Muffler Acoustics - Application to Automotive Exhaust Noise Control

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Week-12
Lecture – 60

Summary of the Topics Covered in This Course, Topics to be Covered in a Future

Welcome to the final lecture of this week as well as for this course on NPTEL course on Muffler Acoustics. So, you know we have we are there in lecture essentially lecture 60.

Because, there is a 12 week course. So, some of the lectures so far we are combined, or lecture 5 of week 12.

So, you know the idea of this lecture is not to the objective here is not to again get into technical discussions of sorts, you know this will be a relatively a shorter lecture and what we will probably do is just you know have a detailed summary of the ground covered so far that is all the topics that we have discussed in detail so far.

And, muffler acoustics being a you know significantly you know a pretty wide field, you know a lot of things have to be covered in properly designing and coming up with the final muffler product lot of topics because of that could not be covered. And, those things can be covered in the next advance course on experimental and numerical techniques and muffler acoustics.

So, the idea is basically to give a very holistic very overall view of the things that we have covered so far. We have learned the principle, the concepts that we have developed MATLAB demonstrations using planar, wave theory, or the 3 dimensional analysis although only a glimpse of that was seen. You know other than that what else can be covered, we can probably have a look at it.

So, you know let us first look at the topics that we covered so far and you know things that we did. So, basically we you know we started off we basically started off with our wave equation. So, development of the wave equation one dimensional wave equation, this is summary of all the topics covered so far.

Summary of Topics Covered in this Course on Muffler Acoustics.

- WAVE EQUATION
- D Alembert's solution D Alembert's solution
- 1-D Helmholtz equation; and propagation in 1-D pipes
- Pipe Carrying Mean Flow, And 1-D Case/ Derivation and Solution
- 3 Dimensional Modal Summation in Rectangular, and Circular Waveguides and Concepts of Cut on Frequency
- SPL Sound Pressure Level the Concept of that, and Intensity Level and Sound Power Level

So, wave equation development is something that we did the one dimensional wave equation and D Alembert's solution D Alembert's solution. So, this is the; the topics that I am writing now is not exhausted, some of the topics I might be missing. But, then wave equation development D Alembert's solution and you know we derived the, you know we basically stated different assumptions to derived the wave equation and the transient solution, that is basically your D Alembert's solution.

And, then we did basically 1-D Helmholtz equation; 1 dimensional Helmholtz equation and propagation in 1-D pipes in 1-dimensional pipes ok. And, then we did we first we introduced a 3 dimensional modal summation in rectangular, and circular waveguides for that we covered. And, you know all those things helped us in you know later parts of the course when we did the perforated tube analysis, where we defined the aero acoustic state variables ok.

So, this is we did this thing Derivation and Solution ok, we did that. And, then we did the 3 Dimensional Modal Summation; Modal Summation 3-D modal summation in rectangular, and circular waveguides, and concepts of cut on frequency. So, this would have helped you when you, you know in the last few lectures and also lectures of week 11, and this will all these things will help you in the advanced course that we might I might offer and you can consider taking that as well.

So, and then you have your sound pressure level, SPL sound pressure level the concept of that, and intensity level and sound power level you know, sound power level is also something that we what we did.

Acoustic Impedance and Reflection Coefficients Considered Reflection Coefficient Lumped System Analysis, Inertance, Compliance

- Concept of End Correction in Pipes
- Helmholtz Resonator
- Acoustic Analogy and Layout, and a General Layout of a Engine System
- TL, IL & LD
- Heart of a Muffler Sudden Area Expansion
- Simple Expansion Chamber
- Extended Inlet and Outlet Muffler (MATLAB, 1-D & 3-D different models different models covered)

And, then we did you know acoustic impedance it first talked about the concept of acoustic impedance, and reflection coefficients we considered reflection coefficient.

And, lumped system analysis we did lumped system analysis. And, inertance, compliance you know all these things had helped us in understanding the you know, the; the basic behavior of you know tubular elements, or Helmholtz resonator cavity, or quarter wave resonator cavities and those sort of things. And, then its only after this that we considered you know the concept of end correction.

Concept of end correction in pipes which are open to the atmosphere or with a flange or without a flange, and Helmholtz resonator. And, most importantly we; we for the first time we had a look at the electro acoustic analogy and layout, and a general layout of a engine system ok, of an overall engine system ok.

So, we did that, and then we defined the muffler performance measure transmission loss, insertion loss, and level difference, and kind of talked in detail under what conditions which parameter is important. Transmission was something that we can compute well, insertion loss is something that we can measure well.

And, level difference is something you know probably very easy to measure compared to insertion loss. But, insertion loss is something that what matters to us the most, whether the thing is working or not in a given frequency range, that takes into account the; the source parameters, source considerations as well.

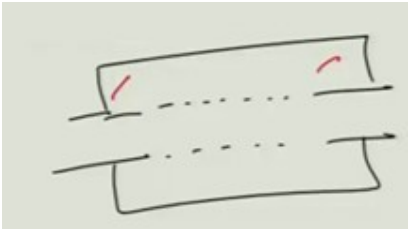
And, then we did a lot of lumped system analysis for a tube lumped analysis, actually I can write it here lumped analysis of a tube. And, then the heart of the muffler that is your heart of a muffler that is your sudden area expansion ok. Sudden area expansion, that is the heart of this of all reactive mufflers. So, we did that and then simple expansion chamber, we did MATLAB plot and analysis of that.

Simple expansion chamber, extended inlet and outlet muffler which we are considering, even until the last point including 3 dimensional effects extended outlet muffler.

And, this is all using MATLAB, but planar wave 1-D as well as 3-D using different models ok, different models we covered and we did lot of MATLAB analysis.

Variable Area Ducts => Conical Mufflers

- Perforated Muffler System
- Review of Different Perforate Impedance Expressions
- CTR Concentric Tube Resonator => Double Tuning of Such System
- Differential Length
- Effect of Grazing Mean Flow on Perforate Impedance and TL Performance
- Cross Flow Perforated Mufflers Like For Example,
- Plug Flow, Etc.
- Multi Pass Perforated Mufflers
- Integrated Transfer Matrix Approach & Network Analysis



And, then variable area ducts, variable area ducts, conical mufflers. And, then we did we spent a lot of time on perforated muffler system ok, perforated muffler system. So, this in this involved you know review of different perforate impedance expressions. This involved a review of a lot of perforated impedance expressions which is used in the literature.

And, then we did a simple CTR that is concentric tube resonator and talked about how to tune it. Concentric tube resonators one of the most important configurations that we are considering in this course, you know something like this. Let me draw this guy again here. So, these extensions were formed at the inlet and outlet and they double tune this thing.

So, double tuning of such systems double tuning of such system. Double tuning actually using a concept of differential length to double tune it ok. And, then we have your the effect of mean flow effect of grazing mean flow on perforate impedance and TL performance ok, we did a lot of that study as well. And, then we considered a cross; cross flow configuration, you know I am not going to do that right now, show that right now. But, basically cross flow perforated mufflers like for example, plug flow etcetera plug flow mufflers, and multi pass perforated tube mufflers, multi pass perforated mufflers.

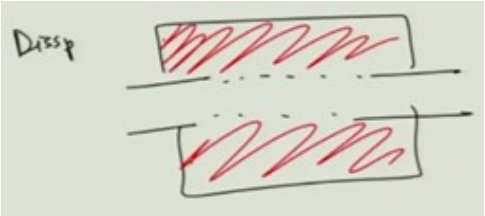
And, did advance muffler analysis you know using integrated transfer matrix approach; and your network analysis of such perforated systems, network analysis. And, other thing actually I probably I am sort of missing here is; obviously, CCTR - conical concentric tube resonator which is a straight through configuration. But, we did we briefly had a look at that as well, and you know detailed development of all these things we did.

But all these things was done within the category of 1 dimensional analysis with the understanding that you know higher order modes are generated at such things. But, then we are taking into account the effect of higher order modes through some end connections which you just briefly mentioned ok.

So, 3-D analysis of such things have not yet been done, and we just did the 1-D analysis. And, then of course, we had multiply connected mufflers ok. Multiply connected muffler systems like Herschel Quincke tubes, and you know multi pass perforate tube mufflers using network analysis like I mentioned.

Multiply Connected Muffler Systems

- 3 Dimensional Analytical Modeling => Piston Driven Model
- Greens Function
- Mode Matching



And, then we you know for the first time we did something like you know 3 dimensional analytical modeling of some simple systems. And, analytical modeling using different approach like piston driven model, Greens function model, piston driven model, Greens function, and mode matching.

And, we showed that mode matching you know is important for systems like extended inlet and outlet. But, then we really have to if the port the port diameter is small we can just consider only planar waves in the port and still we are going to get good results. And, you know then we kind of had a very very something like introduction to an introduction for a dissipative you know something like this kind of a muffler system.

I just ran some MATLAB codes to demonstrate what was going on if I fill this up with a dissipative material. So, you know we covered a lot of topics, but mean flow was not by and large not quite included here, mean flow was not included. But, I guess what we probably could do is basically you know we have covered a lot of ground, but things that could not be covered because of lack of time in this course, and detailed development of equations, MATLAB demonstration.

Some of the topics these topics which have to be covered in a future course.

Numerical and Experimental Methods For Muffler Acoustics

- Numerical Mode Matching Of Perforated Muffler Components + Dissipative
- Dissipative Mufflers => Equation Development
- Lined Duct Muffler
- Hybrid Mufflers.
- Lined Bends, And Parallel Baffle Mufflers
- Plenum Chambers
- Lined Plenum Chambers
- Parallel Baffle Mufflers
- Plenum Chambers
- Absorptive Material

Something like you know numerical and experimental methods, a short course on muffler acoustics on experimental methods for muffler acoustics. Is basically, you know things like numerical mode matching; of well perforated muffler components. Because, everyone uses perforated, perforated plus dissipative muffler components.

Detailed analysis of dissipative mufflers like you know they are things like parallel baffle muffler, dissipative mufflers like for example, some of the topics that you can find on the website we could not quite cover. Development of equations, lined duct muffler, hybrid mufflers. And, your you know lined bends, and parallel baffle mufflers, plenum chambers, lined plenum chambers, parallel baffle mufflers, and your plenum chambers and so on.

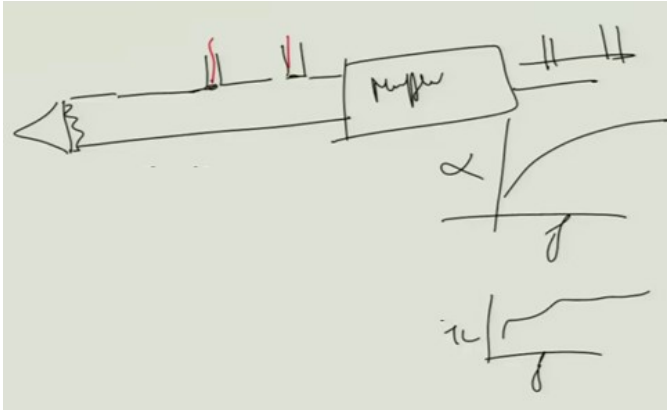
And, then you know all there is a detailed review of the absorptive materials; you know some properties of that delanian base lease coefficients. And, you know detail analysis of such configurations have not quite been done. And, other because these things are use they are used industry this is also used in the a lot in actual applications.

Impedance Tube Measurements

Other thing is of course, you know experimental things for example, which include you know impedance tube measurements, which comprises a host of large range of techniques to measure the, you know the absorptivity coefficient. So, if you have microphone like this you know microphone going in the tube like this and you are putting up a specimen, you have a loudspeaker excitation here.

- Two Source Methods
- Two Load Methods
- Analyzing A Real Time Or Commercial Muffler
- CFD Analysis of Flow Paths in Mufflers.

And, putting a specimen something like here back with the rigid cavity with air.

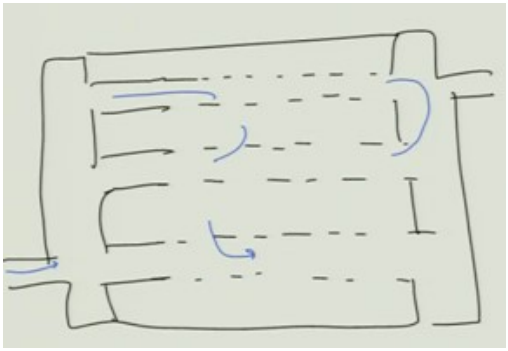


And, you are trying to figure out what the noise would be from the microphones here and finding out the alpha absorption coefficient versus frequency something like this. And, using such a system if you basically you know put a muffler here, muffler one muffler proper and two microphones here.

So, two source two well two source method using 4 microphones that is reverse the direction of the source and get equations, or two load methods using transfer functions and comparison of different methods and so on. So, you know the detailed analysis of such a thing has not quite been covered in this course. So, numerical and experimental methods for such muffler configuration are something that has not quite been covered.

And, also other thing is that something like a reverse engineering not quite, reverse engineering I would say you know analyzing a real time or commercial muffler which is used in automobiles. And development you know employ all the methods 1-D analysis as well as 3-D analysis to analyze the transmission loss performance of such a system whatever it is there.

But before you do that you must also have an another technique basically a CFD computational fluid dynamics analysis of the flow of flow paths in mufflers. So, what it does is that it is going to show you different you know different path. For example, if you have a complicated muffler system like you know 3 paths perforated duct something like this



So, so this is your thing, this is something that you should be familiar with now. So, what happens when you have a flow going in here and coming out and all that sort of a thing. So, we basically don't know how the flow will go around. So, basically Munjal and his colleagues, his students have developed the flow resistance 1 dimensional theory to predict to give an approximate value of flow distribution, through these perforated pipes as well as in the chamber through some approximations.

And, especially in the perforated pipe the flow distribution is important. Because, that will help us to evaluate the dissipative effect of muffler, dissipative effect of perforated impedance. And, using that we can sort of find out the transmission loss performance. But, you know all these 1 dimensional flow resistance theory has to be corroborated by a proper CFD analysis you know using some commercial software.

So, a detailed analysis of the flow, mean flow and such mufflers is also of important. Because, that so, because such mean flow expressions can then be used in the perforate impedance expression to find out the actual real time resistance offered by the perforates for a given frequency, range and for a given operating speed.

So, you know a detailed course on you know these 2 or 3 topics numerical analysis, dissipative mufflers of both the reactive, dissipative combined experimental methods and demonstration and CFD analysis of such a thing. And, then employing all these things to develop a, analyze a commercial muffler suggest some changes to enhance the performance of such a thing would be very handy indeed.

And, once we are able to do that we will come up with a final product of how are we going to develop a commercial muffler and also large industrial mufflers. So, that is something I have not really covered. So, you know those mufflers are really something like one 1, 1, 1, 1.25 meters in cross dimension that is diameter length could be 2 meters

or you know or more. And, you know such things are used a lot in excavation operations and stuff like that.

So, a detailed analysis of such a thing is also very important. So, all these advanced topics will be covered in the possibly in the later course at a suitable time. And, so we have in; in this way we can develop a very niche area of analyzing such muffler components.

So, what I will do is that I will stop the lecture, here stop the course here. And, you know see you all of you guys some interested participants at some later point in future where hopefully we have more such topics for discussion. And, perhaps some laboratory demonstration as well, just like we had MATLAB demonstrations such demonstrations can also be done on MATLAB, or 3-D analysis, or on a commercial software like you know different things are there.

So, and then possibly some impedance tube demonstrations can also happen. So, all these things will be there, and till that time what I will do is that I will stop here and I will see you in the sometime in future. So, thanks a lot.