Quantitative Assessment of Secondary Flows of Single-phase Fluid through Pipe Bends

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ODU IDEA FUSION

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• **Introduction:** There are hundreds of processes within the industry where a fluid is required to pass through a pipeline system. Due to particle contamination within these fluids, erosion in the piping system is a concern. Replacement of eroded pipes is one of the major costs of maintenance, which is an obvious pitfall in the overall cost of operation in industries. The highest erosion rate is most commonly found in bends. In this research we propose to quantitatively analyze the secondary flow by measuring the flow intensity, vorticity magnitude (maximum, and their locations), maximum secondary velocity module, and mean secondary flow velocity of the flows evolution along the bend.

Computational Methods: Using COMSOL Multiphysics the predefined algorithmic equations solved, for both laminar and turbulent flow (k-ε) models, include the three dimensional Navier-Stokes equation also known as RANS for conservation of momentum and the continuity equation for conservation of mass. The mesh was created, and analyzed for sensitivity, based off of the most involved simulation that was computed (Re = 100,000; γ = 1.5; θ = 90˚) then used for all of the simulations included in this study.

Variables
- Reynolds numbers: 100, 1,000, 10,000, and 100,000
- Three curvature ratios (r/D): 1.5, 6.5, and 10
- Three sweep angles (θ): 22.5, 45, and 90 degrees

Parameters
- Flow intensity
- Vorticity magnitude (maximum and location)
- Maximum secondary velocity module
- Mean secondary flow velocity

Boundary Conditions
- Outlet - Pressure controlled
- Inlet - Velocity profile

Conclusions: As shown on these plots the secondary flow formed within the pipe, as the fluid passes through the elbow, generates two counter-rotating vortices. Although not quantified within this study, a relationship can be noted between the vorticity of the fluid and the dean vortical structures

Reynolds Numbers (i.e. Table 1 Rows: 1, 4, 7, 8; Table 2 Column A)
- The maximum secondary velocity module increases until reaching its maximum at the midsection of the elbow.

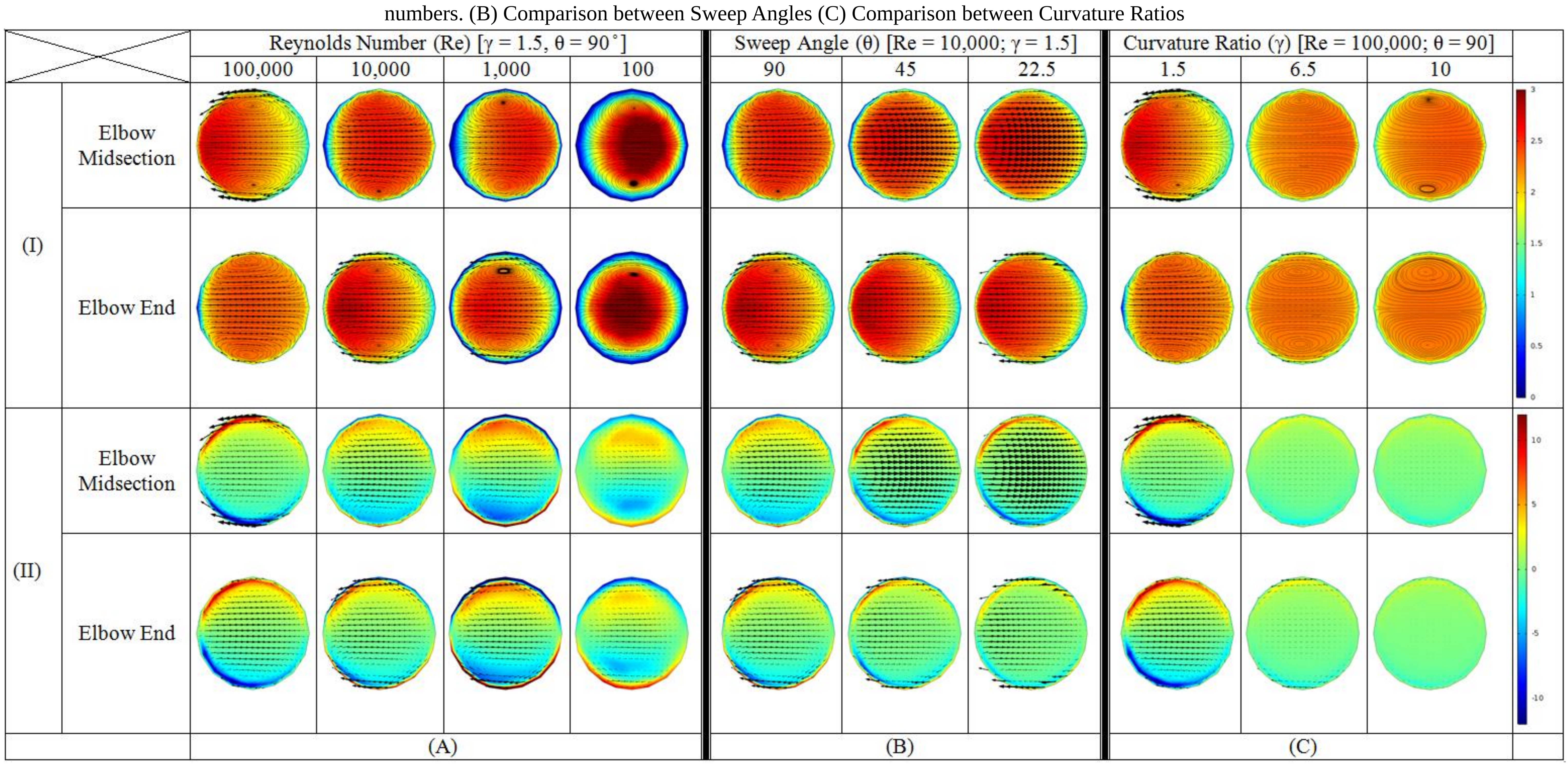
Curvature Ratios (i.e. Table 1 Rows: 1, 2, 3; Table 2 Column C)
- The location of the maximum vorticity at the exit of the pipe elbow are nearly identical.

Sweep Angles (i.e. Table 1 Rows: 4, 5, 6; Table 2 Column B)
- The highest magnitude of vorticity and secondary flow was noted for the 22.5 degree sweep which was not expected.

Table 3 Data for simulations presented on Table 2
(Highlighted are the maximum values within each simulation)

			Mean Axial Velocity [m/s]	Max In-Plane Velocity [m/s]		Maximum Vorticity [1/s]	Location r [m]	Location θ [deg]
1	Re = 100K, γ = 1.5, θ = 90	0 [deg]	3.95	0.50174	0.1270			
		45 [deg]		1.9899	0.5038	888.10	0.0119	17.5
		90 [deg]		1.08009	0.2734	1024.70	0.0119	22.4
		1D		0.60178	0.1523	256.05	0.0116	52.8
		2D		0.383144	0.0970	142.78	0.0108	32.3
		4D		0.1872	0.0474	73.65	0.0105	45.0
2	Re = 100K, γ = 6.5, θ = 90	0 [deg]	3.95	0.17915	0.0454			
		45 [deg]		0.72639	0.1839	288.02	0.0118	20.5
		90 [deg]		0.315492	0.0799	335.33	0.0119	22.5
		1D		0.19199	0.0486	65.72	0.0112	11.6
		2D		0.13132	0.0332	43.60	0.0102	17.3
		4D		0.073613	0.0186	25.62	0.0101	19.2
3	Re = 100K, γ = 10, θ = 90	0 [deg]	3.95	0.15231	0.0386			
		45 [deg]		0.25438	0.0644	187.07	0.0119	0.0
		90 [deg]		0.25936	0.0657	173.54	0.0119	22.5
		1D		0.16642	0.0421	61.06	0.0112	5.5
		2D		0.10782	0.0273	42.30	0.0103	-16.9
		4D		0.081286	0.0206	23.06	0.0103	7.5
4	Re = 10K, γ = 1.5, θ = 90	0 [deg]	0.395	0.051572	0.1306			
		45 [deg]		0.15443	0.3910	63.20	0.0116	31.2
		90 [deg]		0.11655	0.2951	46.23	0.0116	22.4
		1D		0.049049	0.1242	17.51	0.0098	37.1
		2D		0.027904	0.0706	8.72	0.0096	-0.9
		4D		0.011415	0.0289	3.32	0.0100	21.4
5	Re = 10K, γ = 1.5, θ = 45	0 [deg]	0.395	0.048251	0.1222			
		22.5 [deg]		0.1368	0.3463	61.52	0.0119	34.1
		45 [deg]		0.19145	0.4847	76.25	0.0119	45.0
		1D		0.067048	0.1697	14.15	0.0099	22.8
		2D		0.032423	0.0821	6.02	0.0100	36.8
		4D		0.018193	0.0461	1.66	0.0108	27.5
6	Re = 10K, γ = 1.5, θ = 22.5	0 [deg]	0.395	0.041351	0.1047			
		11.25 [deg]		0.16905	0.4280	32.63	0.0119	47.0
		22.5 [deg]		0.20866	0.5283	92.46	0.0119	46.3
		1D		0.070407	0.1782	12.24	0.0107	26.8
		2D		0.040671	0.1030	4.84	0.0104	12.5
		4D		0.012036	0.0305	1.75	0.0100	-7.4
7	Re = 1K, γ = 1.5, θ = 90	0 [deg]	0.0395	0.005117	0.1295			
		45 [deg]		0.022922	0.5803	5.85	0.0107	26.1
		90 [deg]		0.013305	0.3368	5.68	0.0107	12.8
		1D		0.0067318	0.1704	1.94	0.0096	37.4
		2D		0.0033499	0.0848	1.04	0.0078	2.8
		4D		0.0014049	0.0356	0.33	0.0087	3.1
8	Re = 100, γ = 1.5, θ = 90	0 [deg]	0.00395	0.00051575	0.1306			
		45 [deg]		0.0017538	0.4440	0.32	0.0081	8.4
		90 [deg]		0.001403	0.3552	0.34	0.0080	25.7
		1D		0.00037975	0.0961	0.10	0.0071	-14.0
		2D		0.00013363	0.0338			
		4D		0.00011435	0.0289			

Table 2. A comprehensive table for comparison. The top two rows represent axial flow and the bottom two rows represent vorticity. (A) Comparison between Reynolds numbers. (B) Comparison between Sweep Angles (C) Comparison between Curvature Ratios



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