COMPUTATIONAL ANALYSIS OF WESTFALL'S 3000 FLOW CONDITIONER IN WATER

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Executive Summary

Alden Research Laboratory Inc. (Alden) was contracted by Westfall Manufacturing Inc. (Westfall) to aid in the development of a novel leading tab flow conditioner.

The objective of a flow conditioner is to reduce flow meter measurement error by: eliminating swirl, quickly impose a fully-developed velocity profile within the pipe, and minimize turbulence regardless of the flow conditions upstream. A successful flow conditioner will accomplish this with minimal pressure loss, and with the shortest pipe length possible.

The leading tab concept, when coupled with anti-swirl plates, has been proven to be quite effective at reducing swirl and improving the flow distribution at short distances downstream of the conditioner. Turbulence levels are also maintained at fairly low levels, which helps improve measurement accuracy. The principle by which the conditioner operates is that the primary tabs create vortices that mix the flow by turning it “inside-out”, and then quickly dissipate at the pipe wall. The secondary tabs then leave a fully developed, non-swirling flow in their wake.

This report focuses on the flow conditioner implemented in water, whereas the original report (AMG-09-R-08 Rev.C) was an analysis of the flow conditioner performance in air.

The flow conditions achieved in water investigated in this analysis are very similar to the flow conditions that were seen with air in the previous report.

Model Description

The model geometry was developed using the commercially available three-dimensional CAD and mesh generation software, GAMBIT V2.4.6. The computational domains generated for the model consisted of approximately 1,500,000 tetrahedral and hexahedral cells.

Alden used the CFD software package ANSYS-Fluent v14.5 to calculate the full-scale, three-dimensional, incompressible, turbulent flow through the pipe and mixer. A stochastic, two-equation realizable k-ε model was used to simulate the turbulence. Detailed descriptions of the physical models employed in each of the Fluent modules are available from ANSYS-Fluent. CFD solver information is presented in Table 1.

Table 1 - CFD Solver Information

CFD Solver Information:	Units:	Value:
Cell count		1,533,417
Cell Shape		Hexahedral / Tetrahedral
CFD Code		ANSYS-Fluent v14.5
Solver		Pressure-based Segregated
Spacial Discritization		2nd Order Upwind
Density Formulation		Constant
Turbulence Model		k-epsilon, realizable
Near-Wall Treatment		Non-equalibrium Wall Functions
Wall Roughness Height	(ft)	0.0002

The tests were conducted in 6" sch. 40 steel pipe, and the test section consisted of two 90° bends in perpendicular planes separated by 2 pipe diameters. This configuration provides both non-uniform velocity profiles and swirling flow. As noted by the ASME *Measurement of Fluid Flow in Pipes Using Orifice, Nozzle and Venturi* guidelines: "This is not a good upstream installation; a flow conditioner should be used where possible".

The upstream end of the flow conditioner was placed 4 pipe diameters downstream from the second bend, and is used as the datum for comparison (Figure 1). It has been determined through previous testing that the flow conditioner performs similarly at different flow rates, provided the flow is turbulent, so only one water flow rate was tested: 578-gpm (2197-l/min) at a temperature of 68°F (20°C). A uniform velocity inlet was imposed at the model inlet, which was placed 10 pipe diameters upstream of the first bend. A uniform static pressure boundary condition was imposed at the model outlet, which was placed 20 pipe diameters downstream of the mixing device's leading edge so that the impact of the flow conditioner could be documented as a function of downstream distance. On all surfaces, no-slip impermeable adiabatic wall boundary conditions were applied with roughness heights set to 0.0002-ft as appropriate for steel pipe.

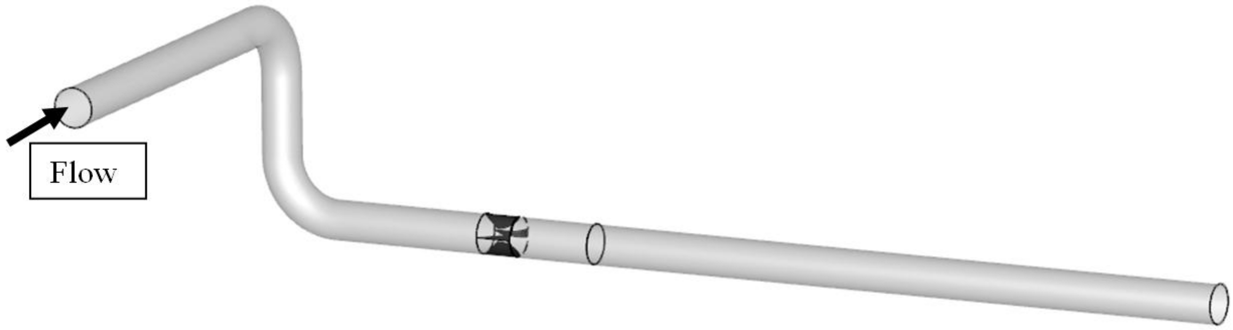


Figure 1 - Model Layout, Isometric View

Two cases were evaluated to evaluate the performance of the flow conditioner in terms of pressure loss, swirl, turbulence, and flow uniformity. The first case had no flow conditioner installed, and the second case had Westfall's 3000 flow conditioner installed as described above.

Deviation from fully developed flow was determined by the coefficient of variance (CoV) of the velocity in each cell from the ideal fully developed profile. The fully developed velocity profile was determined by running a separate CFD model with the same pipe size and water flow rate in a straight pipe with an L/D ratio of 100. The velocity profile at the outlet of that pipe was considered to be fully developed.

More details about the water flow conditions that were analyzed are presented in Table 2.

Table 2 - Process Flow Information

Process Flow Information:	English Units	Metric Units
Pipe Diameter	6 (in)	0.152 (m)
Average Velocity	6.56 (ft/s)	2.00 (m/s)
Volume Flow Rate (total)	1.29 (cfs)	0.0365 (m3/s)
	578.3 (gpm)	2197 (l/min)
Temperature	68 (°F)	20 (°C)
Density	62.3 (lbm/ft3)	998 (kg/m3)
Viscosity	6.74E-04 (lbm/ft-s)	1.00E-03 (kg/m-s)
Reynolds Number =	**304,060**	

Drawings of the flow conditioner that was tested are provided in Figure 2 and Figure 3.

Results

The existing configuration was initially analyzed without a mixer to achieve a baseline result from which comparisons could be made, and conditioner effectiveness could be determined.

The pressure loss attributable to the conditioner was measured by comparing the overall pressure loss through the section of pipe with and without the mixer. The mixer k-value was calculated to be 0.557, which is very similar to previously reported values for this conditioner (Table 3).

Table 3 - Flow Conditioner Pressure Loss Summary

Pressure Loss Results:	English Units	Metric Units
Pressure Loss Without Conditioner	6.97 (inwg)	1.74 (kPa)
Pressure Loss With Conditioner	11.43 (inwg)	2.85 (kPa)
Pressure Loss Due to Conditioner	4.46 (inwg)	1.11 (kPa)
Mixer k-Value =	**0.557**	

Bulk swirl was measured as the ratio of average tangential velocity to average axial velocity downstream of the mixer. The two out-of-plane elbow configuration creates swirl, and a properly conditioned flow should not have any swirl, which can degrade the accuracy of some flow meters.

The flow conditioner was found to reduce swirl to a very low beginning at the conditioner outlet, whereas the swirl without a conditioner slowly degraded from 6.0% to 4.8% over the length of pipe investigated due to friction with the pipe walls (Table 4, Figure 4).

Table 4 - Swirl Downstream of Flow Conditioner Inlet

(Average Tangential Velocity / Average Axial Velocity)

Distance from Conditioner Inlet:	Without Conditioner	With Conditioner
L/D = 2	6.0%	0.5%
L/D = 3	5.9%	0.4%
L/D = 4	5.9%	0.4%
L/D = 5	5.8%	0.3%
L/D = 6	5.7%	0.3%
L/D = 7	5.7%	0.3%
L/D = 8	5.6%	0.3%
L/D = 9	5.5%	0.3%
L/D = 10	5.5%	0.3%
L/D = 11	5.4%	0.3%
L/D = 12	5.3%	0.3%
L/D = 13	5.2%	0.3%
L/D = 14	5.2%	0.2%
L/D = 15	5.1%	0.2%
L/D = 16	5.0%	0.2%
L/D = 17	5.0%	0.2%
L/D = 18	4.9%	0.2%
L/D = 19	4.8%	0.2%
L/D = 20	4.8%	0.2%

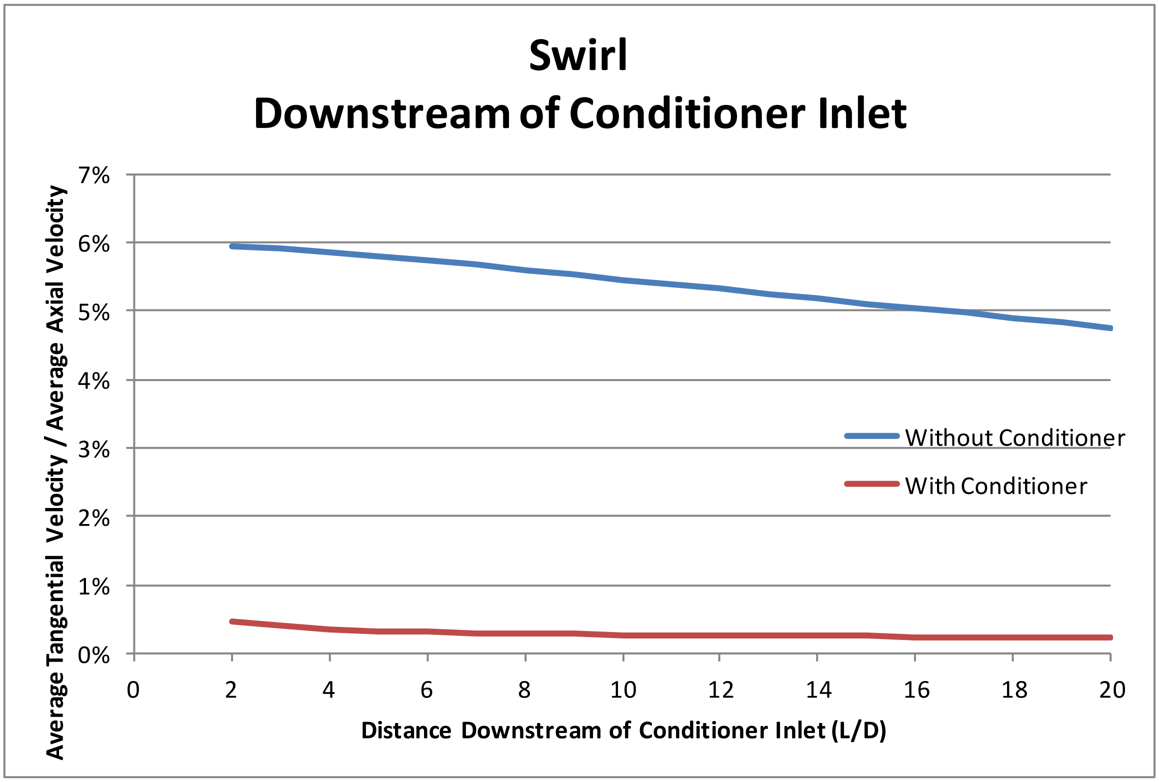


Figure 4 - Swirl Downstream of Flow Conditioner Inlet

Another important consideration for a flow conditioner is the level of turbulence downstream. Excessive turbulence levels can impair a flow meter's ability to take a steady measurement. The Westfall 3000 conditioner crates a high level of turbulence initially, but that turbulence is quickly dissipated along the pipe walls downstream of the conditioner. By 20 pipe diameters downstream of the Westfall 3000 conditioner, the turbulent intensity is down to 5.0%, which is a typical level of turbulent intensity in a fully developed pipe flow.

Table 5 - Turbulent Intensity Downstream of Flow Conditioner Inlet

Distance from Conditioner Inlet:	Without Conditioner	With Conditioner
L/D = 2	5.7%	14.6%
L/D = 3	5.3%	11.0%
L/D = 4	5.1%	9.3%
L/D = 5	5.0%	8.2%
L/D = 6	4.8%	7.6%
L/D = 7	4.7%	7.1%
L/D = 8	4.6%	6.8%
L/D = 9	4.6%	6.5%
L/D = 10	4.5%	6.2%
L/D = 11	4.5%	6.0%
L/D = 12	4.5%	5.8%
L/D = 13	4.5%	5.6%
L/D = 14	4.5%	5.5%
L/D = 15	4.5%	5.4%
L/D = 16	4.5%	5.3%
L/D = 17	4.5%	5.2%
L/D = 18	4.5%	5.1%
L/D = 19	4.6%	5.1%
L/D = 20	4.6%	5.0%

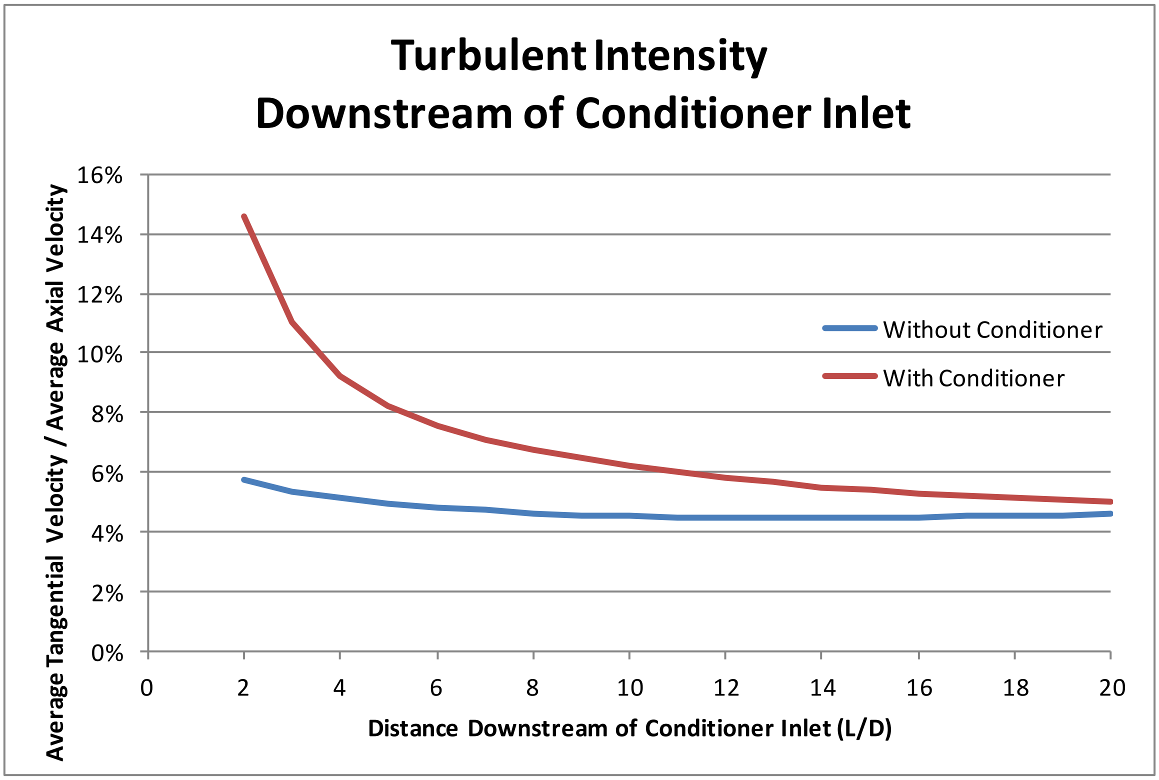


Figure 5 - Turbulent Intensity Downstream of Flow Conditioner Inlet

The most important flow characteristic that the flow conditioner must achieve is a radially symmetric fully developed flow profile. Poor flow distribution naturally occurs after any pipe bend or change in cross section. This causes measurement error in orifice meters as the high and low velocities are not evenly distributed radially, so the pressure measured at the tap is not necessarily an accurate indication of the average pressure at that location.

The leading tab flow conditioner addresses mal-distribution by inducing a small amount of pressure loss, and turning the flow "inside-out" so that momentum is fully exchanged across the flow stream.

Flow distribution is measured as the CoV of the flow from fully developed. Although deviation from fully-developed flow is a useful measure of what distance downstream a flow meter can be placed, it does not directly translate to a quantifiable level of measurement error. Due to the flow disturbance caused by the flow conditioner, the initial deviation from a fully developed profile is greater with the conditioner than without, but by less than 4D downstream, the conditioner creates a better flow profile. The addition of the secondary tabs to the flow conditioner help to develop a fully developed profile more quickly by completely eliminating the swirl from primary tabs. Additionally, the spanwise surface of the secondary tab is tapered towards the wall to further reduce any momentum transfer from the center to the wall (and vice versa) while providing a diffuser section to reduce the peak centerline velocity to that of a

fully developed flow. With these flow features, the velocity profile is within 2% of a fully developed flow profile by 10D downstream of the conditioner inlet.
The deviation from fully developed flow for the conditions analyzed are presented in Table 6 and Figure 6.

Table 6 - Deviation from Fully Developed Flow (CoV)

Distance from Conditioner Inlet:	Without Conditioner	With Conditioner
L/D = 2	6.9%	10.6%
L/D = 4	6.1%	3.9%
L/D = 6	5.9%	2.9%
L/D = 8	5.7%	2.3%
L/D = 10	5.3%	2.0%
L/D = 15	4.8%	1.7%
L/D = 20	4.6%	1.4%

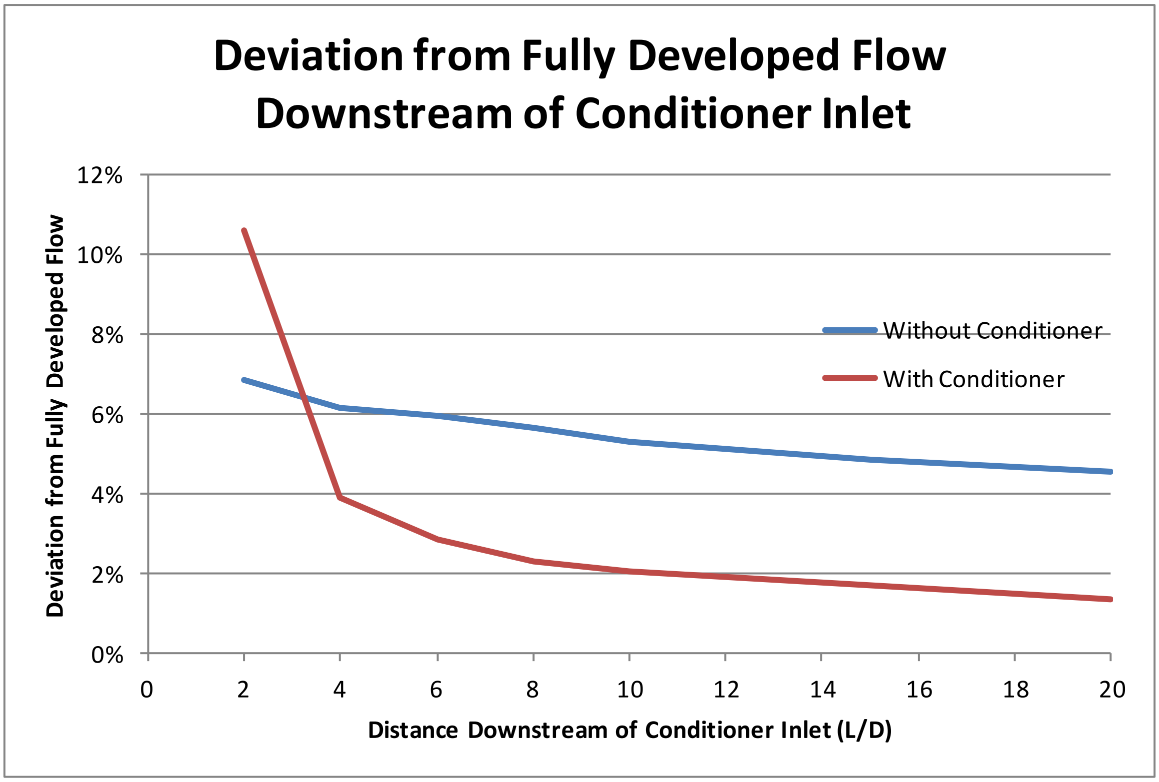
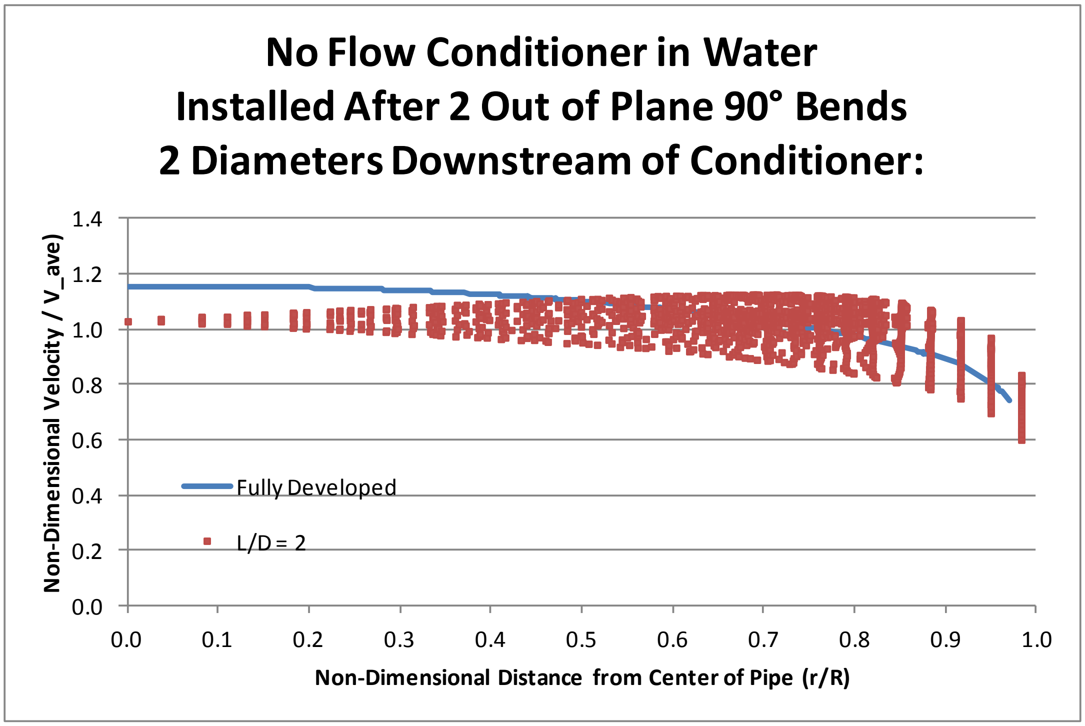


Figure 6 - Deviation from Fully Developed Flow (CoV)

The radial uniformity of flow downstream of the conditioner inlet location is presented for cases with and without the conditioner, and compared to a fully developed flow profile in

Figure 7 thru Figure 13. At each radial position, a large spread in velocity indicates a flow profile that is not radially symmetric. A small spread in velocity, located close to the fully developed profile is desirable.



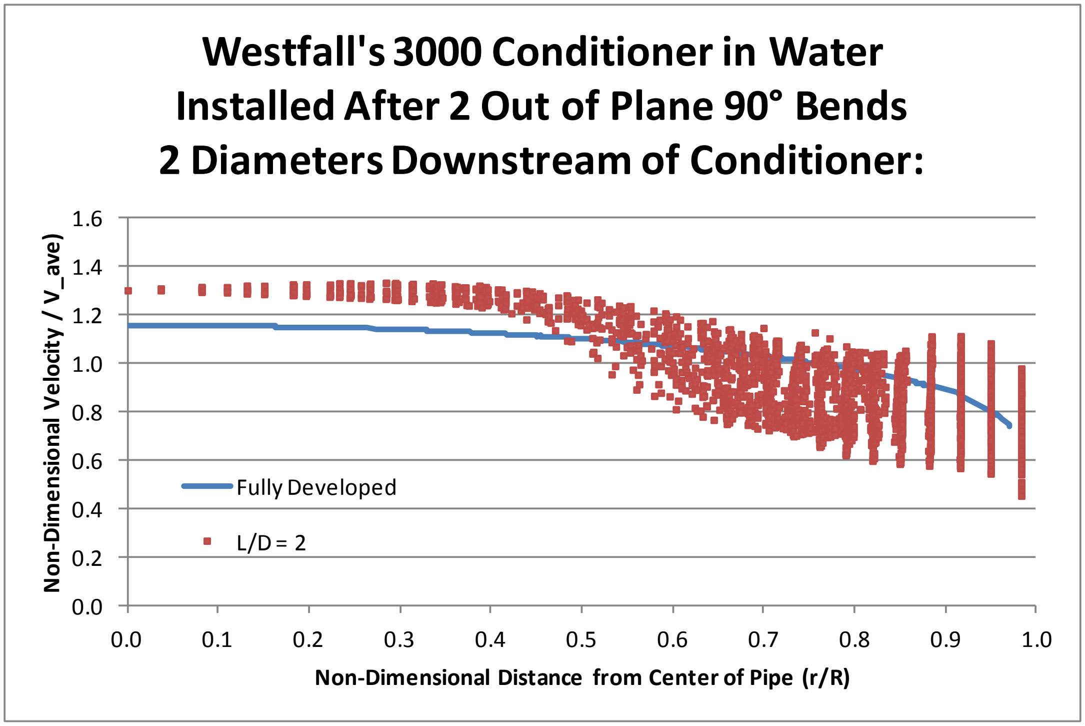
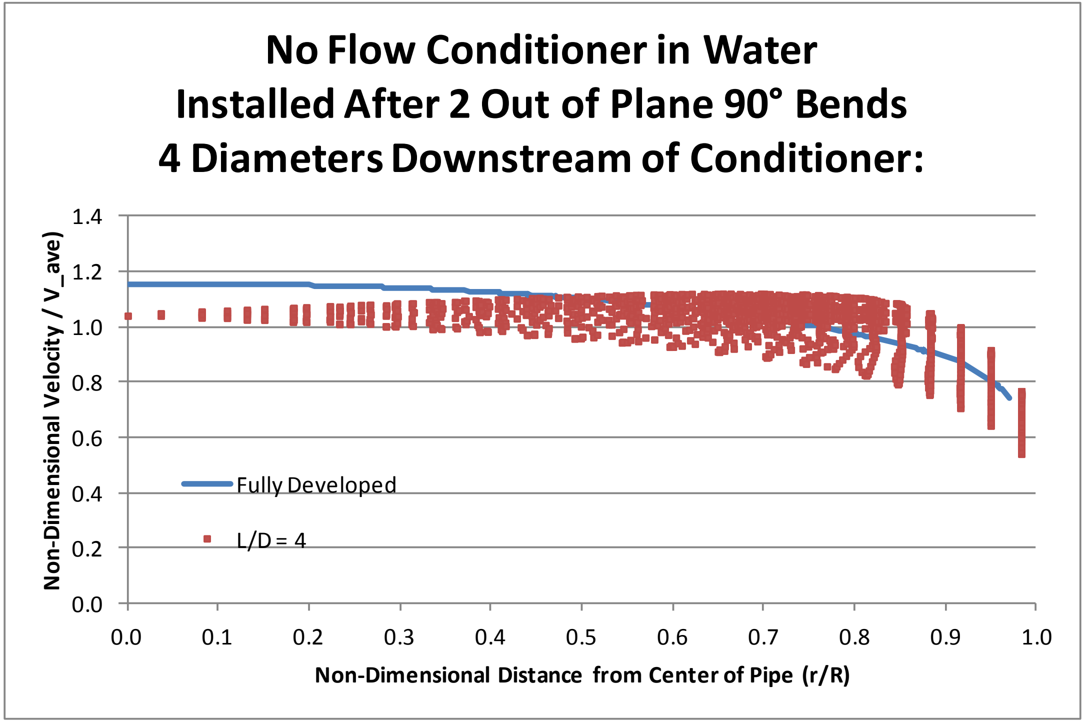


Figure 7 - Radial Uniformity of Flow Downstream of Conditioner Inlet at L/D = 2; Without Conditioner (top) and with Conditioner (bottom)



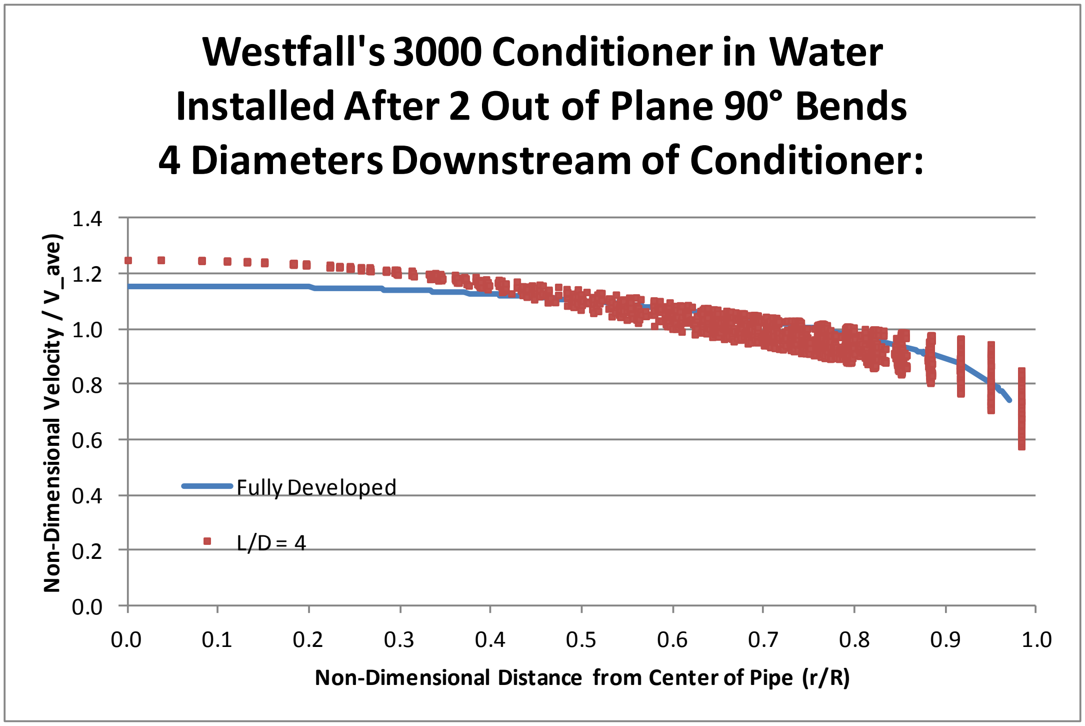
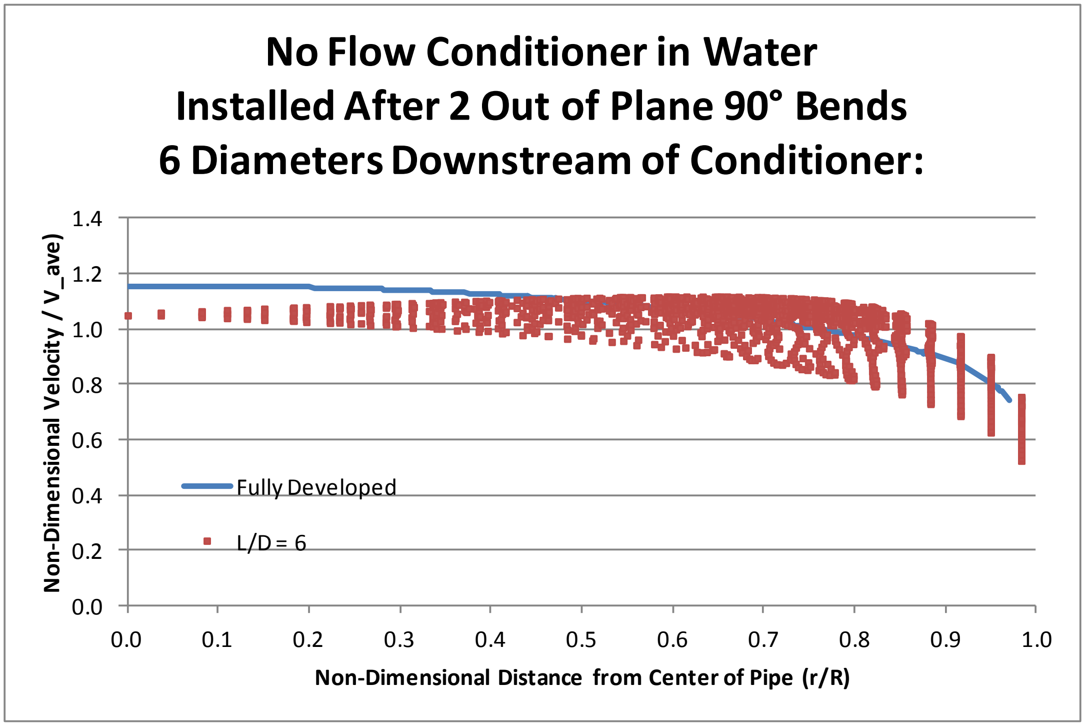


Figure 8 - Radial Uniformity of Flow Downstream of Conditioner Inlet at L/D = 4; Without Conditioner (top) and with Conditioner (bottom)



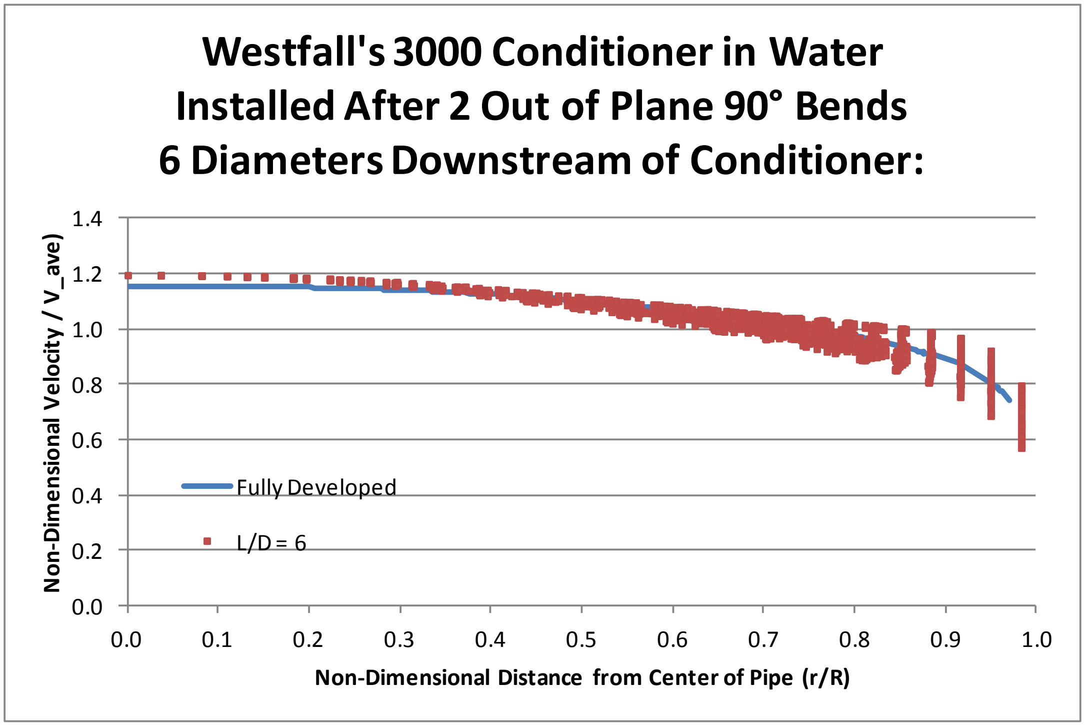
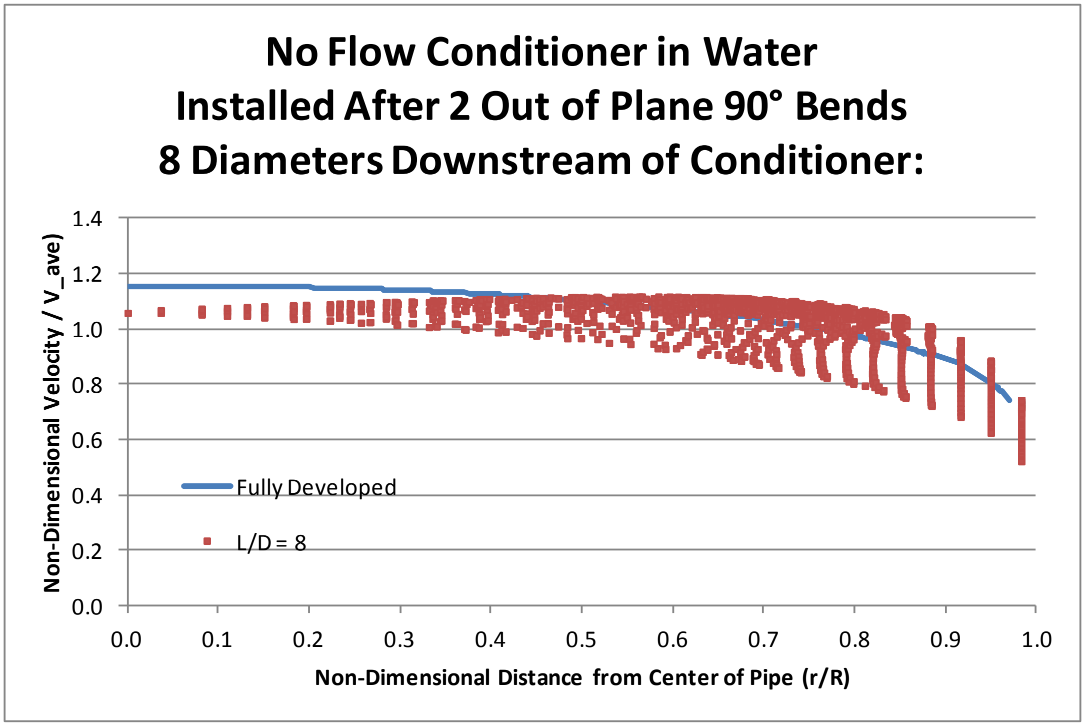


Figure 9 - Radial Uniformity of Flow Downstream of Conditioner Inlet at L/D = 6; Without Conditioner (top) and with Conditioner (bottom)



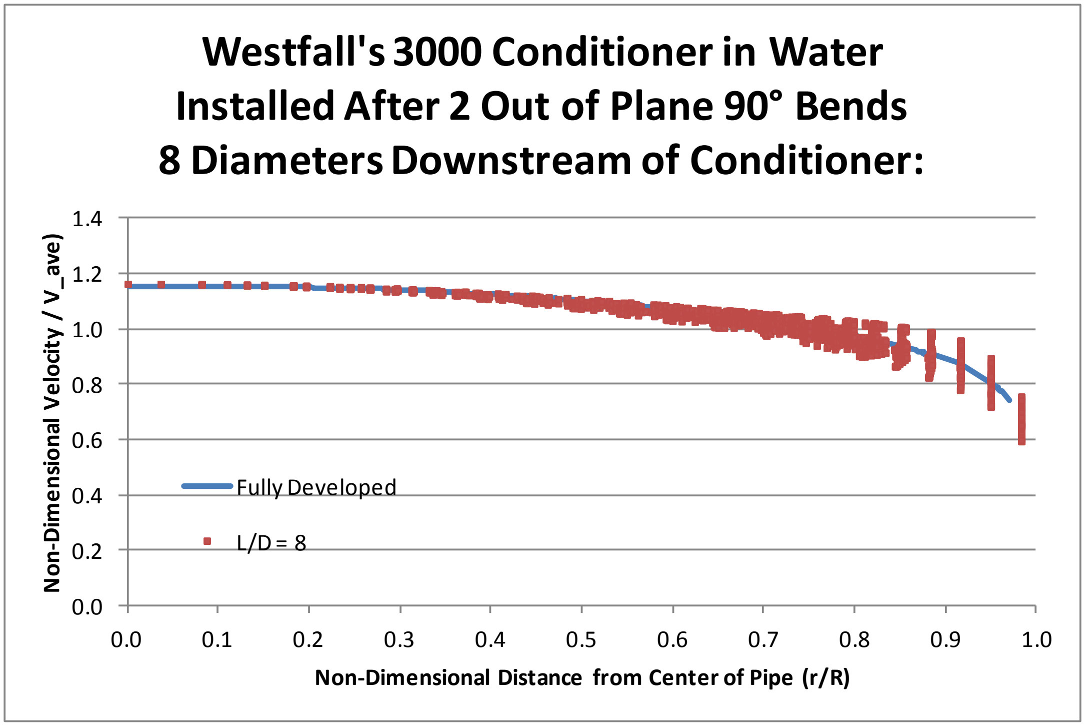
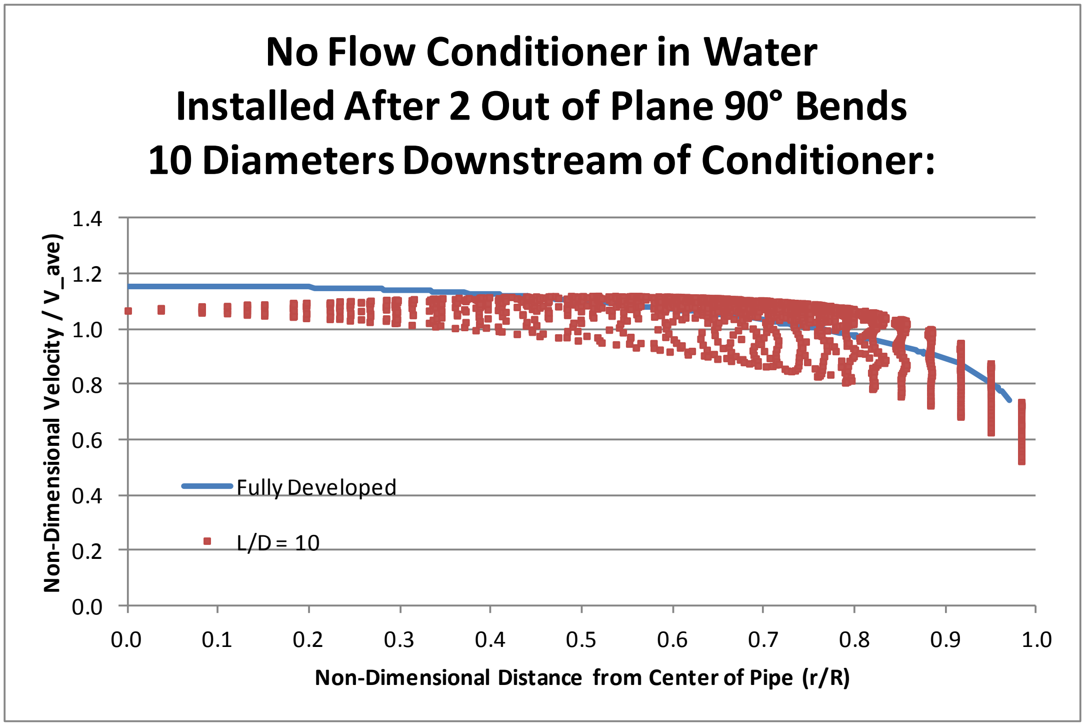


Figure 10 - Radial Uniformity of Flow Downstream of Conditioner Inlet at L/D = 8; Without Conditioner (top) and with Conditioner (bottom)



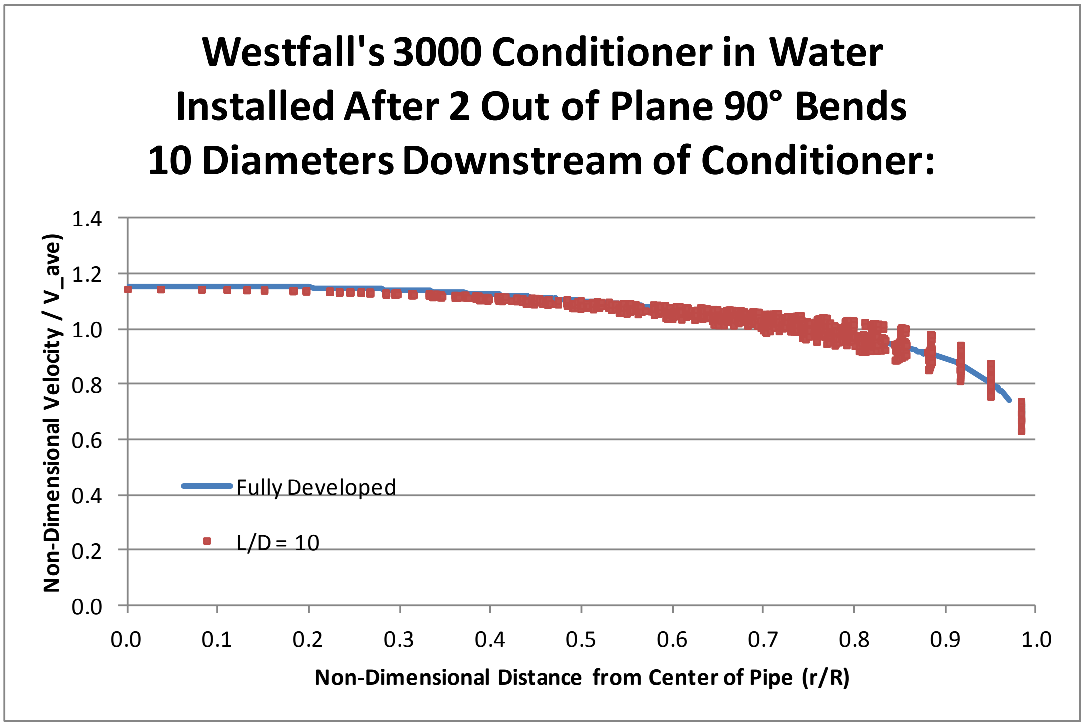
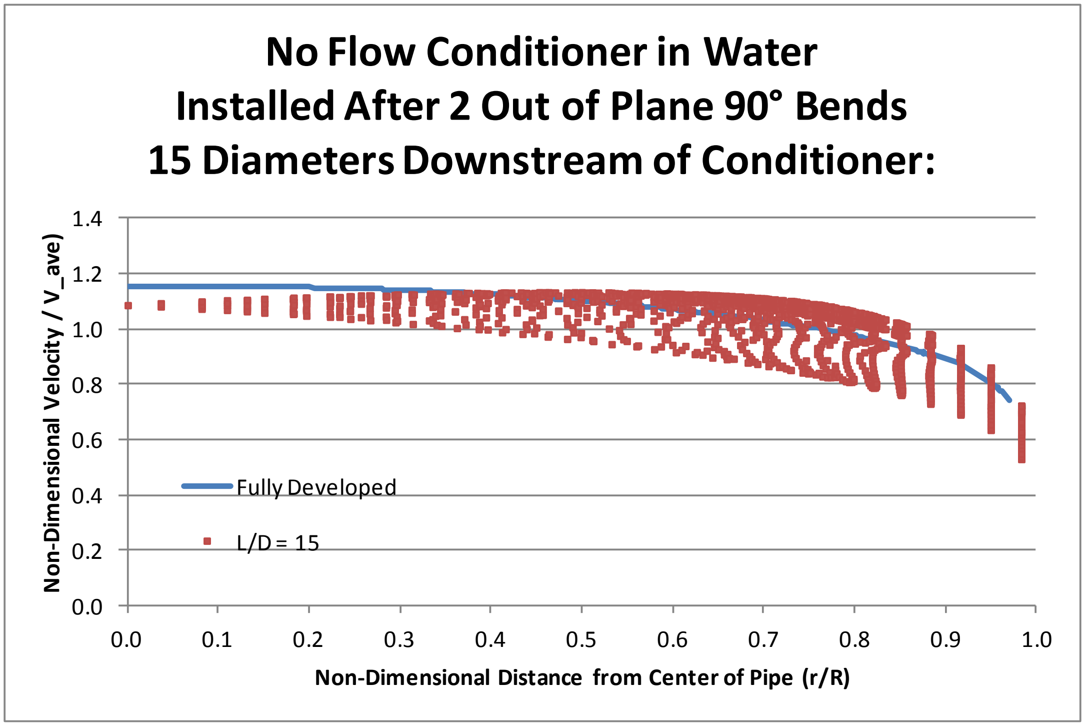


Figure 11 - Radial Uniformity of Flow Downstream of Conditioner Inlet at L/D = 10; Without Conditioner (top) and with Conditioner (bottom)



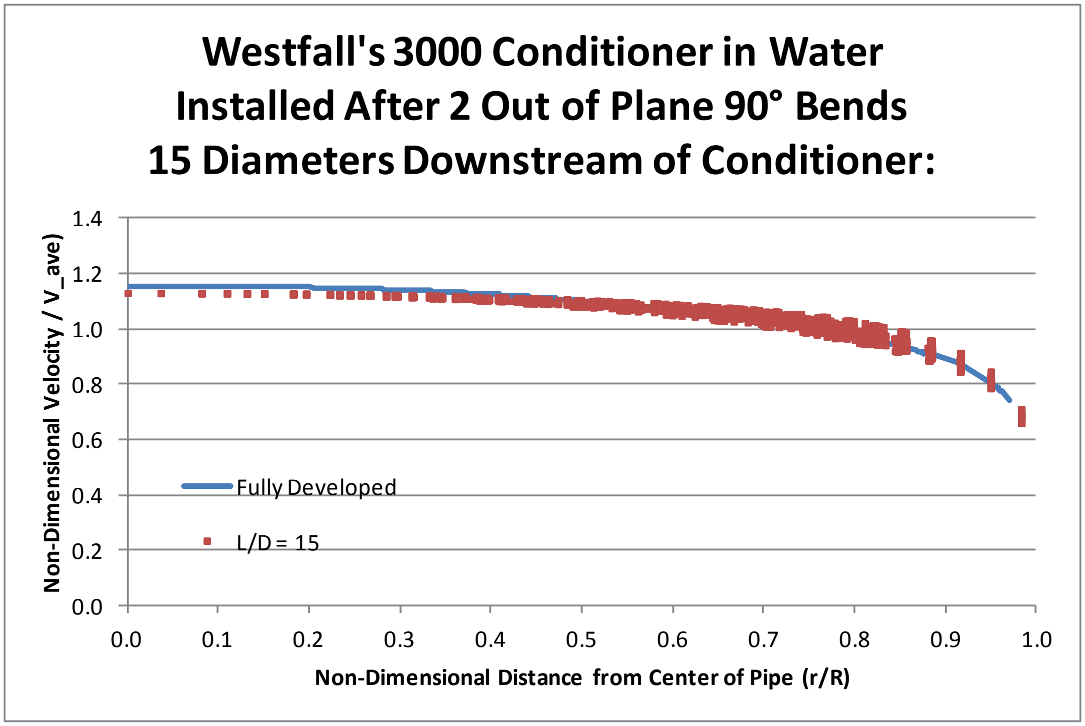
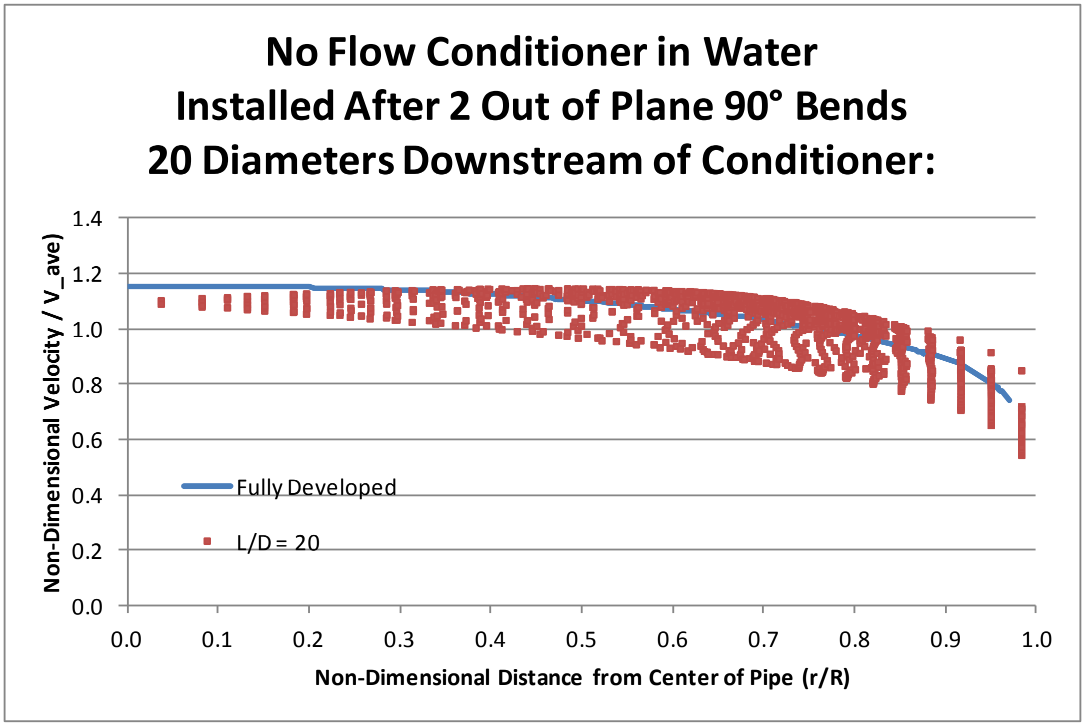


Figure 12 - Radial Uniformity of Flow Downstream of Conditioner Inlet at L/D = 15; Without Conditioner (top) and with Conditioner (bottom)



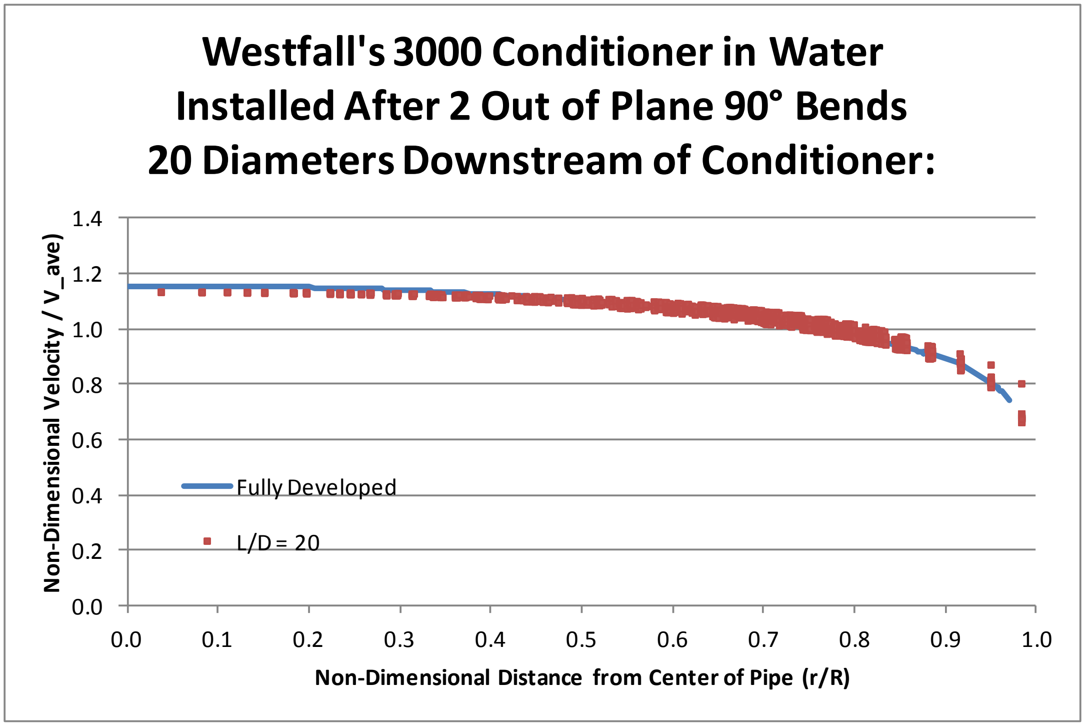


Figure 13 - Radial Uniformity of Flow Downstream of Conditioner Inlet at L/D = 20; Without Conditioner (top) and with Conditioner (bottom)