MODELING ACOUSTIC MODES IN A CONTINUOUS LOOP PIPING SYSTEM

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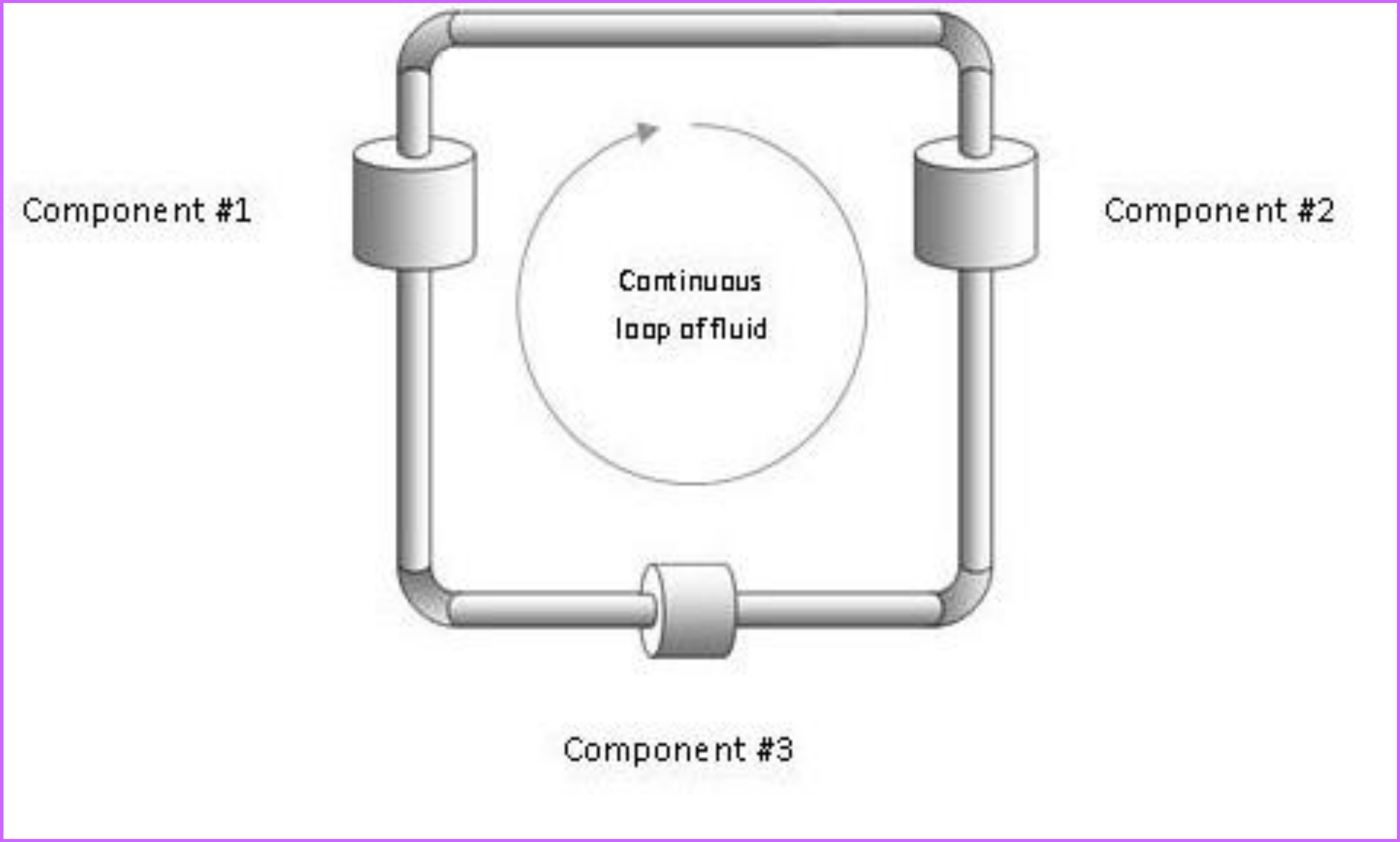
Background

- Closed loop piping systems are a series of inter-connected cylindrical shells intended to transport a fluid from one location to another and are widely used in industry.
- In these systems, the fluid passes from a starting point along a supply path to a location where the quantity within the fluid is transferred into another process through a component such as a heat exchanger, separator or hydraulic actuator. Once the quantity of interest has been transferred, the fluid is recirculated through a return leg to the original location forming a “continuous” loop of fluid.
- Two common examples are hydraulic and heating/coolant systems.

Motivation and Objective

- Fluid resonances can detrimentally impact the operation of fluid systems and components. The unwanted impacts of the fluid resonances include increased system noise, excessive component fatigue, interference with test measurements and monitoring instrumentation, improper system and potentially system or component failure.
- The purpose of the study was to accurately determine the frequency and mode shapes of low frequency axial fluid resonances within a system of piping and components that form a continuous loop.

Schematic of a Simple Closed Loop Piping System



Assumptions/Limitations

- Closed system; Free-free boundary condition
- Neglect body forces and the effects of pipe or component foundations
- The structures of the piping and component walls are assumed to be either rigid or linearly elastic (steel)
- The internal fluid (water) is a liquid and assumed to be free from bubbles or dissolved particulates. The fluid will also be assumed to be at rest and at a uniform temperature and pressure
- The axial loop resonances investigated are restricted to resonances of the lowest order axially symmetric radial mode or plane waves

Material and Piping Properties

Materials

Material	Property	Symbol	Metric Value	Metric Units	English Value	English Units
Steel	Young's Modulus	E	1.95E+11	Pa	2.8282E+7	psi
	Shear Modulus	G	8.30E+10	Pa	1.2038E+7	psi
	Poisson's Ratio	v	0.28	-	0.28	-
	Density	ρ	7700	kg/m^3	2.7818E-1	lb/in^3
	Speed of sound	c_G	6100	m/s	2.4016E+5	in/s
Aluminum	Young's Modulus	E	7.1E+10	Pa	1.0298E+7	psi
	Shear Modulus	G	2.4E+10	Pa	3.4809E+6	psi
	Poisson's Ratio	v	0.33	-	0.33	-
	Density	ρ	2700	kg/m^3	9.7543E-2	lb/in^3
	Speed of sound	c_G	6300	m/s	2.4803E+5	in/s
Water*	Density	ρ	998	kg/m^3	3.6055E-2	lb/in^3
	Speed of Sound	c_0	1481	m/s	58307.1	in/s
	Bulk Modulus	B_f	2.18E+9	Pa	3.1618E+5	psi

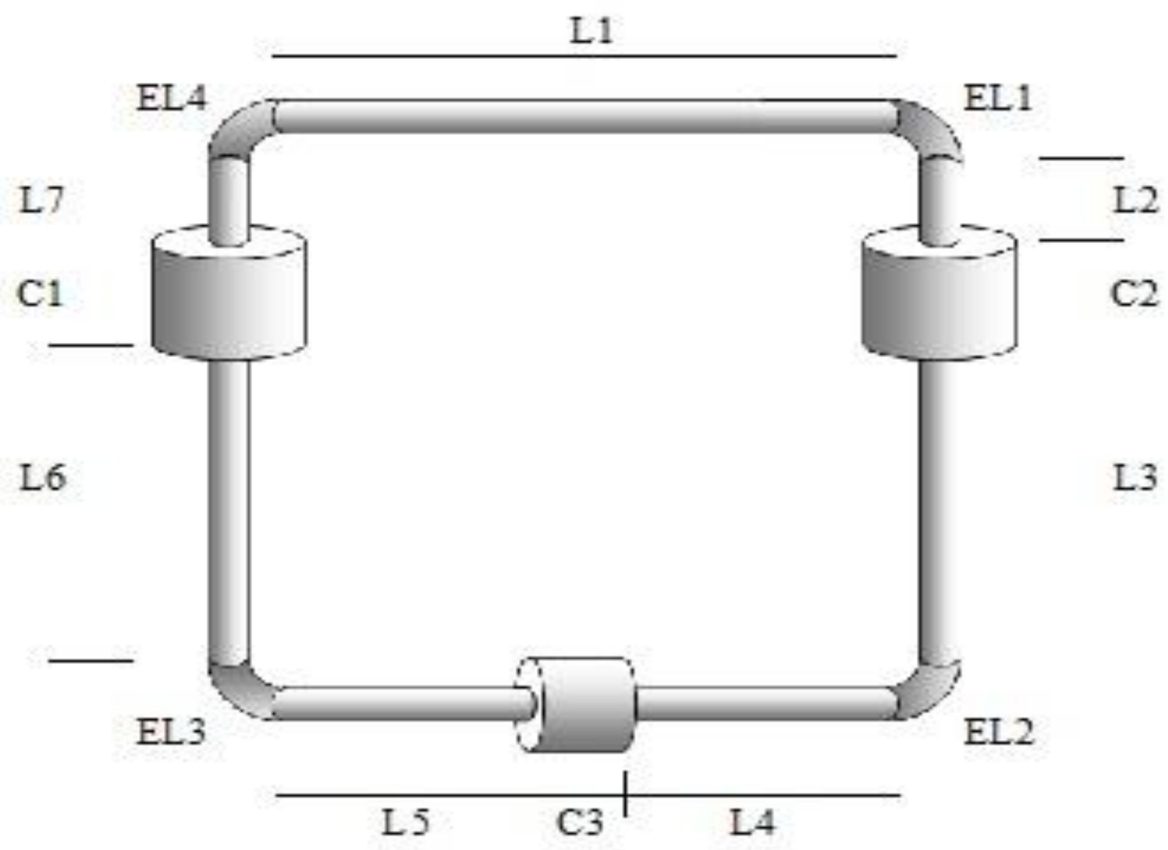
* Water is at 20 °C and 1 atm

Piping

Pipe		Metric	units	English	units
Schedule	-	80	-	80	-
Nominal Pipe Size	NPS	10	-	10	-
Outer Diameter	OD	27.305	cm	10.75	in
Inner Diameter	ID	24.29256	cm	9.564	in
Thickness	h	1.50622	cm	0.593	in
Radius	a	12.14628	cm	4.782	in

Long Radius Elbow		Metric	units	English	units
Outer Diameter	OD	27.305	cm	10.75	in
Inner Diameter	ID	24.29256	cm	9.564	in
Thickness	h	1.50622	cm	0.593	in
Bend Radius	R_E	38.1	cm	(1.5*NPS) = 15	in
Bend Angle	β_E	$\pi/2$	rad	90	deg
Center Line Length	L_{CL}	59.84723	cm	23.5619	in

Closed Loop Piping System Schematic



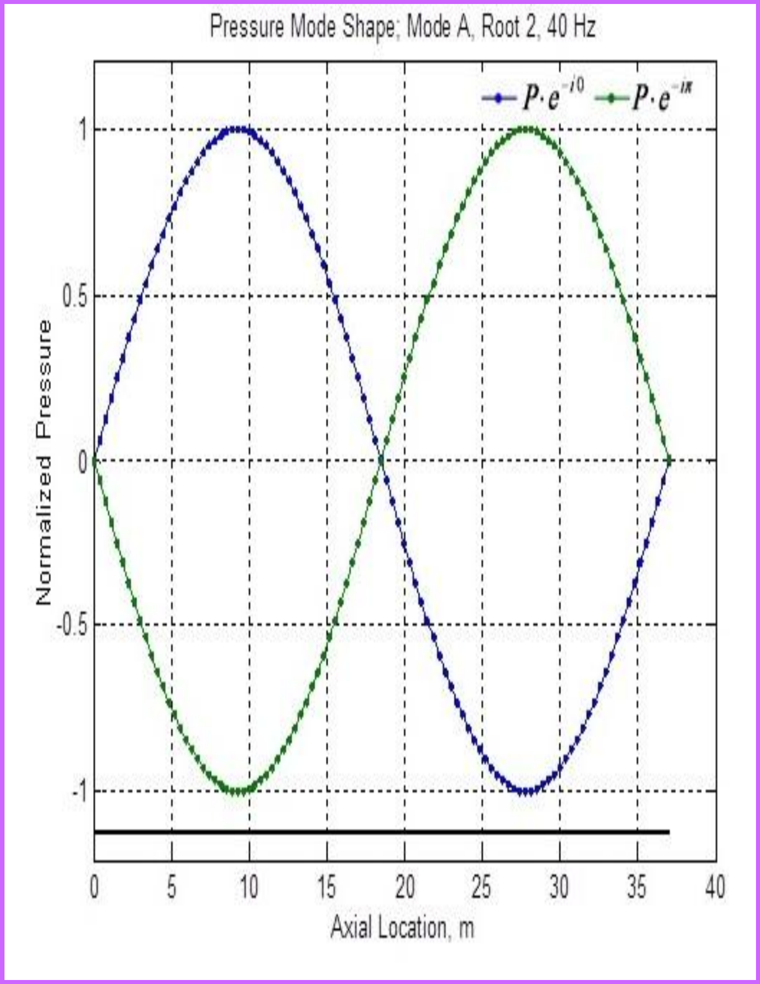
Closed Loop Piping System Details

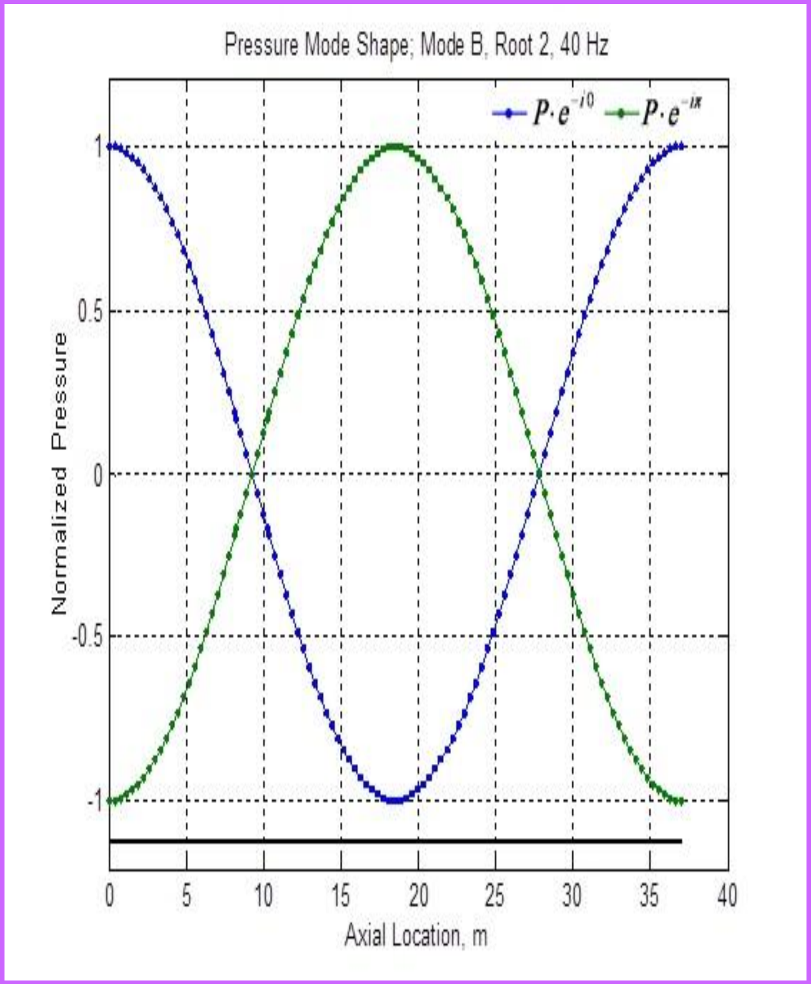
Segment	#	Metric	Units	English	Units
Length 1	L1	865.7777	cm	2199.075	in
Elbow 1	EL1	59.84723	cm	23.5619	in
Length 2	L2	166.44	cm	422.7576	in
Component 2	C2	100	cm	254	in
Length 3	L3	599.3377	cm	1522.318	in
Elbow 2	EL2	59.84723	cm	23.5619	in
Length 4	L4	416.8885	cm	599.3377	in
Component 3	C3	33.0	cm	0.8382	in
Length 5	L5	416.8885	cm	599.3377	in
Elbow 3	EL3	59.84723	cm	23.5619	in
Length 6	L6	599.3377	cm	1522.318	in
Component 1	C1	100	cm	254	in
Length 7	L7	166.44	cm	422.7576	in
Elbow 4	EL4	59.84723	cm	23.5619	in

Governing Equation

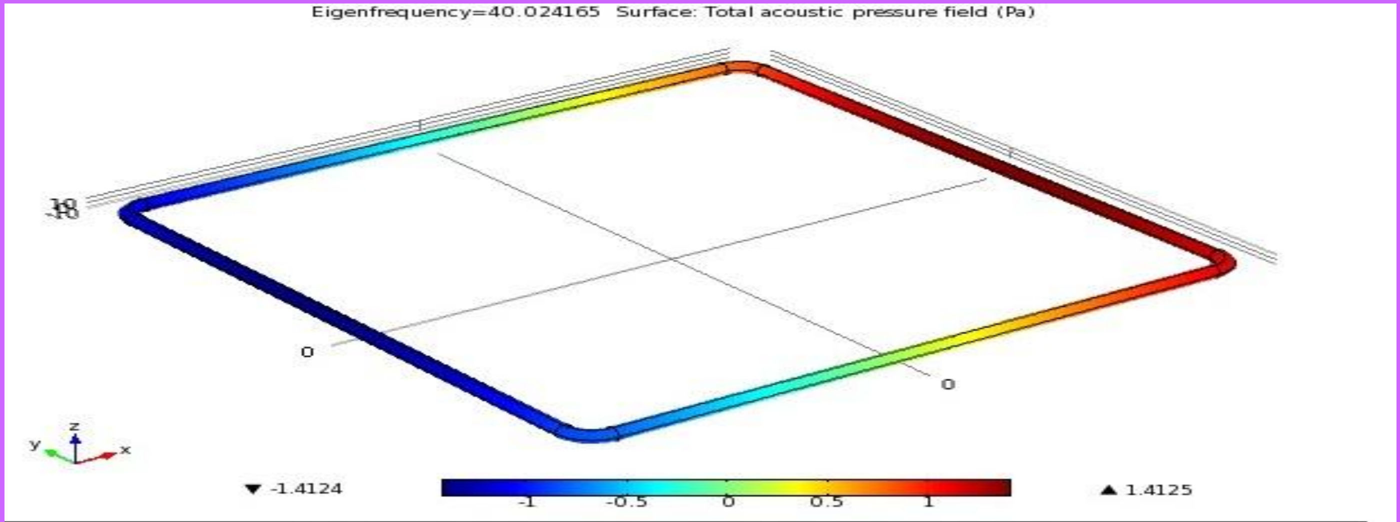
$$\nabla^2 p - \left(\frac{1}{c_o^2}\right)\frac{\partial^2 p}{\partial t^2} = 0$$

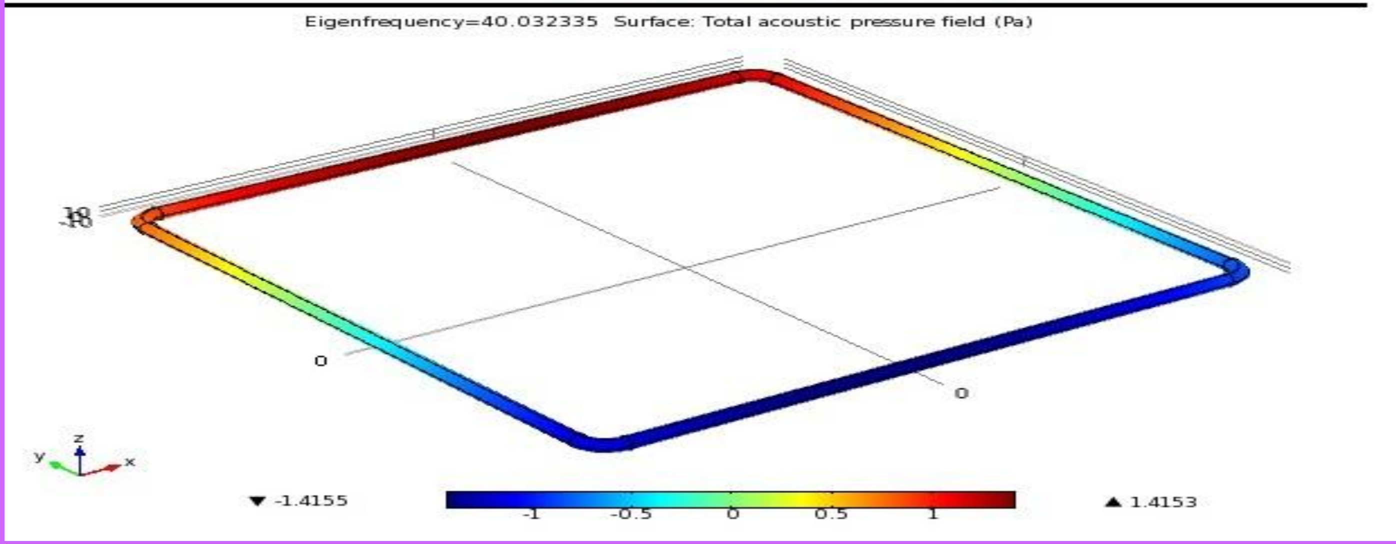
Results: Pressure Mode Shapes
Baseline (uniform) Loop
Transfer Matrix Method



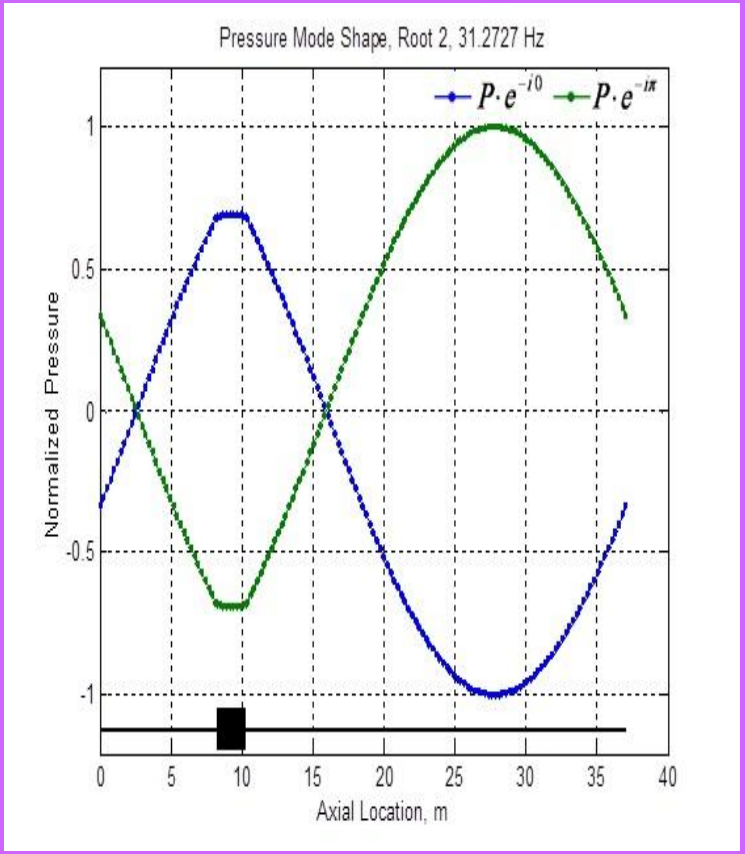


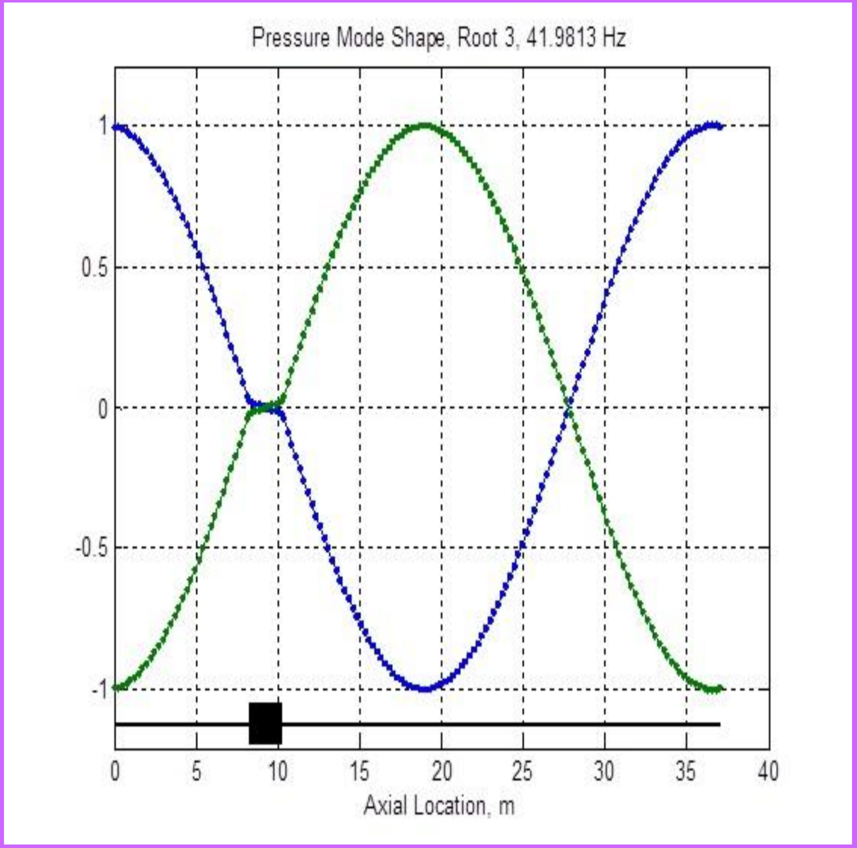
Pressure Mode Shapes
Baseline (Uniform) Loop - COMSOL



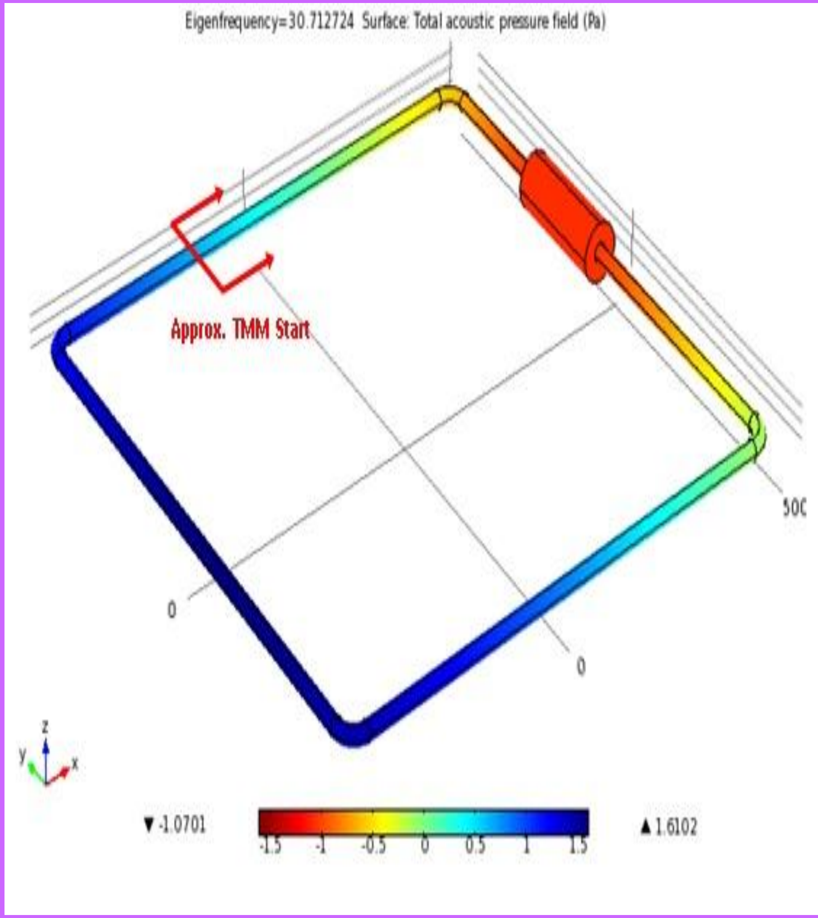


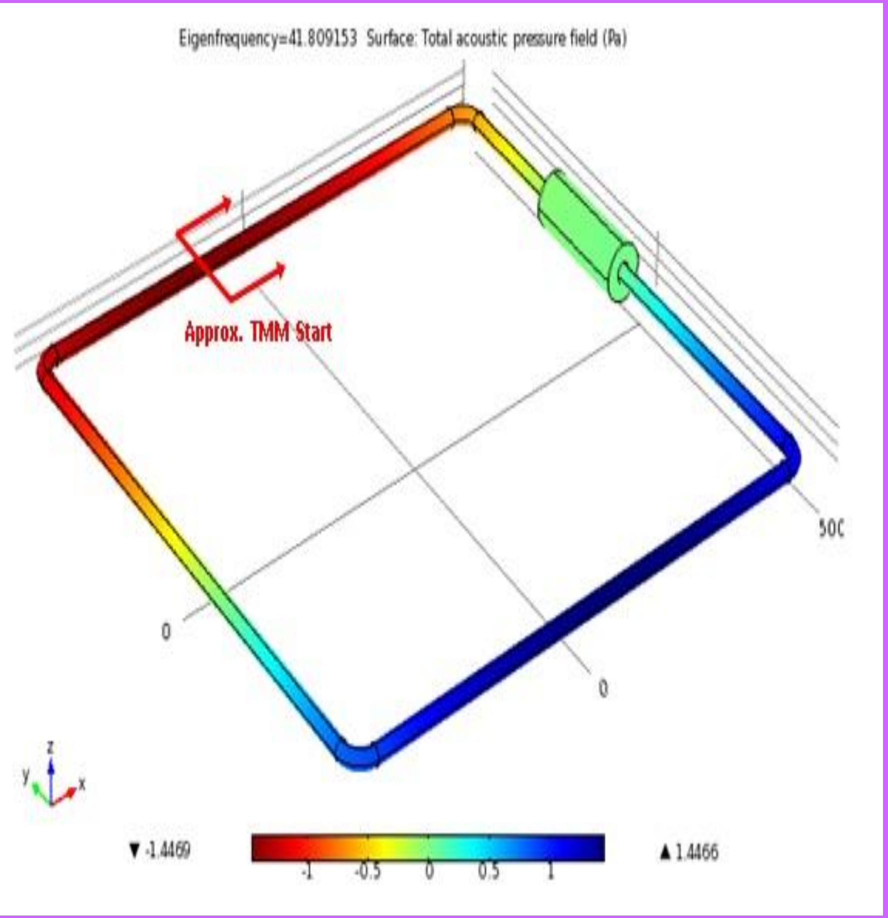
Results: Pressure Mode Shapes
Loop with One Cavity
Transfer Matrix Method



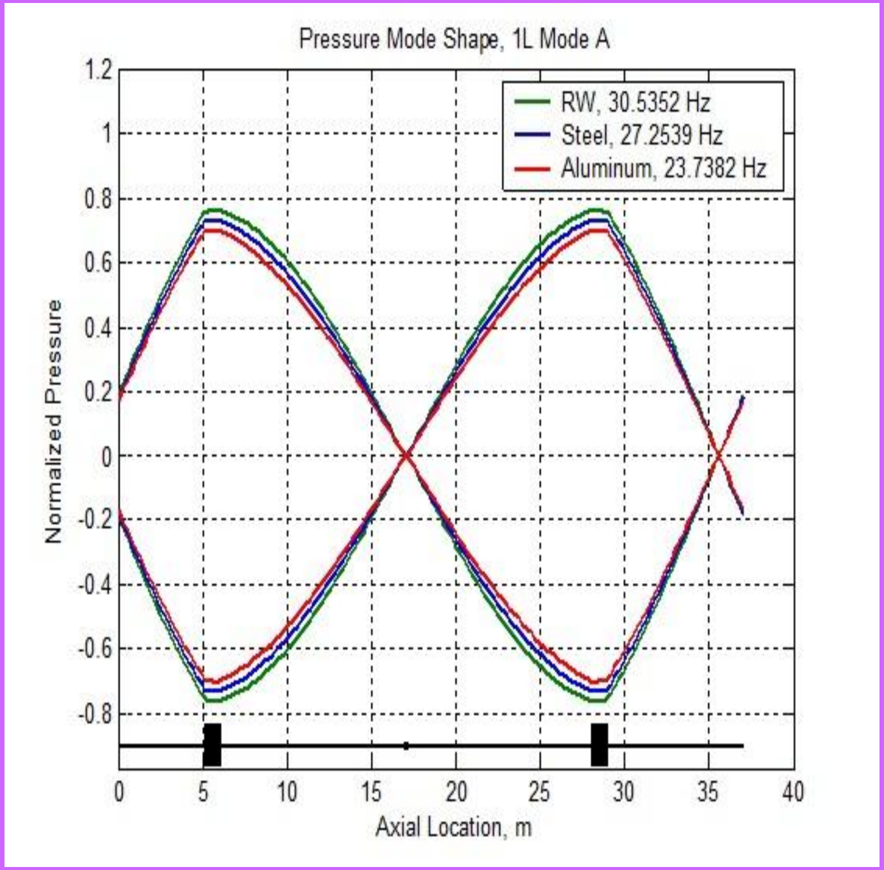


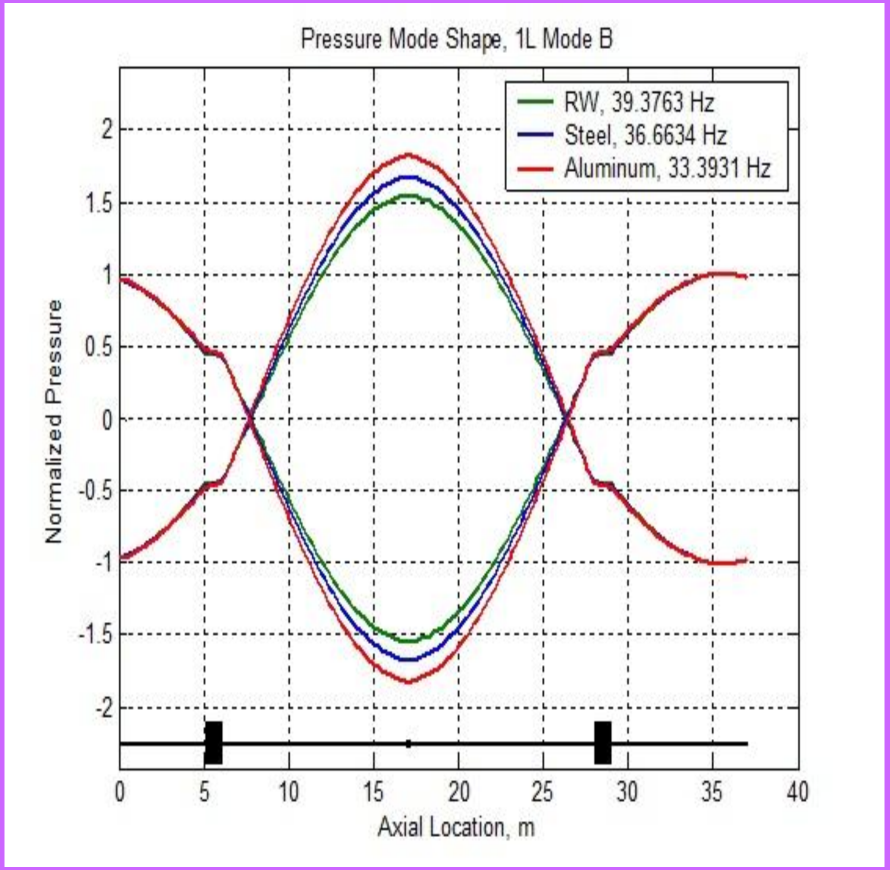
Results: Pressure Mode Shapes
Loop with One Cavity
COMSOL



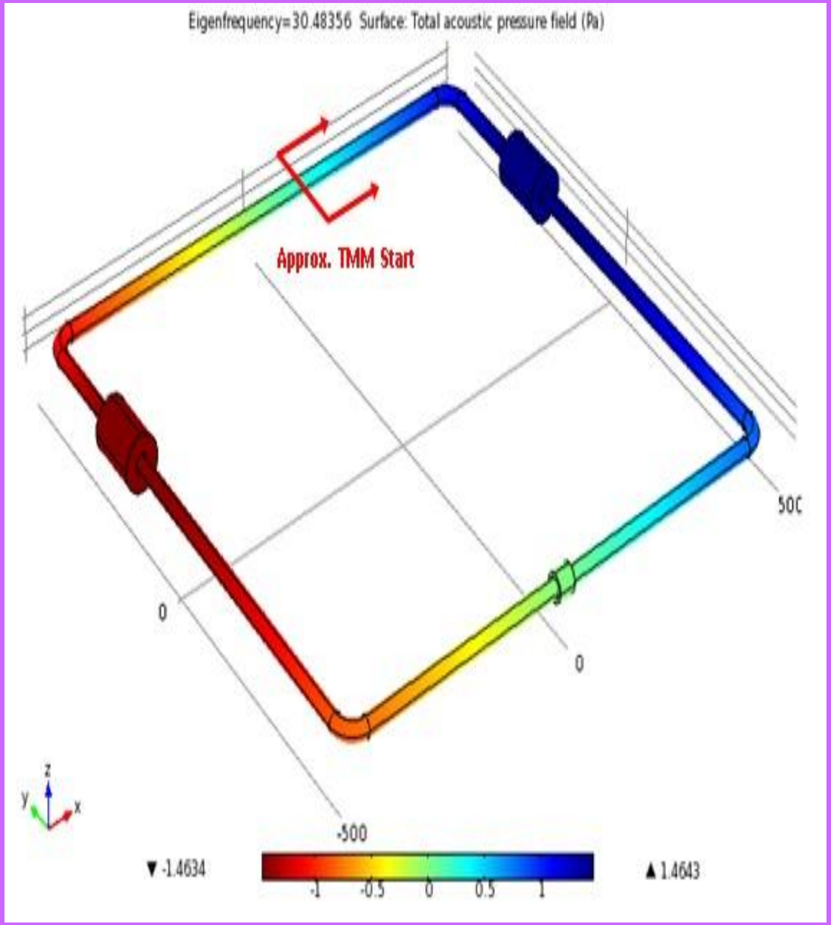


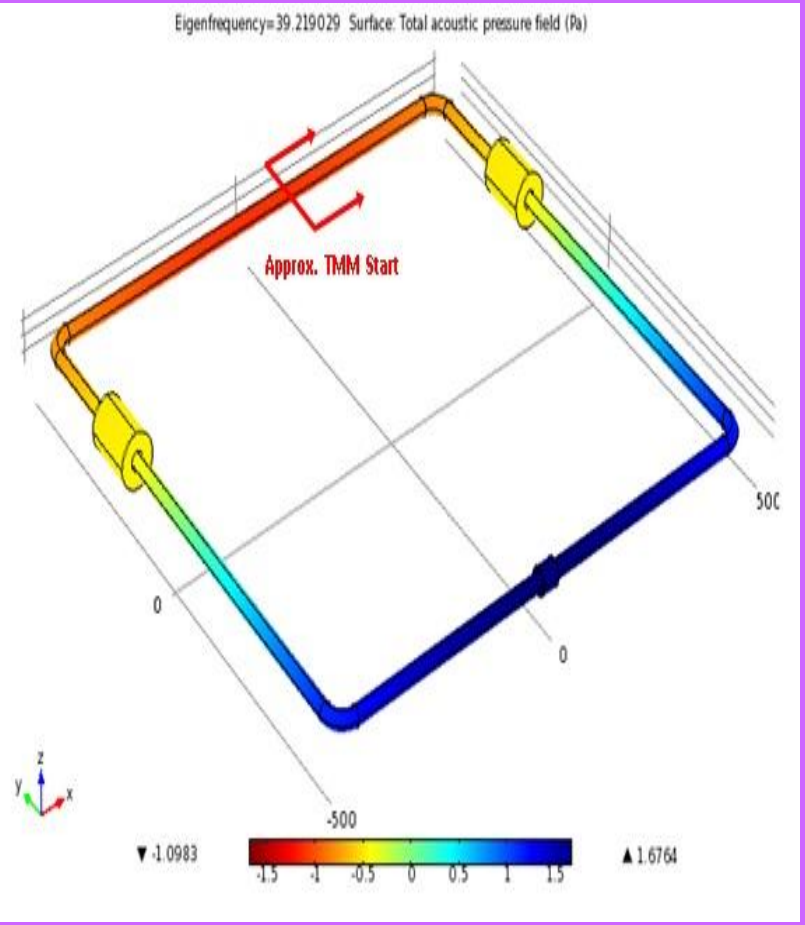
Results: Pressure Mode Shapes
Loop with Three Cavities
Transfer Matrix Method





Results: Pressure Mode Shapes
Loop with Three Cavities
COMSOL





Summary

- The pressure mode shapes were found to have a "kink" at the locations of the impedance and phase angle discontinuities.
- The changes in the frequency and mode shapes of the axial loop modes were much larger due to the impedance discontinuities than the changes in phase velocity due to the elasticity of the cylindrical components and piping.
- The frequencies and modes shapes of the axial loop modes calculated by the COMSOL FE models were in good agreement with acoustic theory and the results from the TMM models.
- For details refer to Mr. Marderness RPI Thesis (www.ewp.rpi.edu/~ernesto/SPR.html) or contact him directly at marderness2@sbcglobal.net