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Paper

UNDERWATER EFFECTIVITY CHARACTERIZATION OF WATERJET PERFORMANCE IN CLEANING APPLICATIONS

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ABSTRACT

A significant amount of research has been conducted in the past regarding the effectiveness of waterjet nozzles as well as the jet quality produced. This research is commonly conducted in an operating condition where the waterjet must travel through air to reach the target. However, many field applications exist where water jetting takes place in an underwater condition. These applications may occur in a body of water, piping system, or a vessel that fills during the cleaning process.

This paper investigates the effectiveness and performance of a waterjet nozzle in operation underwater, while comparing these results with those of a waterjet nozzle operating in air. In order to complete this testing, the variables of nozzle pressure, flow, standoff distance, and traverse velocity were compared on the same target material. Parameters for the investigation included various flow rates, orifice sizes, pressures from 69 MPa (10,000 psi) to 276 MPa (40,000 psi), standoff distances from 51 millimeters (2 inches) to 559 millimeters (22 inches), and traverse velocities of 0.61 m/sec (2 ft/sec) to 4.42 m/sec (14.5 ft/sec).

Machinable wax was used as a target material. The average depth of target material removed was measured to determine jet effectiveness and compared between the two different operation modes.

1. INTRODUCTION

Many waterjet cleaning applications may occur in a body of water, piping system, or vessel that fills during the cleaning process. Currently, limited research has been conducted to assess the actual effectiveness and performance of a waterjet traveling through water as opposed to air. Through the years, some have asserted that underwater cleaning can be more effective than common cleaning operations in air. The theory behind this view pertains to the phenomenon of cavitation. As a waterjet contacts a substrate underwater, the impact of the waterjet creates subsequent cavitation in the surrounding area further enhancing the effectiveness or power of the waterjet. The collapsing voids (cavitation) that implode near the surface of the substrate cause cyclic stress through repeated implosions; subsequently, increasing the material removal and effectiveness of the waterjet. An opposing view held by some, is that a submerged waterjet will show very limited effectiveness and performance or simply not function at all, based on the deterioration of the waterjet as it passes through water.

2. TESTING SETUPS

2.1 Effectivity Testing - Traversing Target and Stationary Lance

Figures 1 and 2 depict the testing setup used to evaluate and test underwater effectiveness. In the tests conducted, the machinable wax target was traversed in a rolling carriage across a rail system using a pneumatic cylinder. The cylinder was capable of providing a consistent traverse speed. Speed was measured by two magnetic pickups oriented in close proximity to the lance location. A lance with an inside diameter of 4.78 millimeters (0.188 inch) and length of 813 millimeters (32 inches) was used upstream of the waterjet orifice. Two types of nozzle orifices were adapted to fit the testing setup, Carbide Nozzles for the 69 MPa (10,000 psi) and the 138 MPa (20,000 psi) testing, and a Sapphire Nozzle for the 276 MPa (40,000 psi) testing.

2.2 Verification and Correlation Setup – Traversing Lance and Stationary Target

Typical waterjet cleaning is completed with the waterjet traversing across a target. Therefore, verification was required of the testing completed using the traversing target test setup described in Section 2.1 and shown in Figures 1 and 2. The correlation testing was completed by duplicating a previous data set while translating the lance in water. The lance translation setup is shown in Figure 3. The limitation of the lance translation test setup was that the maximum traverse speed was limited to 0.61 m/sec (2 ft/sec) based on the design of the test fixtures.

3. EFFECTIVITY TESTING

3.1 Baseline Testing in Air

After the initial test setup was assembled as shown in Figures 1 and 2 (without filling the tank with water), baseline testing was completed by translating the machinable wax target through the air and across the specified waterjet nozzle. Table 1 outlines the tests completed in this method varying pressure, flow, traverse velocity, and standoff distance. The purpose of this baseline testing was to obtain effectiveness and performance for the typical waterjet application. Different tests were completed to provide conclusive results based on the variables selected.

3.2 Underwater Comparison Testing

After the initial test setup was assembled as shown in Figures 1 and 2, underwater testing was completed by translating the machinable wax target through the water and across the specified waterjet nozzle. Table 2 outlines the tests completed in this method varying pressure, flow, traverse velocity, and standoff distance. The purpose of this underwater testing was to obtain effectiveness and performance for the waterjet in an underwater application, which allows for correlation to the baseline air testing. Once again, different tests were completed to provide conclusive results based on the variables selected.

3.3 Verification and Correlation Testing

As previously discussed, typical waterjet cleaning is completed with the waterjet traversing across a target. Both of the first two test setups utilized the traversing target test setup shown in Figures 1 and 2. The verification and correlation testing was completed by duplicating a previous data set as shown in Table 3, while translating the lance in water. The lance translation setup is shown in Figure 3.

3.4 Results

Based on the progression of the testing and the evidence provided by the initial results, some of the originally planned test steps outlined in Tables 1 through 3 were eliminated. This determination was made based on the initial evidence of limited to no material removal in the machinable wax target at specific standoff distances and / or speeds. When this occurred, the original test plan was altered to remove tests that included greater standoff distances and / or higher speeds while utilizing similar waterjet pressures and nozzle diameters. The progression of the Effectiveness Testing Results within this document identifies specific test pressures, nozzle sizes, and traverse speeds for each set of graphical results. The graphical results shown in Figures 4 through 8 directly relate to the Effectiveness Testing outlined in Tables 1 through 3, respectively.

The graphical results depicted in the Figures 4 through 8 indicate the relative performance data collected for the waterjet nozzle testing in both air and underwater. Each test was completed using the same waterjet nozzle with a constant pressure and flow at various standoff distances and two traverse speeds. The results are expressed in terms of nozzle diameters and percent of relative performance. The percent of relative performance was determined with the assumption that the largest amount of material removal for a specific set of test parameters would determine the 100 percent effective performance for comparison purposes.

Black solid lines within the graphical results indicate testing completed in air with a slow traverse speed. Red and Green solid lines indicate testing completed in water with a slow traverse speed, where Red results were acquired using a traversing target setup and Green were acquired using a traversing lance setup. Additionally in the graphical results, Black dashed lines indicate air testing with a fast traverse speed; whereas, Red dashed lines indicate water testing with a fast traverse speed.

No graphical results are provided for the 69 MPa (10,000 psi) with 1.07 millimeter (0.042 inch) waterjet nozzle testing based on the evidence found in the initial testing. A combination of the machinable wax threshold pressure (pressure at which the material can be removed), standoff distances selected, and the traverse speeds of the target did not allow for enough measureable data to provide a clear result.

The results show that in the testing completed, underwater material removal was generally more effective, approximately 10%, when compared to material removal when the waterjet passes through air at close distances. This phenomenon was true at very close standoff distances, typically within 100 nozzle diameters. On the other hand, this phenomenon does not hold true as the waterjet standoff distance was increased. The underwater test results show significantly reduced overall effectiveness as the standoff distance was increased beyond the 100 nozzle diameter threshold. These conclusions are true independent of the test pressure, flow, and nozzle diameter based on the testing completed. However, if the traverse speed of the waterjet was increased by a factor of six times the results were found to provide more variable results. More specific test for each test sequence can be found in Figures 4 through 8.

The data produced by holding all variables constant and simply varying the traverse speed of the target material were found to be very consistent as well. The graphical results for slow traverse speed testing versus increased traverse speed testing provided uniform and consistent results. This was true when comparing air to air as well as water to water curves. The reduction of effectiveness results of the air to air correlation were typically greater, ranging from 20% to 50% reduction. Whereas, the results of the water to water correlation were smaller, ranging from 5% to 20% reduction.

Finally, as shown in Figure 8, the test method used with a traversing target provided test results which did not significantly vary from those within the Verification and Correlation testing section from Table 3. The curves generated from the results of both testing methods closely match with little offset. One major difference found was that the target translation testing was 10% more effective at closest standoff distance when compared to the lance translation testing. This effect was most likely caused by loss of the waterjet power as it traversed through the water, by a lag in the waterjet, or a combination of both. The lag of the waterjet can be thought of as slightly bent or bowed waterjet stream creating a loss of power based on movement in multiple directions in the water (i.e. traversing through the water and moving through the water toward the target.)

4. CONCLUSIONS

Many conclusions can be drawn from the results and evidence provided by this Effectiveness and Performance Testing Program. The results of this testing show that underwater waterjet cleaning can be greatly effective within the 100 nozzle diameter range; conversely, underwater waterjet cleaning may be ineffective and very limited beyond the 300 nozzle diameter range. Additionally, the graphical trends show that the smaller and more cohesive the waterjet, the more effectiveness you will be able to achieve at a greater distance. This trend was true in both the air and underwater test conditions.

The effectiveness and performance testing completed in this test program was not intended to be able to produce underwater material removal rates for waterjet cleaning; however, it does give an indication that the closer cleaning distance to the substrate that can be achieved in the underwater condition, the more effective the cleaning will be. Furthermore, greater performance deterioration would be expected with larger standoff distances. Based on the results, if the cleaning distance can be reduced to within 100 nozzle diameters, waterjet effectiveness and performance can be expected to be approximately 10% more effective than when cleaning in air. This would authenticate the first theory outlined previously in this paper that the effectiveness of underwater waterjet applications is greater at distances closer than 100 nozzle diameters. However, this research does not pinpoint the exact mechanism or phenomenon (i.e. cavitation, etc.), which allows this to happen.

5. ACKNOWLEDGMENTS

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6. REFERENCES

None

7. NOMENCLATURE

None

Table 1. Baseline Testing Data Points – Target Translated in Air

Pressure [MPa (kpsi)] Note: +/- 7 MPa (1000 psi)	Calculated Flow [lpm (gpm)]	Nozzle Ø for Flow [mm (in)]	Traverse Velocity [m/sec (ft/sec)] Note: +/- 0.46 m/sec (1.5 ft/sec)	Standoff Distance [mm (in)] Note: +/- 2.54 mm (.1 in)	Standoff Distance [Nozzle Ø's]
69 (10)	18.0 (4.75)	1.07 (0.042)	0.61 (2)	559 (22)	524
				406 (16)	381
				203 (8)	190
				51 (2)	48
69 (10)	18.0 (4.75)	1.07 (0.042)	4.42 (14.5)	559 (22)	524
				406 (16)	381
				203 (8)	190
				51 (2)	48
138 (20)	11.3 (2.98)	0.71 (0.028)	0.61 (2)	559 (22)	786
				406 (16)	571
				203 (8)	286
				51 (2)	71
138 (20)	11.3 (2.98)	0.71 (0.028)	4.42 (14.5)	559 (22)	786
				406 (16)	571
				203 (8)	286
				51 (2)	71
138 (20)	25.4 (6.72)	1.07 (0.042)	0.61 (2)	559 (22)	524
				406 (16)	381
				203 (8)	190
				51 (2)	48
138 (20)	25.4 (6.72)	1.07 (0.042)	4.42 (14.5)	559 (22)	524
				406 (16)	381
				203 (8)	190
				51 (2)	48
138 (20)	57.2 (15.11)	1.60 (0.063)	0.61 (2)	559 (22)	349
				305 (12)	190
				83 (3.25)	52
				51 (2)	32
276 (40)	6.6 (1.74)	0.46 (0.018)	0.61 (2)	559 (22)	1222
				406 (16)	889
				203 (8)	444
				51 (2)	111
				25 (1)	56
276 (40)	6.6 (1.74)	0.46 (0.018)	4.42 (14.5)	559 (22)	1222
				406 (16)	889
				203 (8)	444
				51 (2)	111
				25 (1)	56

Table 2. Underwater Comparison Testing Data Points

Pressure [MPa (kpsi)] Note: +/- 7 MPa (1000 psi)	Calculated Flow [lpm (gpm)]	Nozzle Ø for Flow [mm (in)]	Traverse Velocity [m/sec (ft/sec)] Note: +/- 0.46 m/sec (1.5 ft/sec)	Standoff Distance [mm (in)] Note: +/- 2.54 mm (.1 in)	Standoff Distance [Nozzle Ø's]
69 (10)	18.0 (4.75)	1.07 (0.042)	0.61 (2)	559 (22)	524
				406 (16)	381
				203 (8)	190
				51 (2)	48
69 (10)	18.0 (4.75)	1.07 (0.042)	3.81 (12.5)	559 (22)	524
				406 (16)	381
				203 (8)	190
				51 (2)	48
138 (20)	11.3 (2.98)	0.71 (0.028)	0.61 (2)	559 (22)	786
				406 (16)	571
				203 (8)	286
				51 (2)	71
138 (20)	11.3 (2.98)	0.71 (0.028)	3.81 (12.5)	559 (22)	786
				406 (16)	571
				203 (8)	286
				51 (2)	71
138 (20)	25.4 (6.72)	1.07 (0.042)	0.61 (2)	406 (16)	381
				305 (12)	286
				203 (8)	190
				51 (2)	48
138 (20)	25.4 (6.72)	1.07 (0.042)	3.81 (12.5)	406 (16)	381
				305 (12)	286
				203 (8)	190
				51 (2)	48
138 (20)	57.2 (15.11)	1.60 (0.063)	0.61 (2)	559 (22)	349
				305 (12)	190
				83 (3.25)	52
				51 (2)	32
276 (40)	6.6 (1.74)	0.46 (0.018)	0.61 (2)	559 (22)	1222
				406 (16)	889
				203 (8)	444
				51 (2)	111
				25 (1)	56
276 (40)	6.6 (1.74)	0.46 (0.018)	3.81 (12.5)	559 (22)	1222
				406 (16)	889
				203 (8)	444
				51 (2)	111
				25 (1)	56

Table 3. Correlation Testing Data Points

Pressure [MPa (kpsi)] Note: +/- 7 MPa (1000 psi)	Calculated Flow [lpm (gpm)]	Nozzle Ø for Flow [mm (in)]	Traverse Velocity [m/sec (ft/sec)] Note: +/- 0.46 m/sec (1.5 ft/sec)	Standoff Distance [mm (in)] Note: +/- 2.54 mm (.1 in)	Standoff Distance [Nozzle Ø's]
138 (20)	25.4 (6.72)	1.07 (0.042)	0.61 (2)	305 (12)	286
				203 (8)	190
				152 (6)	143
				102 (4)	95
				51 (2)	48

Figure 1. Traversing Target Effectivity Testing – Top View

Figure 2. Traversing Target Effectivity Testing Setup – Front View

Figure 3. Verification and Correlation Setup – Traversing Lance

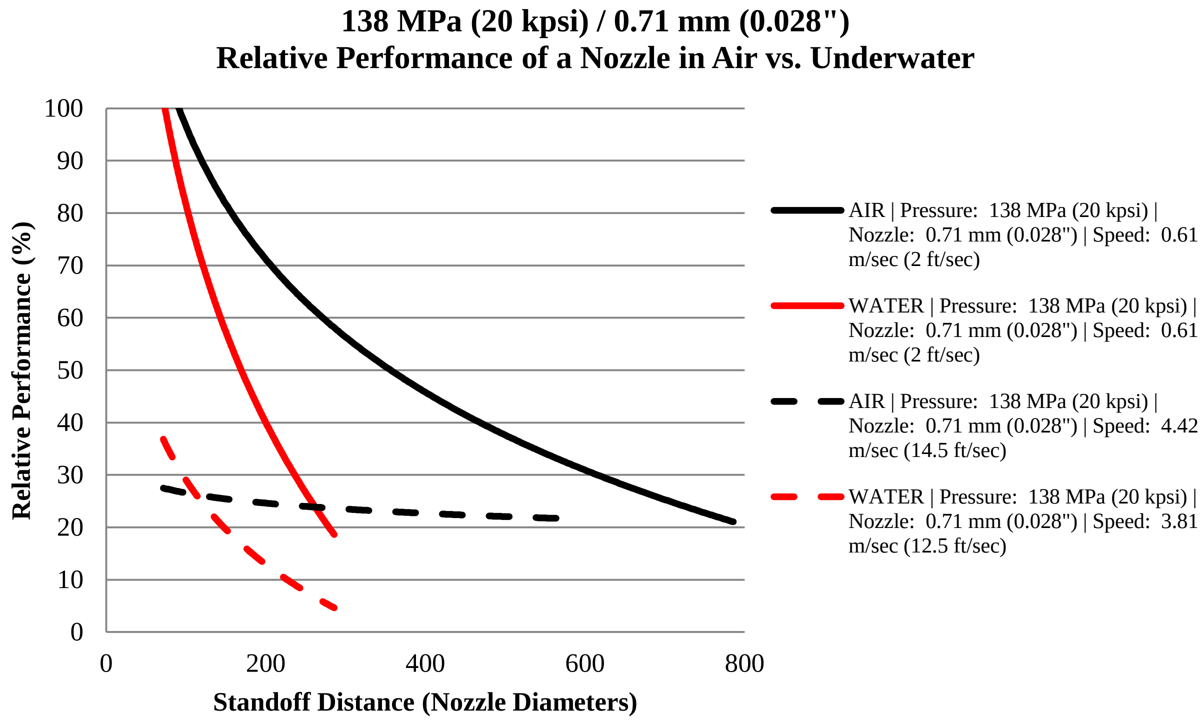

Figure 4. 138 MPa (20 kpsi) / 0.71 mm (0.028") Relative Performance

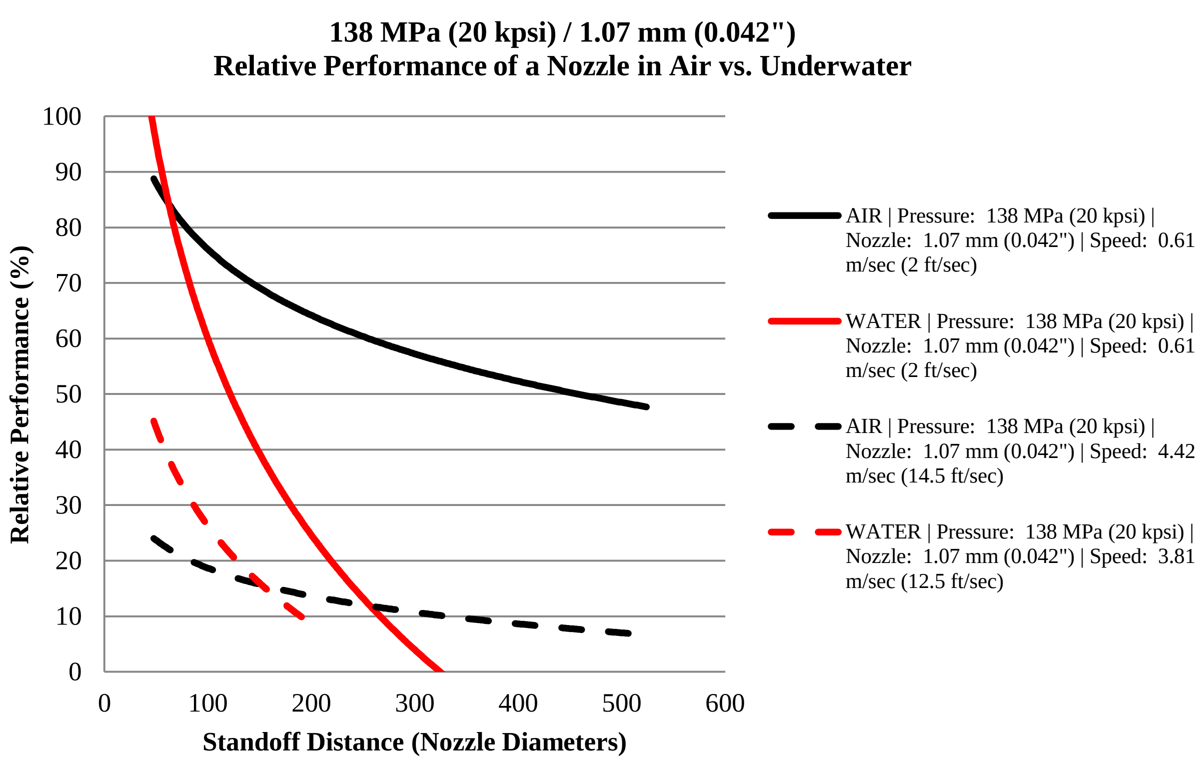

Figure 5. 138 MPa (20 kpsi) / 1.07 mm (0.042") Relative Performance

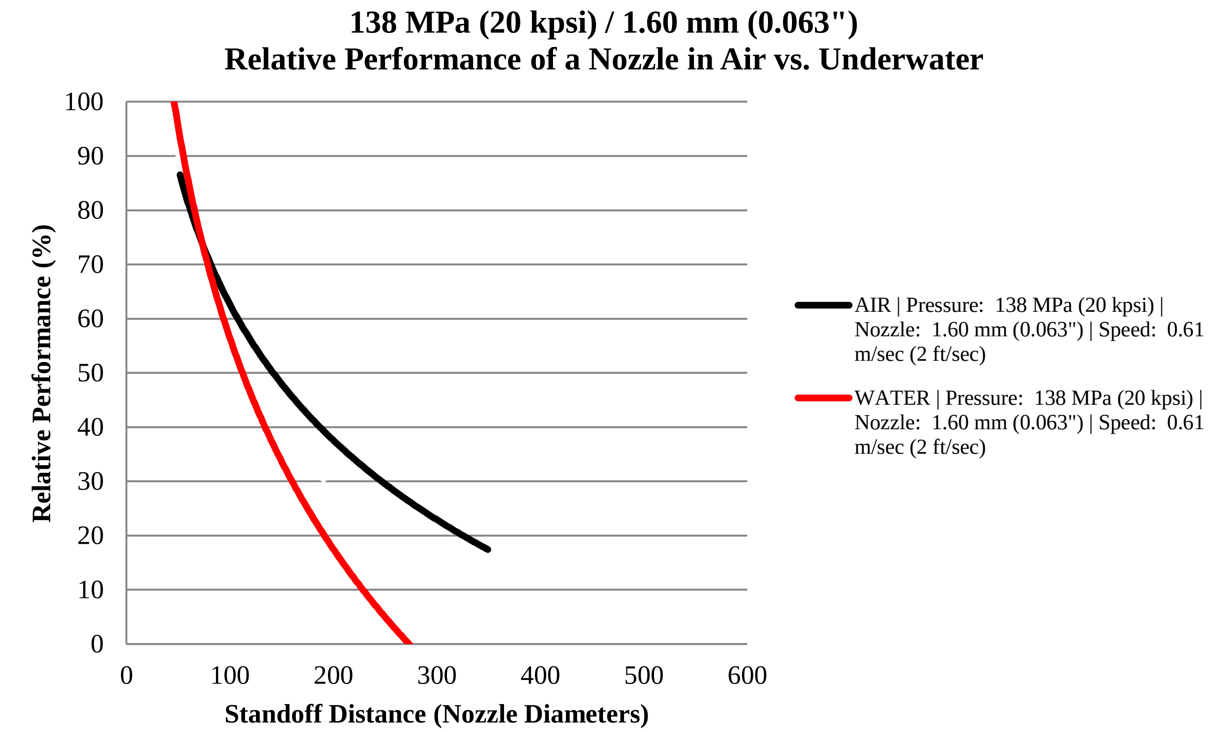

Figure 6. 138 MPa (20 kpsi) / 1.60 mm (0.063") Relative Performance

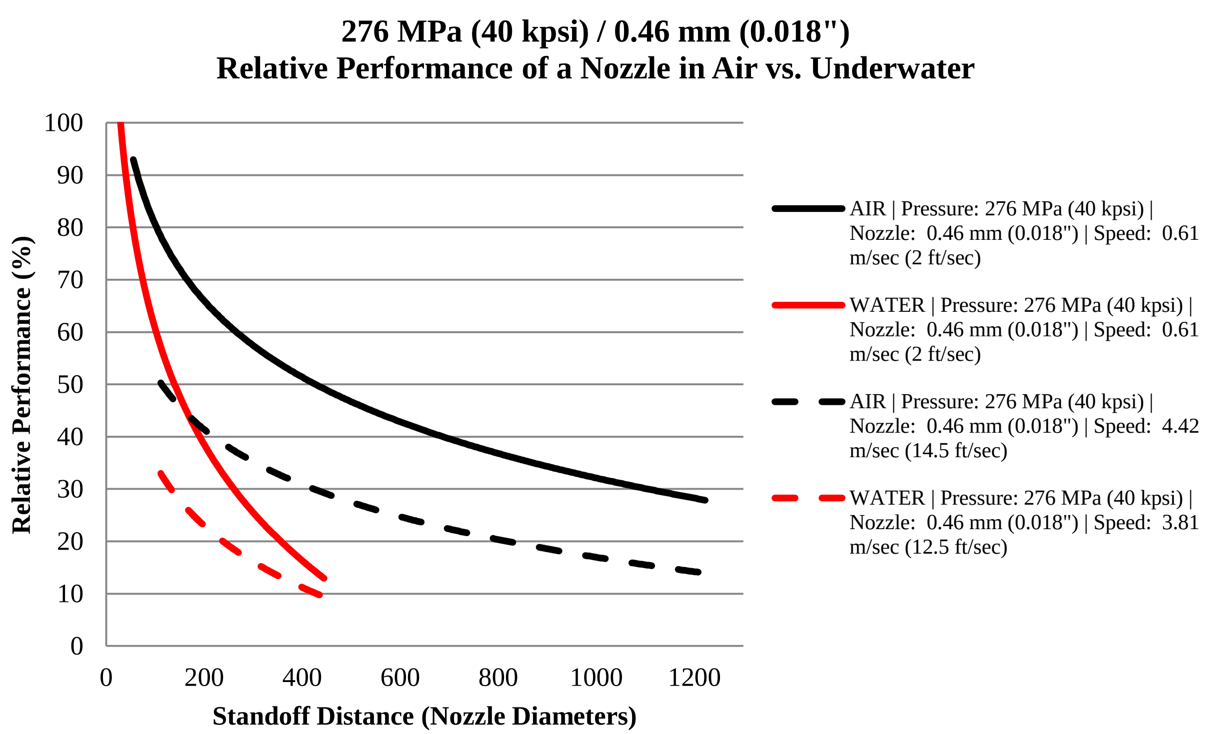

Figure 7. 276 MPa (40 kpsi) / 0.46 mm (0.018") Relative Performance

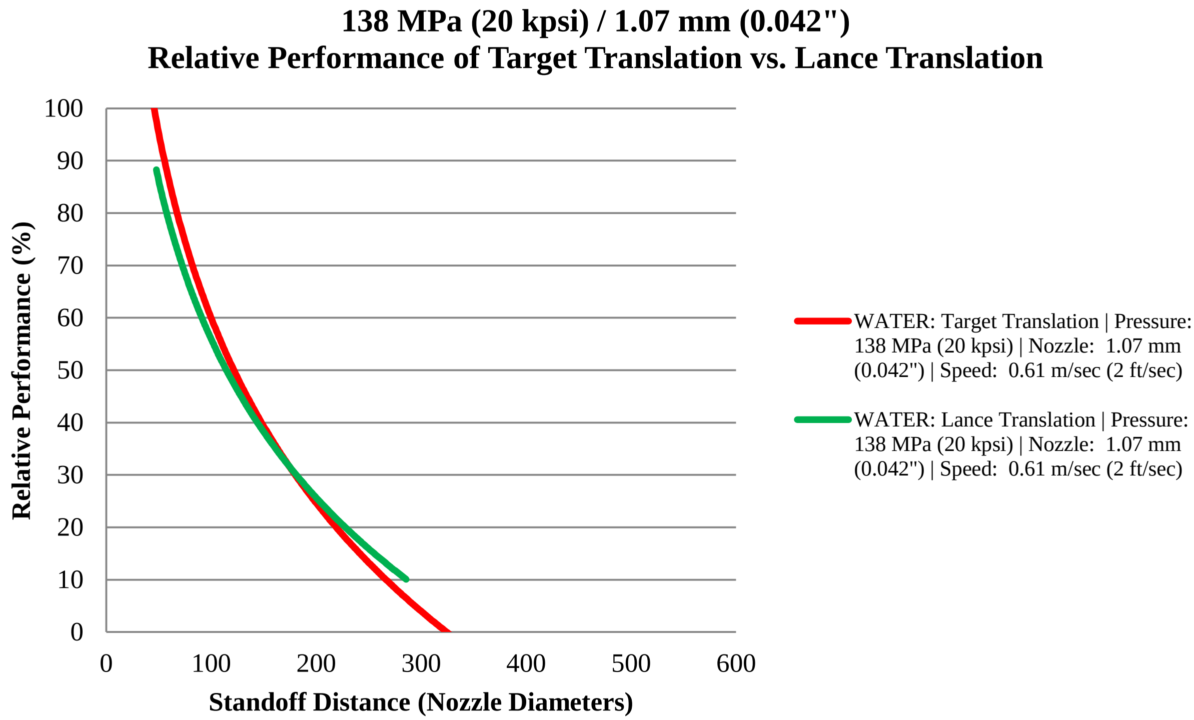

Figure 8. 138 MPa (20 kpsi) / 1.07 mm (0.042") Verification and Correlation