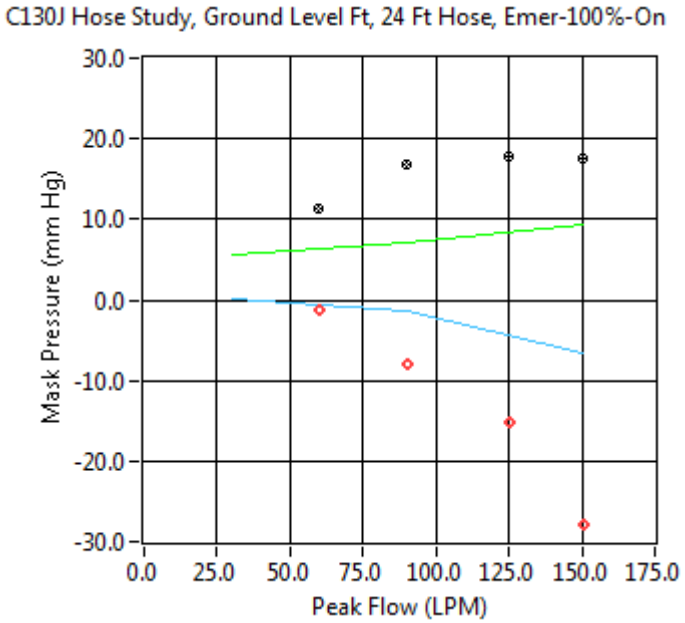


Figure C-12

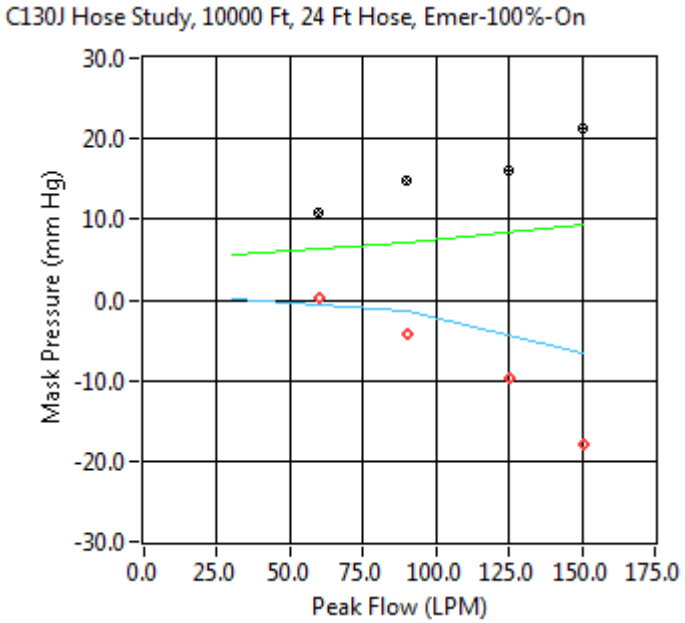


Figure C-13

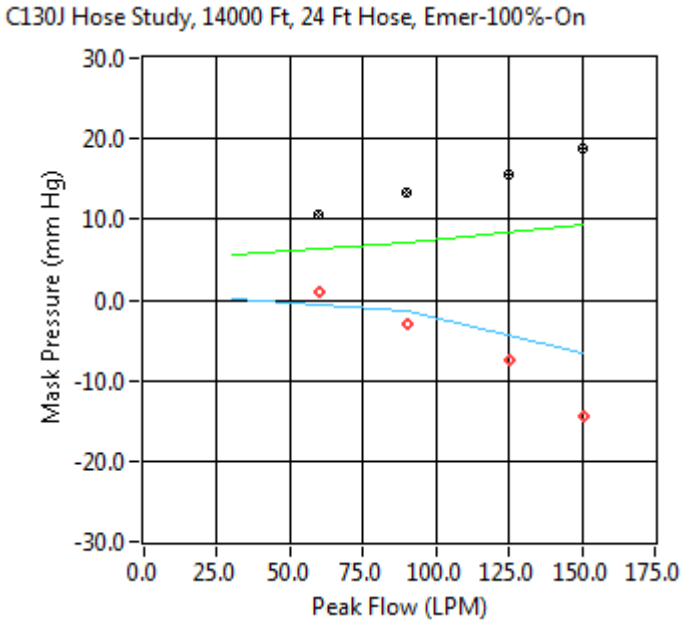


Figure C-14

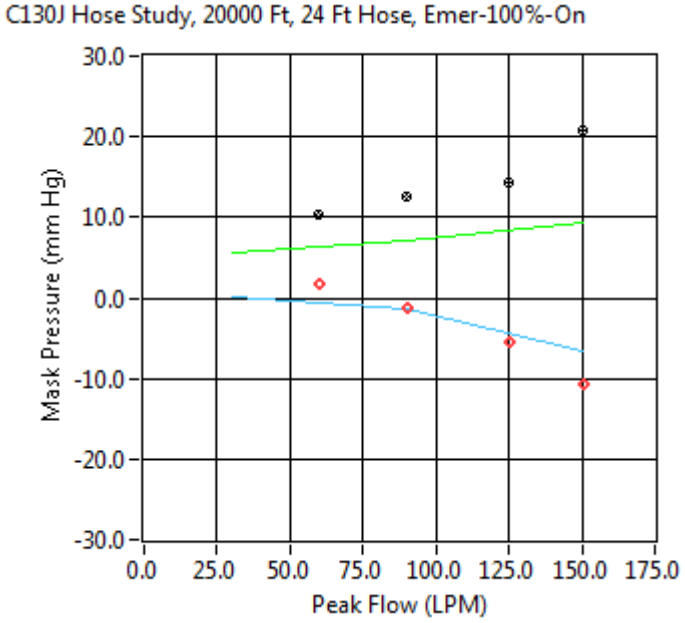


Figure C-15

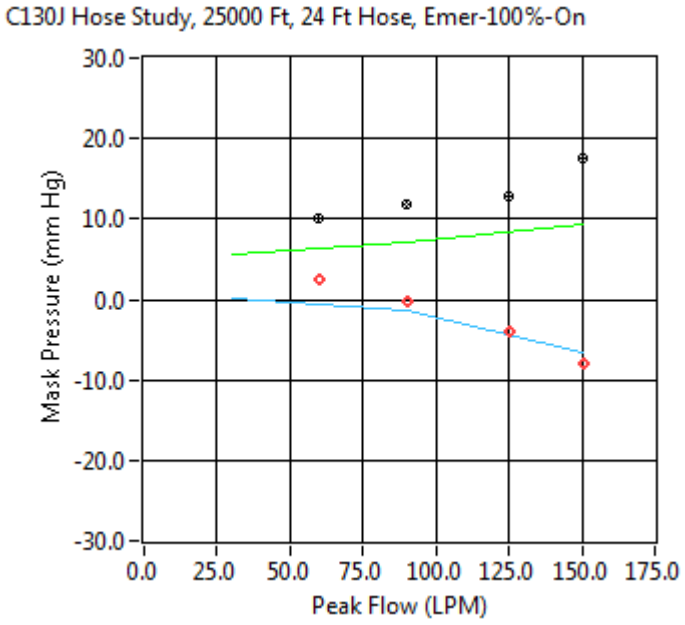


Figure C-16

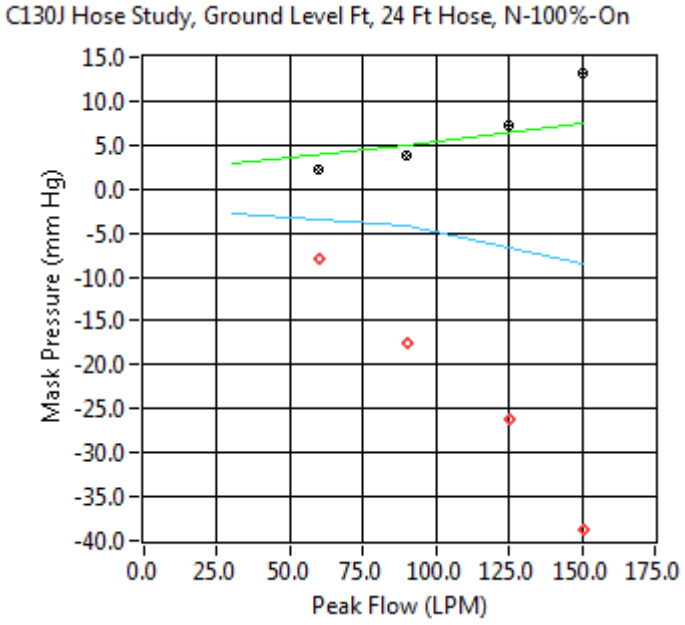


Figure C-17

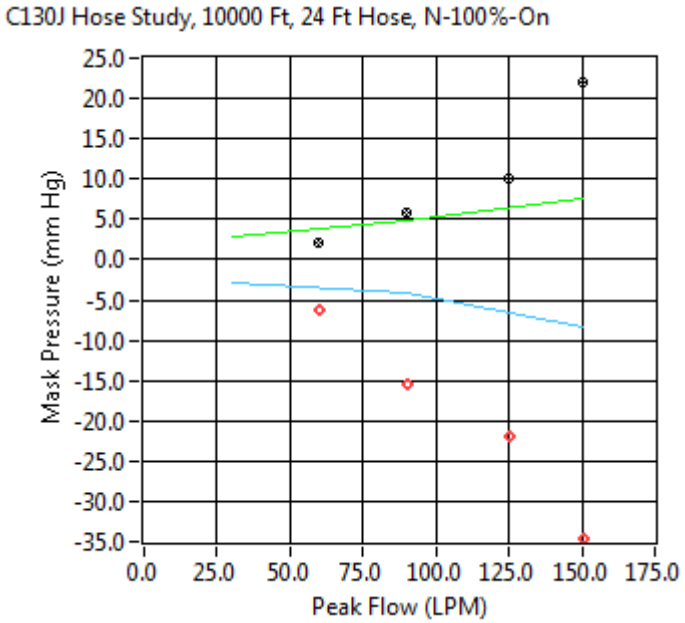


Figure C-18

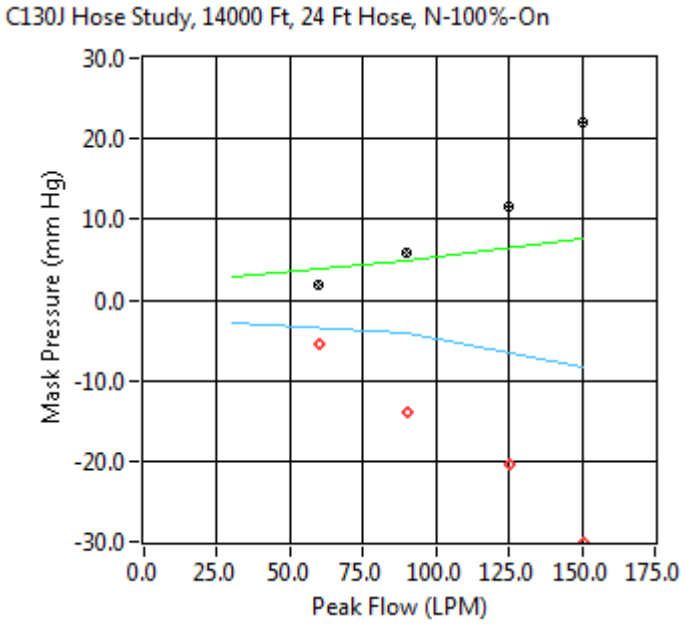


Figure C-19

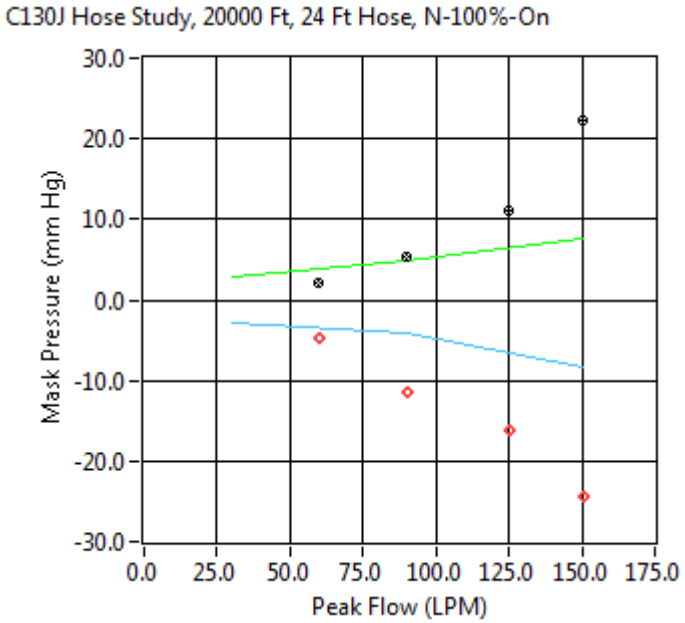
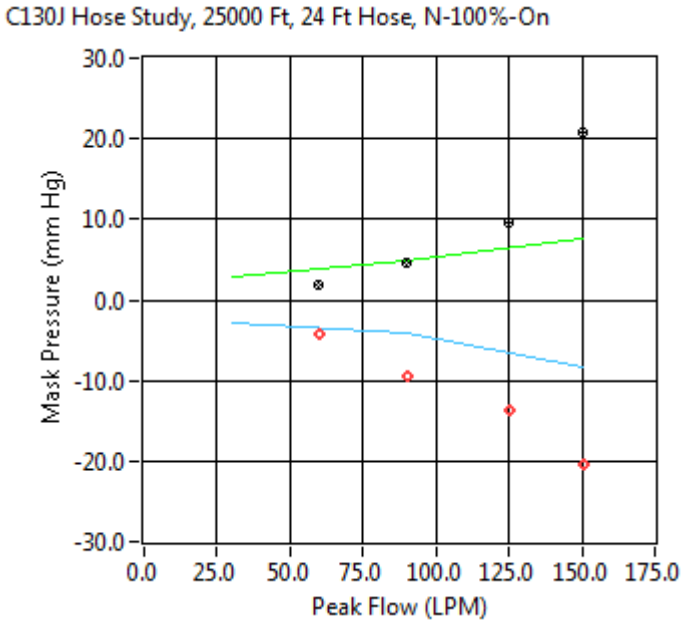


Figure C-20



Appendix D
CRU-73 Breathing Resistance Data: 30’ Hose Length

Figure D-1

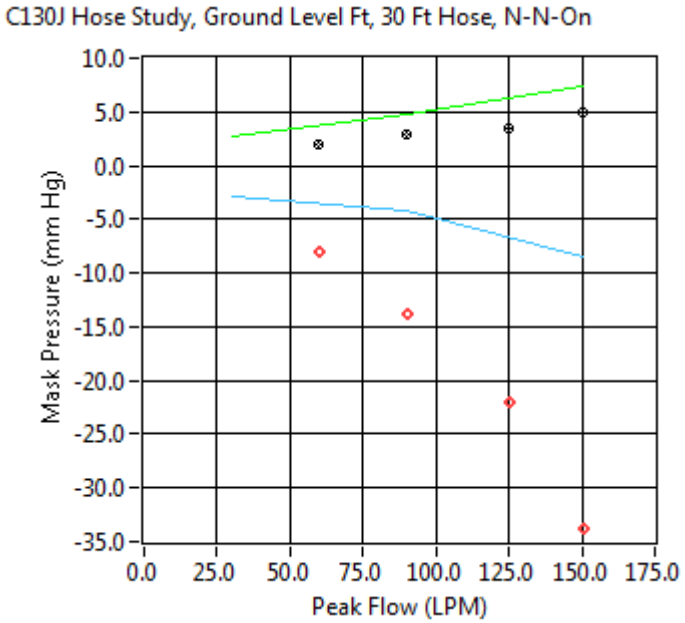


Figure D-2

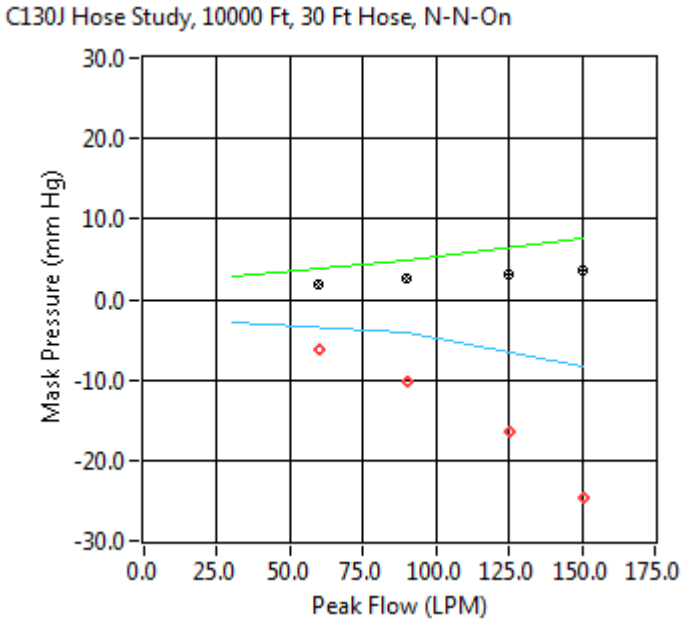


Figure D-3

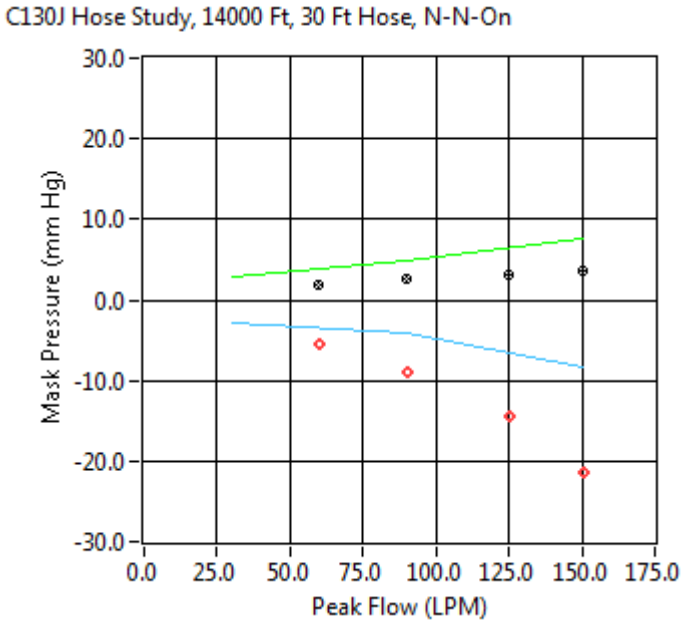


Figure D-4

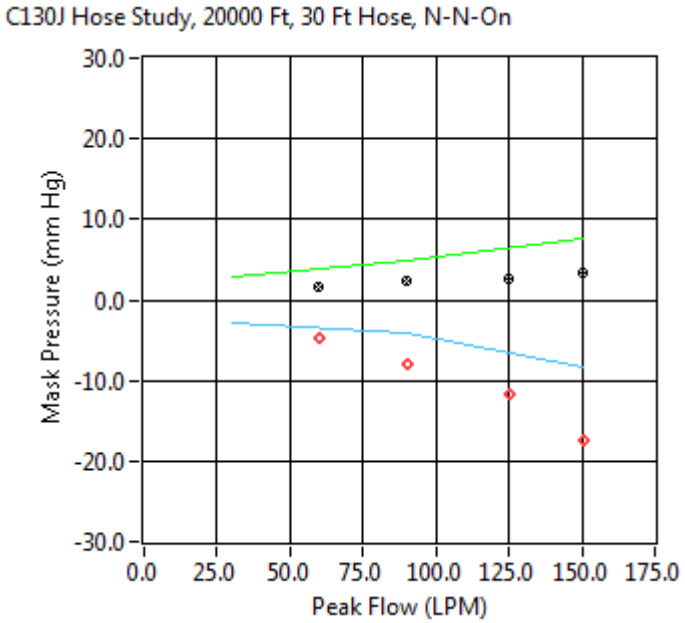


Figure D-5

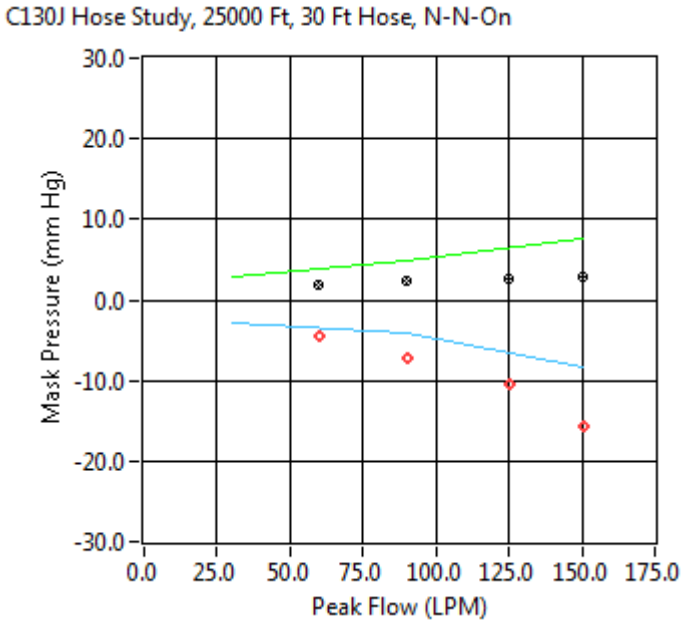


Figure D-6

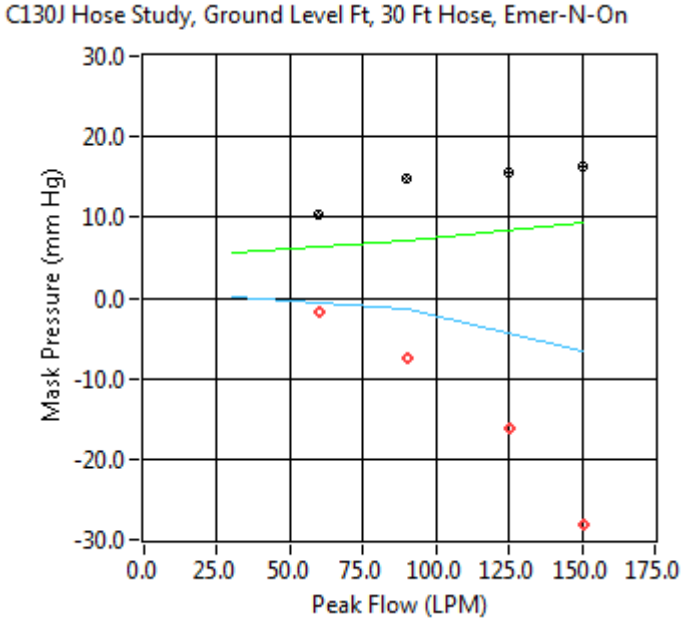


Figure D-7

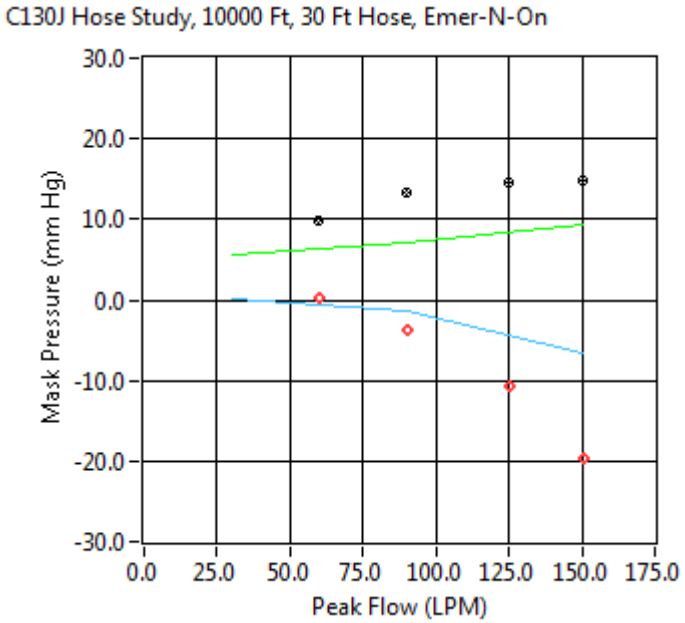


Figure D-8

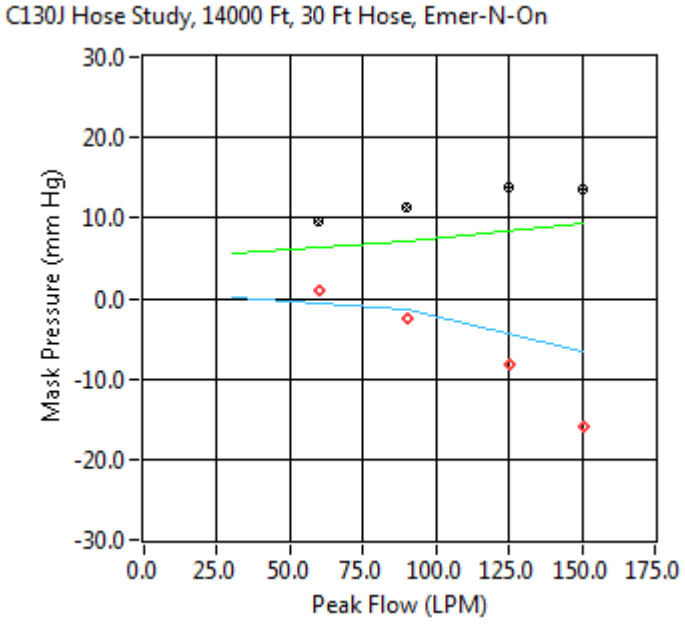


Figure D-9

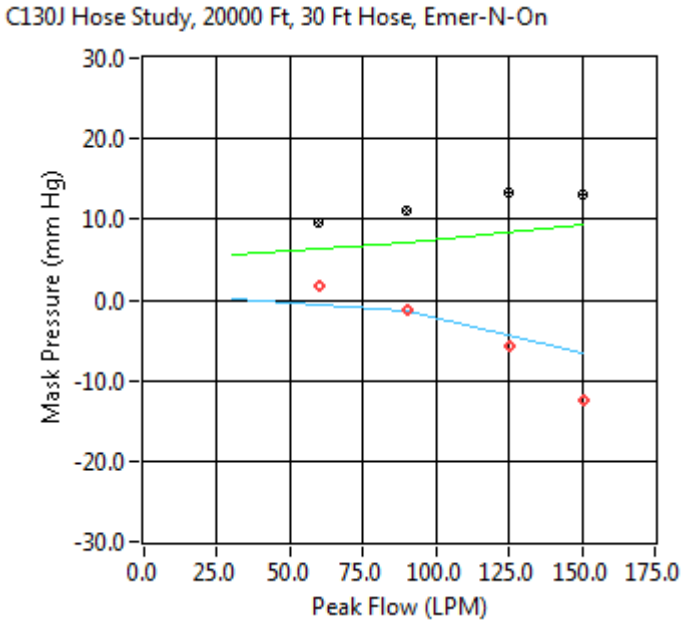


Figure D-10

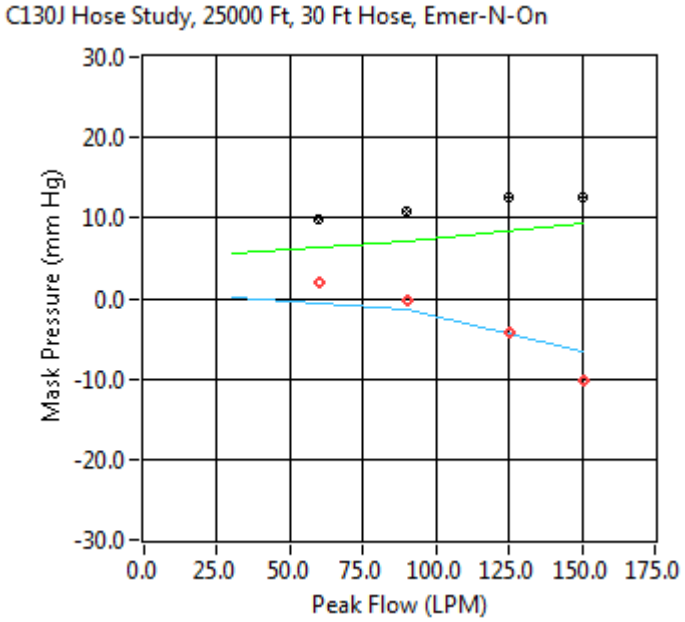


Figure D-11

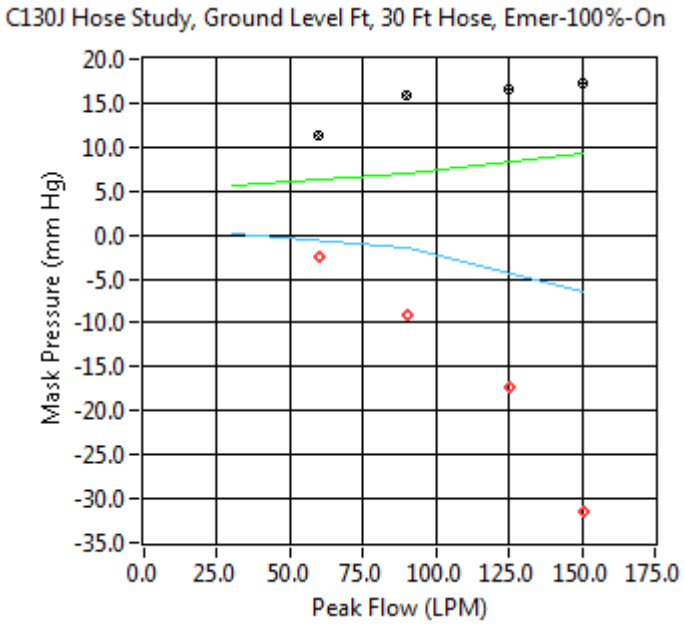


Figure D-12

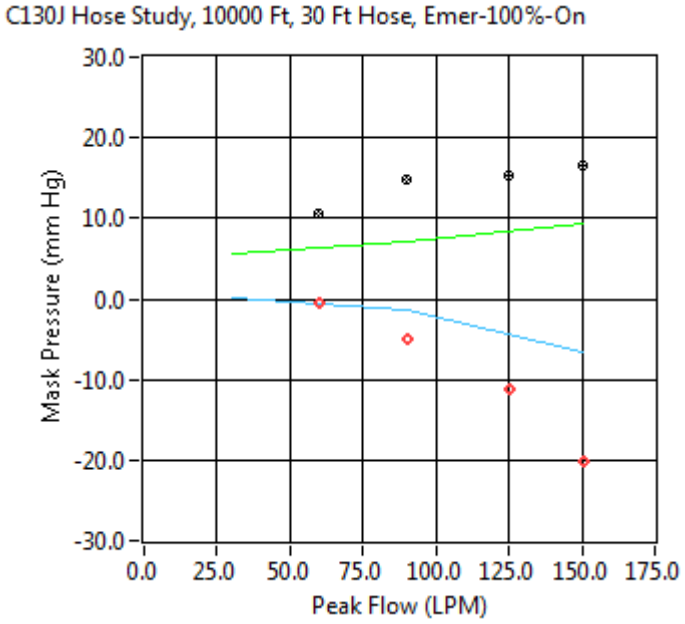


Figure D-13

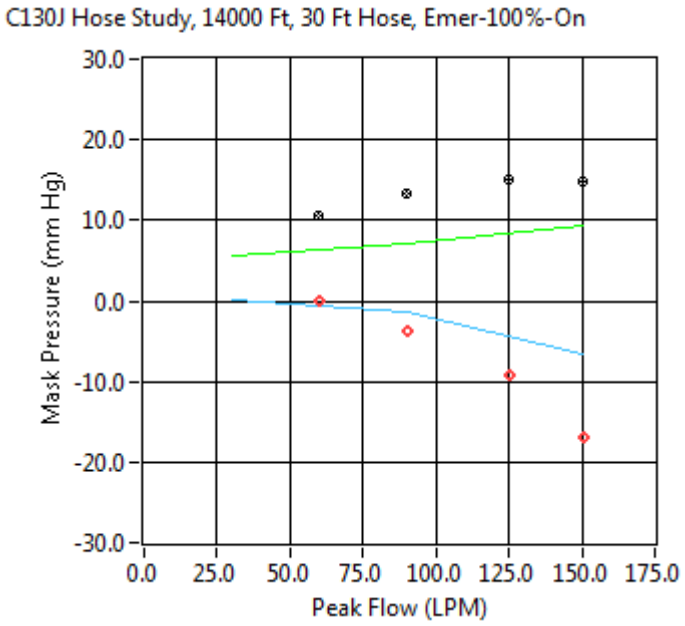


Figure D-14

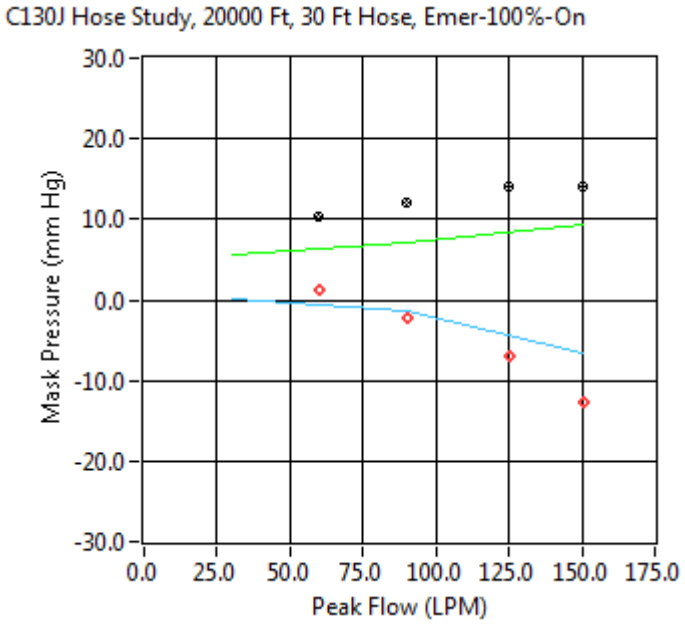


Figure D-15

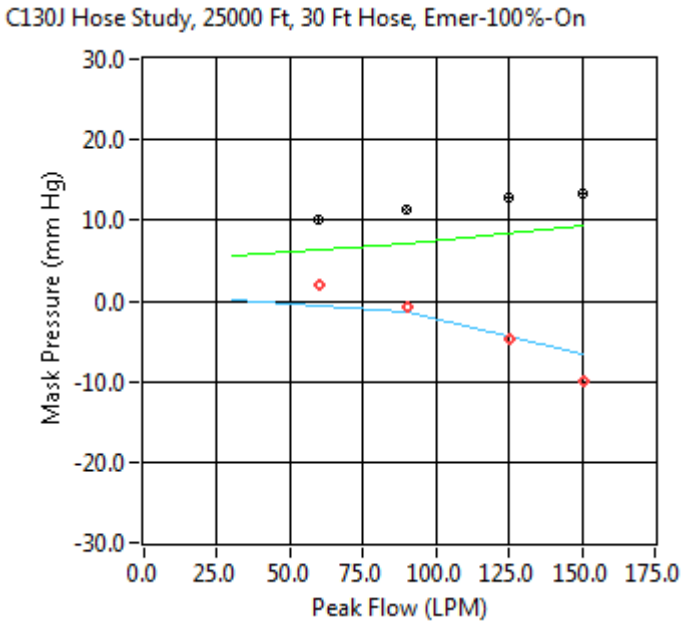


Figure D-16

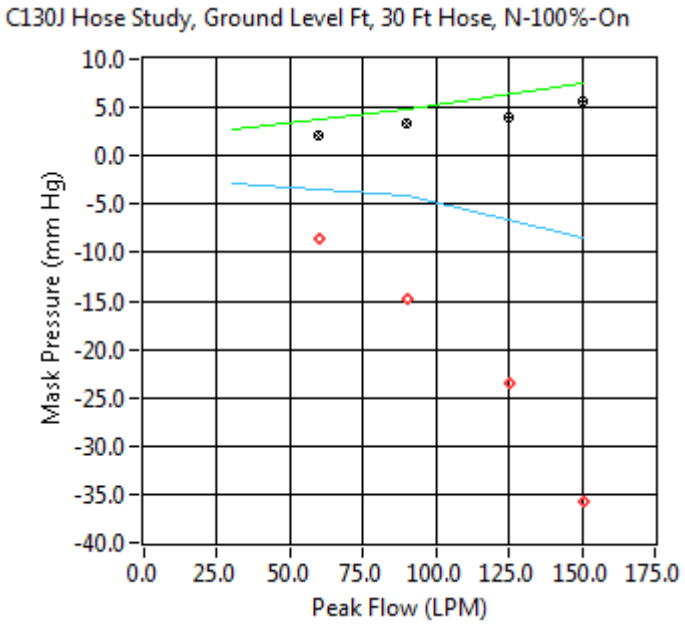


Figure D-17

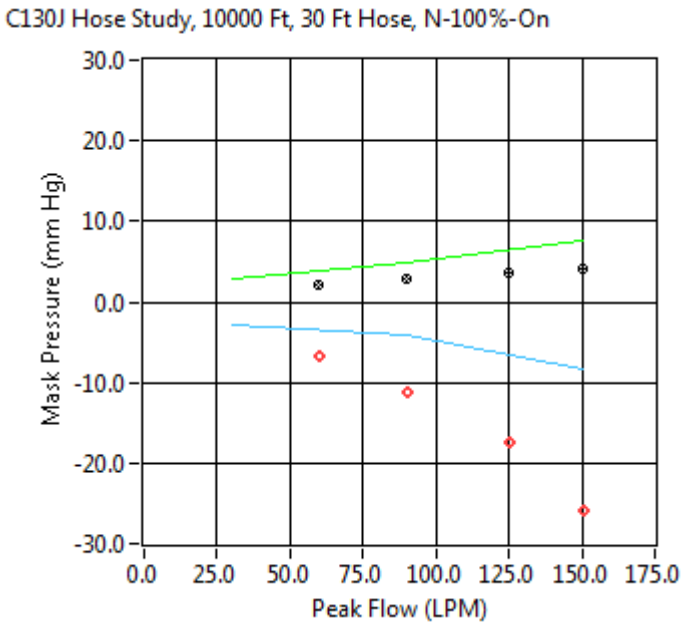


Figure D-18

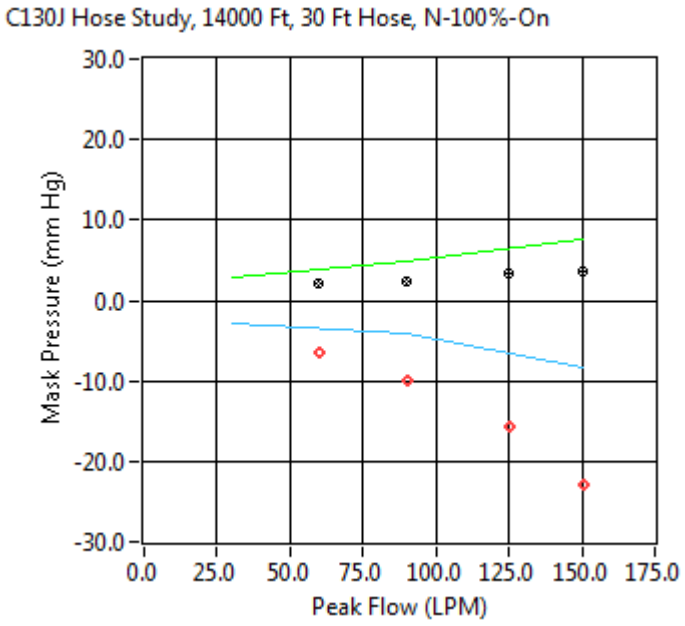


Figure D-19

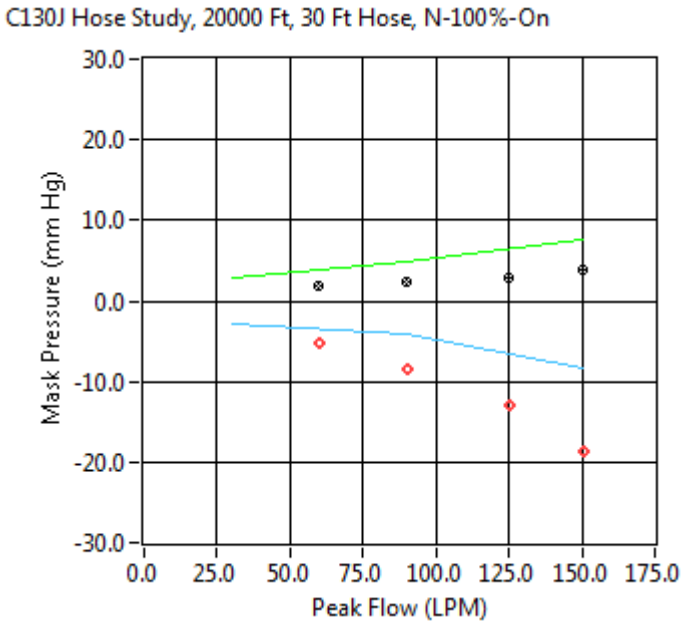


Figure D-20