Muffler Acoustics-Application to Automotive Exhaust Noise Control

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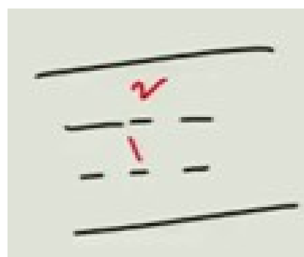
Lecture - 40
MATLAB Demonstration for Fully and Partially Perforated CTR

Welcome to lecture 5 of week 8. So, this is the final lecture for this week and all the momentum that we have been building to finally demonstrate the MATLAB results the MATLAB plots some simulation in MATLAB for the CTR; that is what we are going to do in this lecture. So, before we do that. Let us just very briefly review what we had done in the last thing.

So, this, these were the slides for the last class. You know you see these equations,



$$\frac{d}{dz}[\Delta]\{X\} = [A]\{X\}$$

$$\{X\} = \begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ p_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}$$

$$\frac{d\{X\}}{dz} = [B^{-1}][A]\{X\}$$

Where, X is your vector which was written in this manner and we found out that once we do B inverse A and what we have calling this as matrix C. Now, we had purposely recast them. These equations in a manner which is basically rearranging writing the momentum equation first, then the continuity equation in the duct one on the airway, then your momentum equation two and the continuous equation two. So, with this arrangement M_1

C_1 M_2 C_2, you know we what we get is basically, leads to the form where we have your B matrix in the in this form. So, this gives you if you set M_0 is 0, then it we get by the identity matrix and we need not invert it.

$$A = \begin{bmatrix} 0 & -jk_0 & 0 & 0 \\ -jk_0 - \frac{4}{d_1\zeta} & 0 & \frac{4}{d_1\zeta} & \\ 0 & 0 & 0 & -jk_0 \\ \frac{4d_1}{(d_2^2-d_1^2)\zeta} & 0 & -jk_0 \quad \frac{-4d_1}{(d_2^2-d_1^2)\zeta} & 0 \end{bmatrix} \begin{matrix} M_1 \\ C_1 \\ M_2 \\ C_2 \end{matrix}$$

$$X\{0\} = [T]X\{L\}$$

$$expm\ (-[C]L)$$

$$B = \begin{bmatrix} 1 & M_0 & 0 & 0 \\ M_0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} B = I$$

You can just simply I times this is just your variable state vector. Now, if M_0 is non-zero then, it is good idea to inverse the matrix invert the matrix and multiply, it with A. So, pre multiplied with [A] so, to get [C]. Now, what we can do is that basically, we just need to invoke the function expm [-C][T]. So, I have just shown the derivation only just discussed it is derivation in a little bit detail in the last class.

So, basically what happens is that

$$\{\vec{X}\} = expm\ ([C]x)\{\phi\}$$

Where ϕ is a constant you know phi is your set of constant

$$\phi = \begin{Bmatrix} \phi_1 \\ \phi_2 \\ \vdots \\ 4 \end{Bmatrix}$$

which are to be determined from the boundary conditions. Basically, relating things upstream and downstream.

So, now what are those? Basically,

$$\begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}_{x\,=\,0} = \; expm\;([C]0)\{\phi\}$$

let me call this matrix well. For now, I am just writing this guy as like this and at x is equal to 0 you know I just have to put 0 to get the phi thing.

So, e to the power expm to the power 0; that is that will just give me I matrix remember, the definitions that we had. We had the definitions e exponential to the power A is your I plus A plus A square by 2 factorial plus A cube by 3 factorial and so on. So, we here, we are just getting what? 0, 0 matrix you know.

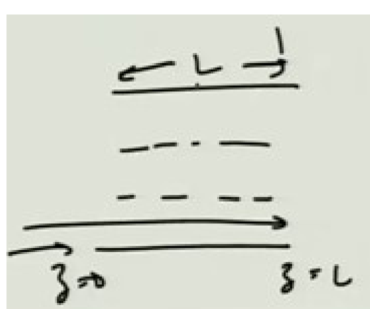
$$\begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}_{x\,=\,0} = \; = expm\;(0)\{\phi\}$$

So, we just get we can replace expm by

$$\begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}_{x\,=\,0} = \; [\mathrm{I}]_{4\times 4}\,\{\phi\}_{4\times 1}$$

So, I times identity times which is the 4 cross 4 and this 4 cross 1 here, we just get back your ϕ vector.

$$\begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}_{x\,=\,0} = \; \{\phi\}_{4\times 1}$$



So, phi constant; so, phi constant is nothing, but your state vector or the variable vector at x = 0. So, remember your perforated section something like this you know. So, this was the sections z = 0 and this was z = L. So, this constant can then, be your state vectors at x is equal to 0 ok. We will put all these guy here, is not it and then,

$$\{X\} = expm\ ([C]x) \begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}_{x=0} \quad inv\ (.)$$

$$\begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}_{x\,=\,L} = expm\ \{[C]L\} \begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}_{x=0}$$

Now, if you go back to our figure this was x is equal to L. So, at this point this was x is equal to L

$$expm\ \{-[C]L\} \begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}_{x\,=\,L}$$

$$= \begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}_{x=0}$$

So, this is x is equal to L. Now, in transfer matrices we usually relate things that are upstream to that at the downstream. So, what we can do from this guy from this equation is that, if we were to multiply both sides by to e the power minus CL that is expm that is what we can do is that you know expm minus.

We just put a minus sign and multiply this thing L being the length you know L is the this length, is not it? So, once we do that and

$$\begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}_{x=0} = \frac{expm\,\{-[C]L\}}{[T']} \begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \tilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \tilde{U}_2 \end{Bmatrix}_{x=L}$$

upstream variable upstream variable

Now, this will be equal to what expm, exp minus CL multiplied by expm in whole of C into L that is that becomes expm to the power 0 or that is your identity matrix. So, this will then become your identity times that is simply your p thing p_1 c_1 I mean p1 at x is equal to 0 ok. So, then here, basically, that is what; that is what we have.

So, now, writing this in a more you know more arranged manner this we can write this as expm. So, all we need to do to solve this thing of course, perforates now, one thing I want to note here, is that just provide some general information that perforates has been around since a lot of time ok, perforates have been around since almost like last 30-40 years.

This it becomes an integral component of all mufflers, but computation cheap computational power is there only since the past 15-20 years or so. Now, in lot of packages you have inbuilt commands for example, MATLAB which I have associated with the course. We just use this command expm and minus C which is a C matrix which is really you are A B inverse A.

And this entire matrix what we can do is that we can call this matrix as let say, $[T]^1$. So, and another thing that just calculate this guy and invert this. So, rather than inversion, you would rather rely on you know suppose, if we calculated this matrix expm {[C][L]} and try to invert that matrix using the command inv something like this or this is the matrix.

So, you could have done that, but a more clever technique is just use expm {-[C][L]} and let us denote this as $[T]^1$. So, upstream variable this is your upstream variable and this is your downstream variables. So, we have related upstream and downstream variables. Now, how do we; how do we go about using this information; that is what we have to see.

Now, having denoted this matrix as T_1, we probably would want to reshuffle a few things, because we just trying to follow the convention available in the literature regarding plane wave analysis of concentric or well perforated mufflers. So, as a result what we would like to do is basically, if we just reshuffle the matrix in the sense that you know let me just sort of rub this guy.

$$\begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \widetilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \widetilde{U}_2 \end{Bmatrix}_{x=0} = \begin{bmatrix} T'_{11} & T'_{12} & T'_{13} & T'_{14} \\ T'_{21} & \cdots & \cdots & \cdots & T'_{24} \\ T'_{31} & \cdots & \cdots & \cdots & T'_{34} \\ T'_{41} & T'_{12} & T'_{13} & T'_{44} \end{bmatrix} \begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \widetilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \widetilde{U}_2 \end{Bmatrix}_{x=L}$$

And write it something like this $T'_{11} \quad T'_{12} \quad T'_{13} \quad T'_{14}$. So, this will become like this ok. Now, if we were to just reshuffle this by putting p_2 in the second row and getting this guy here. Similarly, p_2 at the downstream will be here, this will be here. So, this will be followed by some sort of a; some sort of a rearrangement of the equations; that is your rows as well as some of the columns. So, if you were to do it.

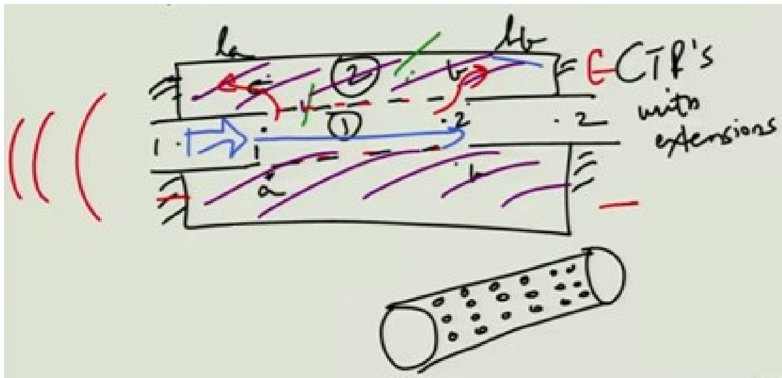
$$\begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \widetilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \widetilde{U}_2 \end{Bmatrix}_{x=0} = \underbrace{\begin{bmatrix} T'_{11} & T'_{12} & T'_{13} & T'_{14} \\ T'_{31} & T'_{32} & T'_{33} & T'_{34} \\ T'_{21} & T'_{22} & T'_{23} & T'_{24} \\ T'_{41} & T'_{42} & T'_{43} & T'_{44} \end{bmatrix}}_{[T]} \begin{Bmatrix} \tilde{p}_1 \\ \rho_0 C_0 \widetilde{U}_1 \\ \tilde{p}_2 \\ \rho_0 C_0 \widetilde{U}_2 \end{Bmatrix}_{x=L}$$

Let see how the final thing or the form that will be amenable to application of boundary conditions would look like. So, here this is looking like this. So, this would be T'_{11} and this would clearly be T'_{13}. So, this no this is a fairly easy thing so, here since we are moving $\tilde{p}_2$ in the second; in the second spot and $\rho_0 C_0 \widetilde{U}_1$ in the third spot in the column.

We would basically reshuffle this guy comes here this guy comes here. So, as a result what we would really have is, $T'_{12} \quad T'_{13}$ and nothing will happen to this thing. Similarly, this will become T'_{23} and $T'_{22} \quad T'_{24}$ and I am so, sorry my mistake this will become T'_{33} and 32 34, because remember we have just interchanged this thing here, this thing comes here, this row entire row and we are just shuffling across the different columns. So, this is irelia T'_{33} will come in the in this place and so on.

So, this will become $T'_{21} \quad T'_{23}\, T'_{22}$ and it will be something like this ok. So, all these thing will be there and $\tilde{p}_1 \, \rho_0 C_0$ I am so, sorry ok at x is equal to L this is the vector here. Once, we have this sort of an arrangement of the transfer matrix and let us call this entire, this entire guy as the T matrix ok. So, there was a reason why I called this as T_1 this is simply the T matrix. So, we can write this entire thing as T times this thing.

$$\frac{p_1 - p_2}{\rho_0 C_0 U^*} = \zeta$$



Now, going back to our E-CTR configuration extended concentric tube resonator or just CTR with so, it is also name as E - CTR. E - CTR means Extended Concentric Tube Resonator so; that means, with neck extensions at the inlet and outlet.

So, once we have got this kind of a thing, it is a will be a good idea to have a look at the boundary condition. So, let me go back to this figure. At this particular boundary, you have a rigid plate you can also have a yielding plate, but for simplicity, because nothing is rigid really.

We just assume the normal velocity to be 0. So, that our analysis becomes bit simple, but in principle you can have you know a coupled or one way coupled system, meaning that the you can have sort of a non-yielding walls. So, here one needs to go to structural acoustics concepts here, at this interface the normal velocity or the basically, the normal velocity of the fluid is equal to the normal velocity the time rate of displacement normal to the plane of the plate.

And your plate itself is governed by may be your Kershaw equation. It could be a thin or thick circular plate with a concentric hole in at the middle and then, your other condition is a pressure condition which acts like a loading condition and this will radiate noise outside in the far field.

And similarly, here, but maybe we can those are still advanced topics and we probably would not be bothered about that, but my purpose of introducing this was that in real life imposing this rigid condition is only an approximation, because plates can sort of vibrate they will yield no matter how thick you make them.

So, but for our purpose, we will introduce a rigid ball boundary condition there as a result what will happen. Actually, let me go back to this place at this particular place you know a and this is b,

$$\frac{Pa}{\rho_0 C_0 Ua} = +\,jcot\; k_0 la$$

Assuming that this is la and this is lb ok. So, here the velocity is; obviously, looking into the cavity, but if we have to really change its sign. So, here we have to put a minus sign. So, this will become plus. Similarly, at this point the point b

$$\frac{Pb}{\rho_0 C_0 Ub} = -jcot\; k_0 lb$$

The velocity direction of velocity is not a problem we just have lb ok. So, now, with these conditions, we are good to proceed ahead and let us get back to these equations. What we will do is that now, putting those boundary conditions.

$$\left.\begin{aligned} \frac{\tilde{p}_2(0)}{-\tilde{U}_2(0)} &= -j\rho_0 C_0\; cotk_0 la \\ \frac{\tilde{p}_2(L)}{\tilde{U}_2(L)} &= -j\rho_0 C_0\; cotk_0 lb \end{aligned}\right\}$$

So, we will have these boundary conditions. Now, after a lot of manipulations remember, we are dealing with the system with certain with the boundary conditions mentioned here; these ones.

So, we need to somehow incorporate these boundary conditions in this equation. We had already done that in probably lecture 3, I recommend and then, we kind of slightly digressed and moved on to different things probably perforated impedance expressions and all that. But now, once we incorporate these boundary conditions and simplify those for those equations that we discussed in the last in week lecture 3 I believe of this week.

What we will get is basically, the following transfer matrix between the points I will if I call this point as you know 1 and this as point 2 just in the pipe just outside the perforate. So, we would get

$$\begin{Bmatrix} \tilde{p}_1(0) \\ \rho_0 C_0 \widetilde{U}_1(0) \end{Bmatrix} = \begin{bmatrix} T_a & T_b \\ T_c & T_d \end{bmatrix} \begin{Bmatrix} \tilde{p}_1(L) \\ \rho_0 C_0 \widetilde{U}_1(L) \end{Bmatrix}$$

So, we will get something like this ok. Where T a is given by

$$T_a = T_{11} + A_1\, A_2, \quad T_b = T_{13} + A_2\, B_1$$

T_{11} this particular element. So, I am just writing down the equations and we need to introduce a few more variables which you can which basically, come from the previous lecture 3. Once you simplify these things, you will be able to get it.

$$T_C = T_{31} + A_1\, B_2, \quad T_d = T_{33} + B_1\, B_2$$

So, what are A_1 A_2 B_1 B_2 what are those. So, A_1 is nothing, but your another variable

$$A_1 = \frac{(X_1 T_{21} - T_{41})}{F_1} \qquad B_1 = \frac{(X_1 T_{23} - T_{43})}{F_1}$$

$$A_2 = T_{12} + X_2 T_{14} \quad B_2 = T_{32} + X_2 T_{34}$$

$$F_1 = T_{42} + X_2 T_{44} - \quad X_1 = T_{22} - X_1 X_2 T_{24}$$

So, what is. So, we know now, A 1 A 2 B F 1 is known everything is known. Only thing that is not known is

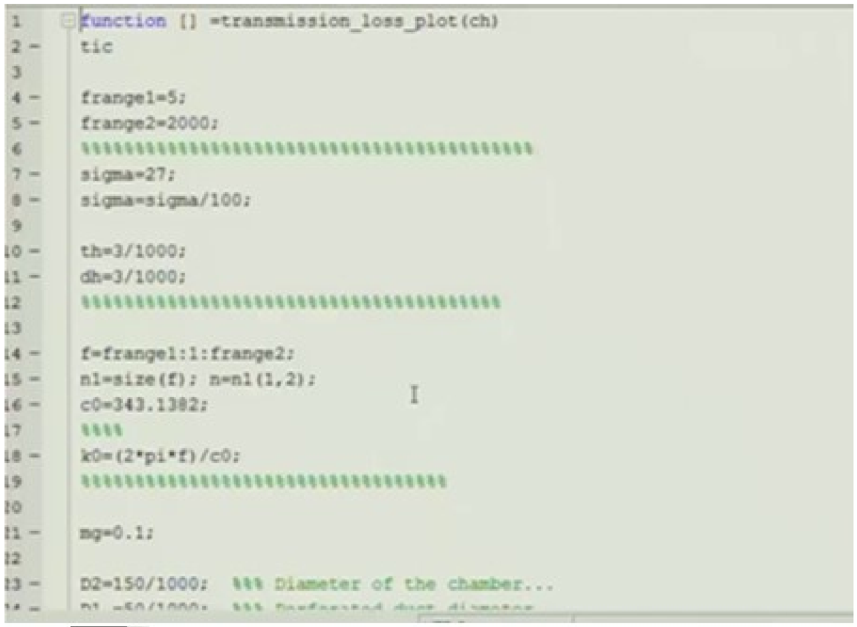
$$X_1 = -j tan k_0 la$$

$$X_1 = -j tan k_0 lb$$

$$20 \log \frac{M}{2}$$

$$20\, log_{10} \frac{1}{2} 9$$

something like this ok. So, this is basically, your inverse of once you kind of. I mean this tan terms comes from these boundary conditions once we invert these things and you will get to know that. So, once you know the four pole parameters the transmission loss can be easily evaluated in terms of these expression.



So, I guess now is the time to jump on to MATLAB and we have already written the code for that. So, here are some of the codes let me go through this only in a very sustained manner the code. So, frequency ranges the first and lower and upper bounds are 5 hertz and 2000 hertz you can choose whatever values you want.

But make sure that you are well within the plane wave range and this is more than plane wave region just for the continuity sake the. So, the results will not be accurate up to this range much before that, but just for argument sake, I have taken 2000 hertz and porosity you can change you can put its like 30 percent.

```
function [] =transmission_loss_plot(ch)
tic

frange1=5;
frange2=2000;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
sigma=30;
sigma=sigma/100;

th=3/1000;
dh=3/1000;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

f=frange1:1:frange2;
n1=size(f); n=n1(1,2);
c0=343.1382;
%%%%
k0=(2*pi*f)/c0;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

mg=0.1;

D2=150/1000;  %%% Diameter of the chamber...
```

And th d_h. so, this is the thickness of the perforate holes. And now, these are the parameters. So, you have 100 mm of annular area; 50 mm on each side. So, that will make up your entire 150 mm length is 400 mm. These are some of the values.

```

f=frange1:1:frange2;
n1=size(f); n=n1(1,2);
c0=343.1382;
%%%%
k0=(2*pi*f)/c0;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

mg=0.1;

D2=150/1000;  %%% Diameter of the chamber...
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=200/1000;      %%% Extended-inlet length
lb=100/1000;     %%% Extended-oulet length...
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),th,dh,sigma,mg);
end
figure(2)
plot(f,Tl,ch)
```

So, I would choose. Let us say; let us begin with 200; that is your 0.5 times this thing and this is your 1 4. So, let us keep like this. Now, perforated length is the difference of the extension length and this one. And actually, what I would do is that really put this as 0 initially.

```
f=frange1:1:frange2;
n1=size(f); n=n1(1,2);
c0=343.1382;
%%%%
k0=(2*pi*f)/c0;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

mg=0.1;

D2=150/1000;  %%% Diameter of the chamber...
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=0/1000;      %%% Extended-inlet length
lb=0/1000;     %%% Extended-oulet length...
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
T1(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),th,dh,sigma,mg);
end
figure(2)
plot(f,T1,ch)
grid minor
toc
```

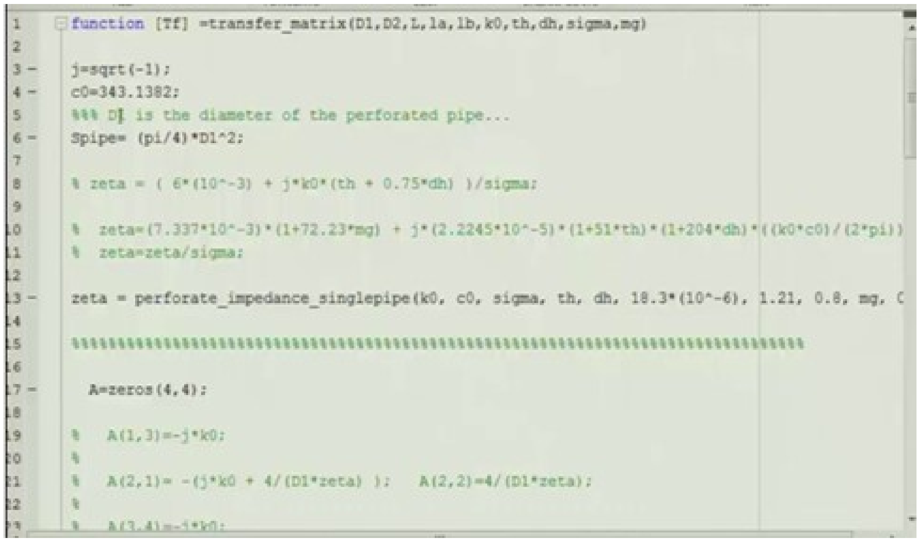
And similarly, this also 0 so, we really have a CTR with no extensions. And this function calls in the transmission loss file that is basically nothing, but thing to compute the value.

```
function [T1]=transmission_loss(D1,D2,L,la,lb,k0,th,dh,sigma,mg)
j=sqrt(-1);
c0=343.1382; %%% sound speed...

S1=(pi/4)*(D1^2);   Y1=c0/S1; %%% upstream pipe
S2=(pi/4)*(D1^2);   Y2=c0/S2; %%% downstream pipe
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[Tf] =transfer_matrix(D1,D2,L,la,lb,k0,th,dh,sigma,mg);

v=abs(     ((Y2/Y1)^0.5)*(Tf(1,1)+(Tf(1,2)/Y2)+(Tf(2,1)*Y1)+(Tf(2,2)*(Y1/Y2))) );
T1=20*log10(v/2);
```

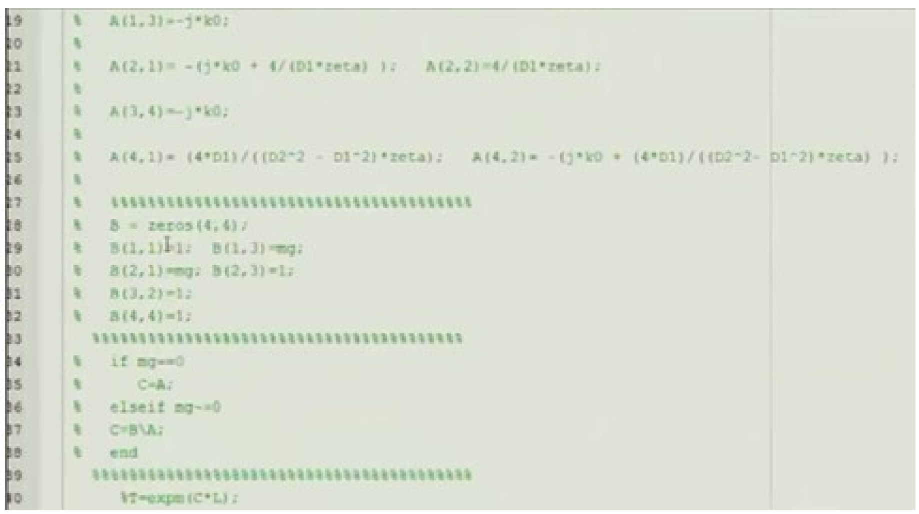
So, this is nothing new in this code. This always has to be used. But, main thing is your transfer matrix. So, this is the key thing. So, it takes in the inner diameter, outer diameter length la lb frequency value; that is your wave number at that frequency thickness and diameter holes porosity and the grazing flow value. So, computes the pipe area.

And now, they are different perforated impedance expression, that is why I reviewed it initially. So, this was for the stationary medium and it is given in Salamat's paper in by the book by Munjal and also Melling has suggested the use of 0.85, but it would not make too much of difference and he suggested use of 0.06 rather than 0.006.

So, it would not make too much of a difference for a stationary medium. This is only this expression is only for a stationary medium. For a grazing flow medium; this is the one, but which is given in the Rao and Munjal's paper published a long time back; found out experimentally using an impedance tube test set up. And this is yet another expression for a perforate.

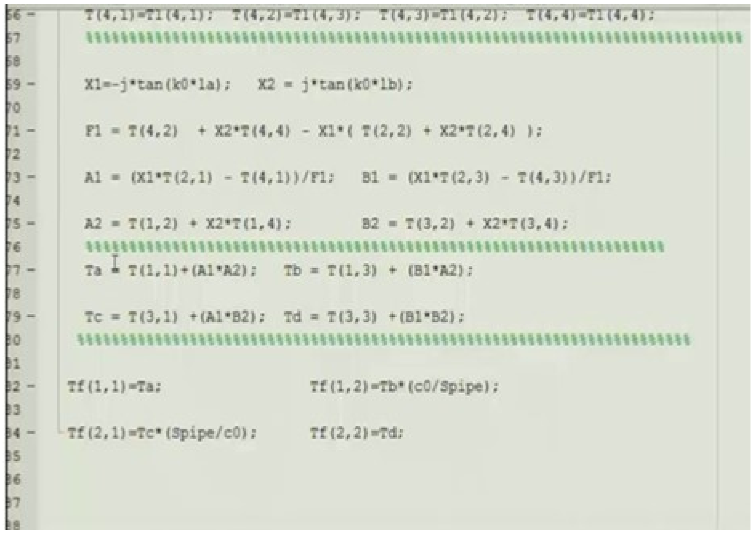


```
function [Tf] =transfer_matrix(D1,D2,L,la,lb,k0,th,dh,sigma,mg)

j=sqrt(-1);
c0=343.1382;
%%% D1 is the diameter of the perforated pipe...
Spipe= (pi/4)*D1^2;

% zeta = ( 6*(10^-3) + j*k0*(th + 0.75*dh) )/sigma;

%  zeta=(7.337*10^-3)*(1+72.23*mg) + j*(2.2245*10^-5)*(1+51*th)*(1+204*dh)*((k0*c0)/(2*pi))
%  zeta=zeta/sigma;

zeta = perforate_impedance_singlepipe(k0, c0, sigma, th, dh, 18.3*(10^-6), 1.21, 0.8, mg, C

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

  A=zeros(4,4);

%   A(1,3)=-j*k0;
%
%   A(2,1)= -(j*k0 + 4/(D1*zeta) );   A(2,2)=4/(D1*zeta);
%
%   A(3,4)=-j*k0;
```



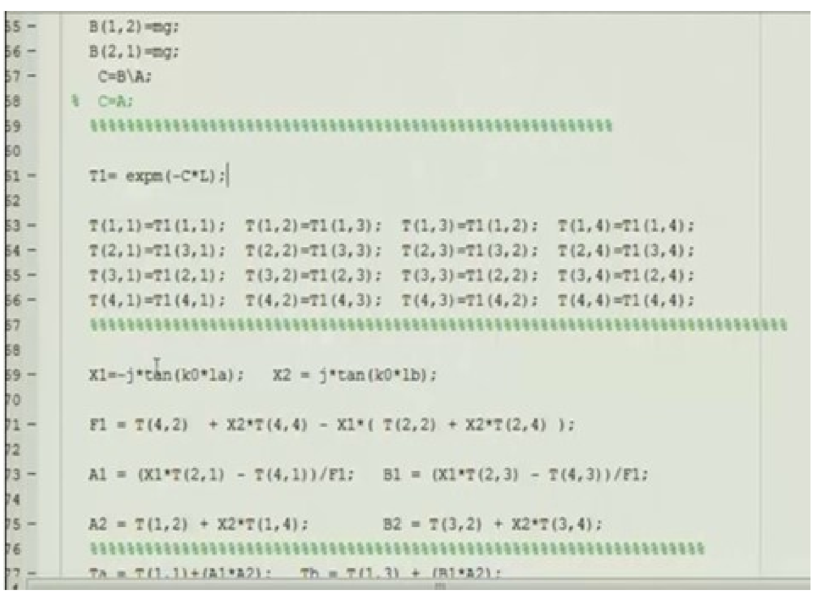
```
%   A(1,3)=-j*k0;
%
%   A(2,1)= -(j*k0 + 4/(D1*zeta) );   A(2,2)=4/(D1*zeta);
%
%   A(3,4)=-j*k0;
%
%   A(4,1)= (4*D1)/((D2^2 - D1^2)*zeta);   A(4,2)= -(j*k0 + (4*D1)/((D2^2- D1^2)*zeta) );
%
%   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%   B = zeros(4,4);
%   B(1,1)=1;  B(1,3)=mg;
%   B(2,1)=mg; B(2,3)=1;
%   B(3,2)=1;
%   B(4,4)=1;
  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%   if mg==0
%      C=A;
%   elseif mg~=0
%   C=B\A;
%   end
  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    %T=expm(C*L);
```

You know use rather more you know in the modern times with the one given in the book or the paper by El Nady and others. So, here we can have grazing flow and bias flow happening concurrently. So, we do not have a bias flow really. So, we just set the bias flow value to be 0 and put mg some value.



So, these are all commented things you do not have to worry about that. These are the A matrix written in a certain manner. So, I would not go through all the details, but these are basically of the form that you know pertains to your I guess the ones that we discussed here, is not it? Somewhere, something along these lines ok.

So, $A_{1,2}$ and $A_{2,1}$ and all that. So, and this is your eye matrix; that is identity matrix. And only when you have non-zero mean flow non-zero grazing mean flow; you define these things and C is equal to B slash A when this is 0 when this is not 0 and simply use C is equal to a which I have commented out. And this is the guy what I was talking about expm minus C L.



And then, you re-shuffle or rearrange the matrices. This is the [T_1] matrix; I was just talking about this is the [T] matrix and then, these are your these are kind of your boundary conditions which comes from the boundary condition. They are themselves are not the boundary conditions, but they arise these terms, because of the implementation of boundary condition due to the neck extension.

So, when la and lb are both 0, X_1 and X_2 are tending to 0 they are 0 and as a result, all these terms will go away and this term will go away this term will also go away this term and this term. The resulting expression will be much more simplified expression and we will get a concentric tube resonator without extensions as the one the case that we are about to discuss.

Then once we get Ta Tb Tc Td parameters these are really four pole parameters and now, we convert this in terms of mass velocity by simple multiplication by characteristic impedance and division of this thing by this thing. So, this is fairly simple standard procedure. Main thing is these rather complicated expressions which kind of can be nightmarish if you were to do it by hand calculation.

So, I avoided doing that and used a little bit of computer algebra and some known literature to verify things. So, this I would suggest that you please practice it in your free time and using the long hand manner. Now, one more thing before we go into parametric studies, because from now onward, we spend a few minutes to do some parametric studies. So, this is the perforate impedance file.

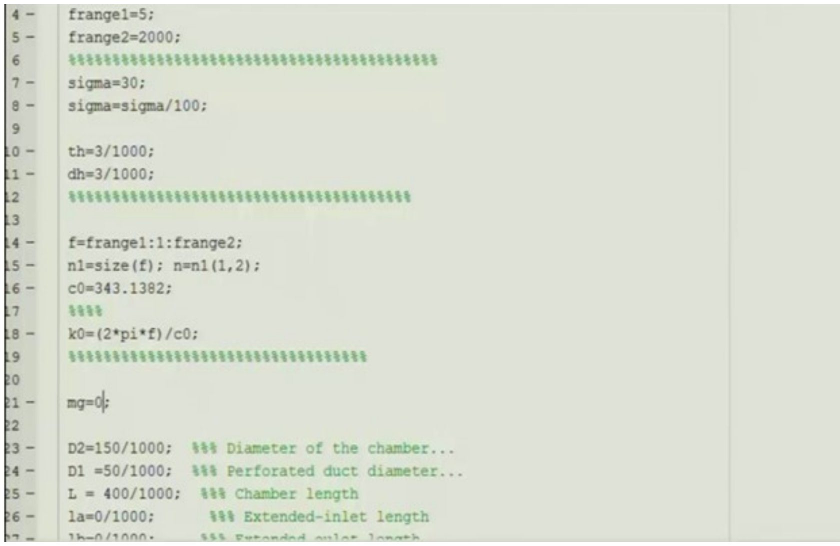
```
function [xeta] = perforate_impedance_singlepipe(k0, c, poro, tw, dh, mu, rho, Cd, mg, mb)
% --------------------------------------------------------------------------
% It evaluates and returns the perforate impedance of single perforated
% pipe by using Elnady et al. expressions. (see Eqs. 4.68 to 4.72 in AODAM by M.L.Munjal)

% poro = Porosity of the inner pipe in fraction
% tw = Perforated pipe thickness in m
% dh = Diameter of perforated hole in m
% k0 = Wave number in 1/m
% c = Speed of sound in m/s
% mg = Grazing flow Mach no.
% mb = Bias flow Mach no.
% mu = Dynamic viscosity of the exhaust gases in kg/m.s
% rho = Density of the exhaust gases kg/m^3
% Cd = Coefficient of discharge
% xeta = non-dimensional perforate impedance
% --------------------------------------------------------------------------

f_int = 1-1.47*poro^0.5+0.47*poro^1.5;
del_re = 0.2*dh+200*dh^2+16000*dh^3;

mu1 = 2.179*mu;
```

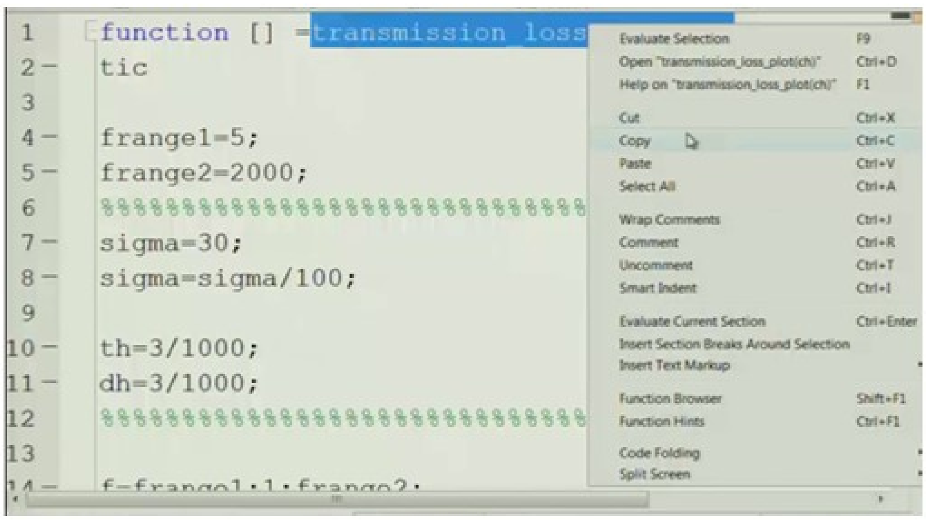
```
K = sqrt(-1j*(k0*c)/nu);
K1 = sqrt(-1j*(k0*c)/nu1);

B = besselj(1,(0.5*K*dh));
J1_kd = besselj(1,(k0*dh));
B1 = besselj(0,(0.5*K*dh));
F_mu = 1-(4*B/(K*dh*B1));

B2 = besselj(1,(0.5*K1*dh));
B3 = besselj(0,(0.5*K1*dh));
F_mu1 = 1-(4*B2/(K1*dh*B3));

% ---------------------------------------------------------------------------
% REAL PART:
% ---------------------------------------------------------------------------
re1 = (1j*k0/(poro*Cd))*((tw/F_mu1)+(del_re*f_int/F_mu));
re1 = real(re1);
re2 = (1/poro)*(1-(2*J1_kd/(k0*dh)));
re3 = 0.3*mg/poro;
re4 = 1.15*mb/(poro*Cd);

theta = real(re1+re2+re3+re4);
```

```
% ---------------------------------------------------------------------------
% REAL PART:
% ---------------------------------------------------------------------------
re1 = (1j*k0/(poro*Cd))*((tw/F_mu1)+(del_re*f_int/F_mu));
re1 = real(re1);
re2 = (1/poro)*(1-(2*J1_kd/(k0*dh)));
re3 = 0.3*mg/poro;
re4 = 1.15*mb/(poro*Cd);

theta = real(re1+re2+re3+re4);

% ---------------------------------------------------------------------------
% IMAGINARY PART:
% ---------------------------------------------------------------------------
im = (1j*k0/(poro*Cd))*((tw/F_mu1)+(0.5*dh*f_int/F_mu));
khi = imag(im);

xeta = theta+1j*khi;

end
```

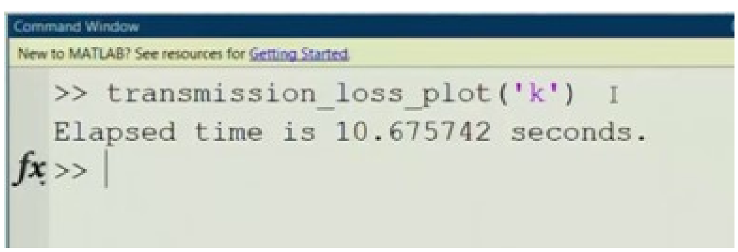
Which I have written sort of separately; so, this is your rather complicated thing that I have shown you about. So, one needs to be have little bit of practice with programming. So, that will be useful. This can be done in Fortran or you know there are so, many things Octave or Python or something like that whatever you are comfortable with and.

So, basically these are this file basically takes in all the parameters and at the end, it gives you the zeta parameter that is your perforate impedance. So, porosity mu kinematic viscosity and all these things are sort of well computed. Now, once we have these things all, we need to do is basically invoke this function ch really means what color you would want to plot with. So, let us see what happens and we can keep changing the value. So, I have set mean flow to 0.1.

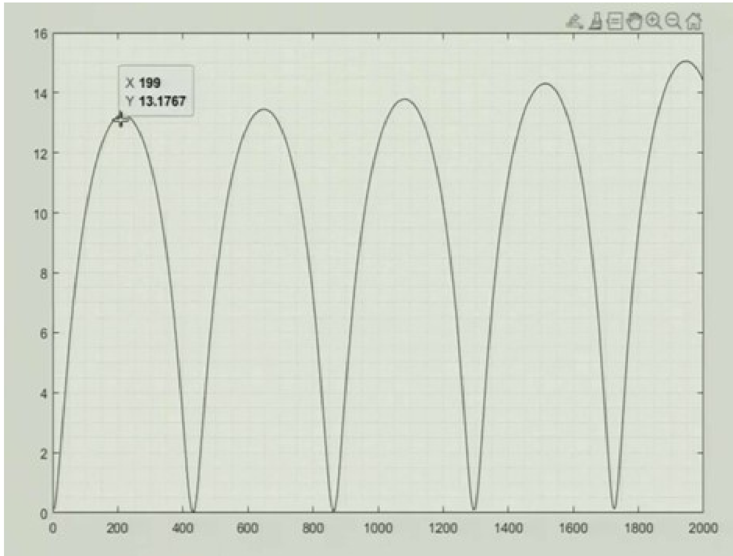




But we can put it to 0. So, let us do some transmission loss parametric studies.



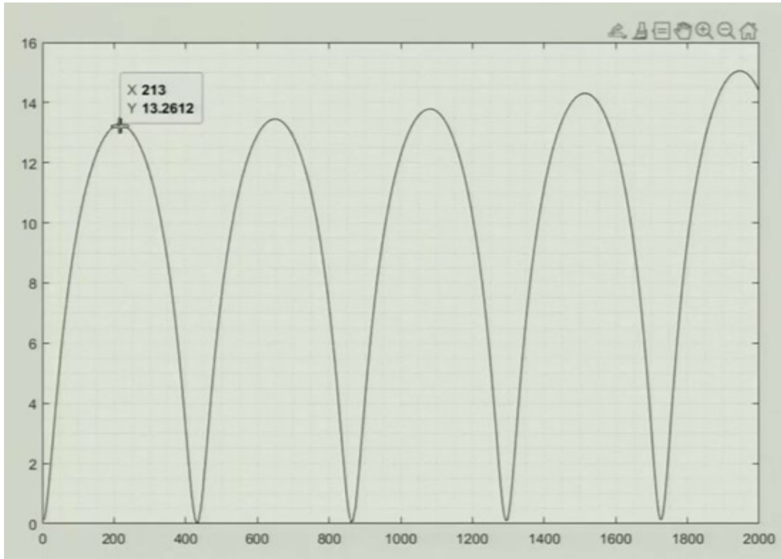
So, what we do is we just click this function and with the parameter set, what we will do is that. Let us plot with black color. It should basically get as the transmission loss.



You see the maximum transmission loss is about it follows the dome and trough pattern you know; exactly what you have for a simple expansion chamber, but do not be-fooled by do not just go with the fact that, well this is looking just like a simple expansion chamber. So, what is the use why to do this algebra?

I have already told you the reasons why we should must use a perforated thing and use do some extra work in you know deriving the equation then, you know getting the proper perforate impedance expressions and all that. Although, we with this thing we would just get this thing. We will soon see how the extensions can dramatically affect the performance can enhance the performance exactly, like we saw for the you know extensions without any perforate.

So, the; however, I must point out that the transmission loss performance of a E-CTR; that is Extended Concentric Tube Resonator will be quite different in terms of tuning of the length compared to a simple expansion chamber with neck extensions, for the simple reason that perforate impedance has a major, major role to play. And you notice the slide, the transmission loss is not identically 0. Although, it tends to that. Practically it is 0, but there are troughs that are lifted.



Now, expansion reach this maximum transmission loss you know. Some of the assignments that you would have solved, you can easily figure out that the maximum transmission loss for something

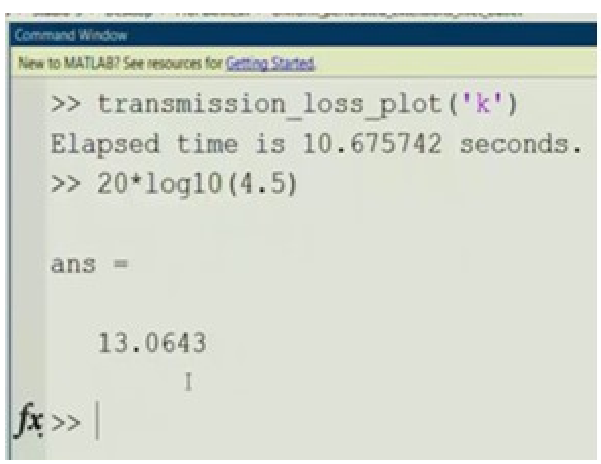
$$X_1 = -jtank_0la$$

$$X_2 = jtank_0lb$$

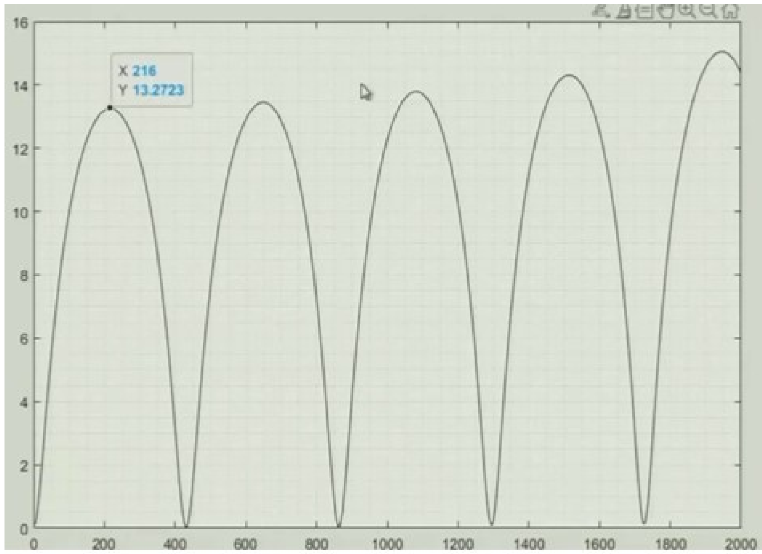
$$20\log\frac{M}{2}$$

So, this for the m is your area ratio ok. So, this would become 3 square that is 9. So, this will become 4.5.

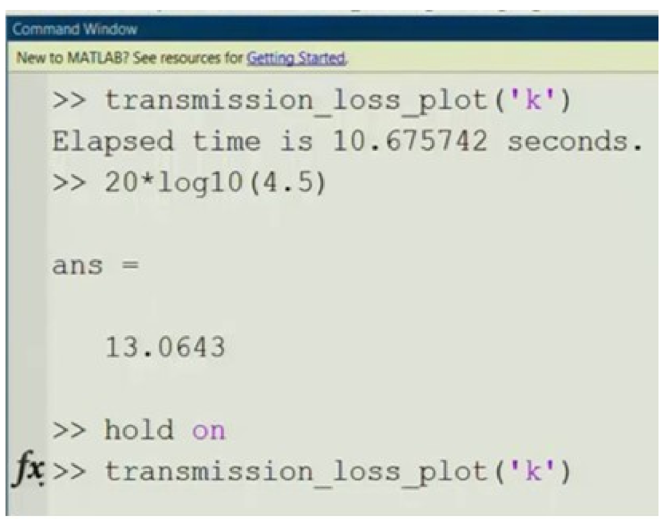
$$20\ log_{10}4.5$$



And if we ask MATLAB to help us with the computation, we will get log 10 4.5 so, 13.06 for a simple expansion chamber.



And what are we getting here? We are getting 13.27 very very close to that you know. Because of the perforate impedance, it has certain value. So, basically this will these troughs, these domes will keep on has an increasing sort of a trend and what we will do is that.



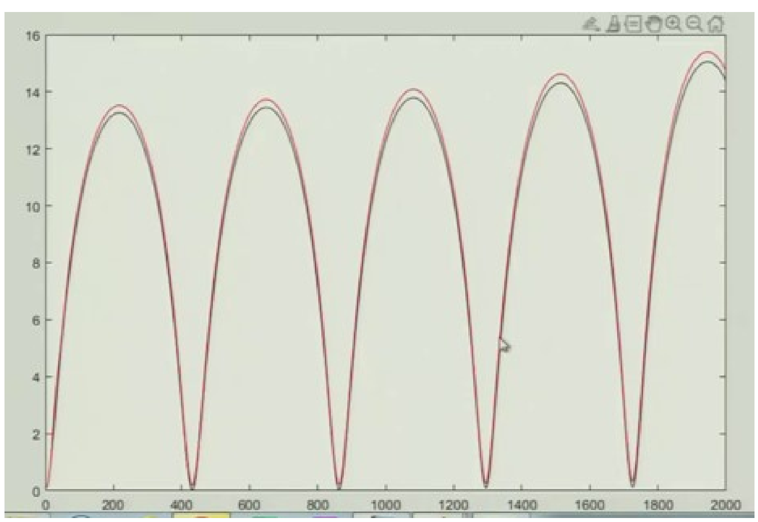
We will hold on to this figure we will hold on and have some fun with it.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

mg=0.05;

D2=150/1000;  %%% Diameter of the chamber...
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=0/1000;      %%% Extended-inlet length
lb=0/1000;     %%% Extended-oulet length...
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
```

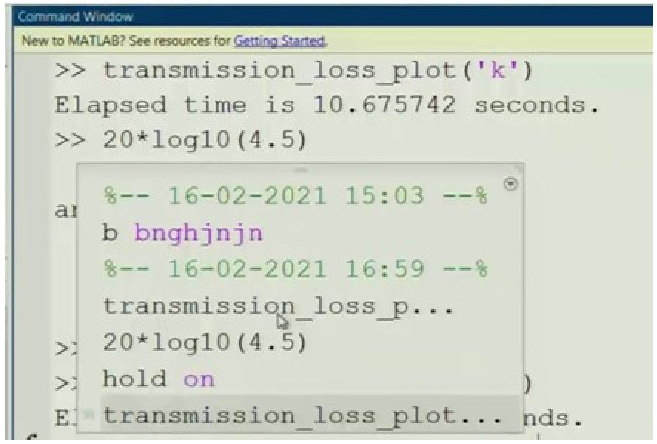
Let us do some parametric studies. Let us put some mean flow 0.05 ok.

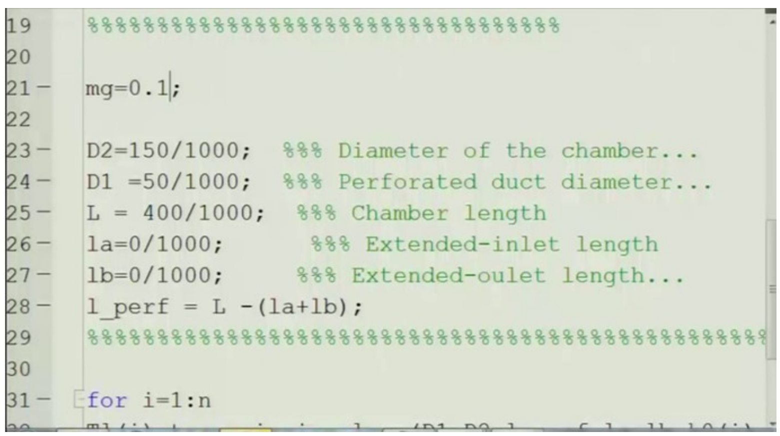
```
Command Window
New to MATLAB? See resources for Getting Started.
>> transmission_loss_plot('k')
Elapsed time is 10.675742 seconds.
>> 20*log10(4.5)

ans =

   13.0643

>> hold on
>> transmission_loss_plot('r')
Elapsed time is 1.356270 seconds.
```

And you hold on and plot with other color which is red.

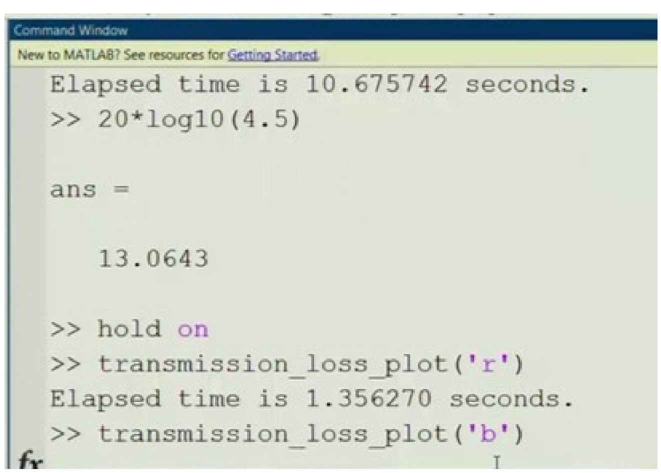


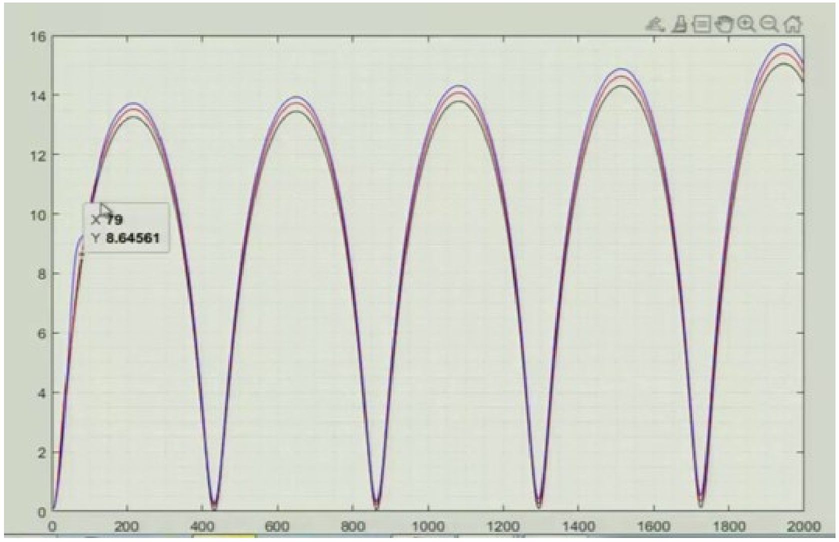
So, in a fraction of a second, it did give us well 1.35 seconds to evaluate for the whole frequency. Plane wave is very fast. So, it definitely does increase this thing and the troughs also tend to increase the flow.





And let us do one sort of 0.1. We can say you remember maximum Mach number that we can have is about 0.1 5 or something like that.

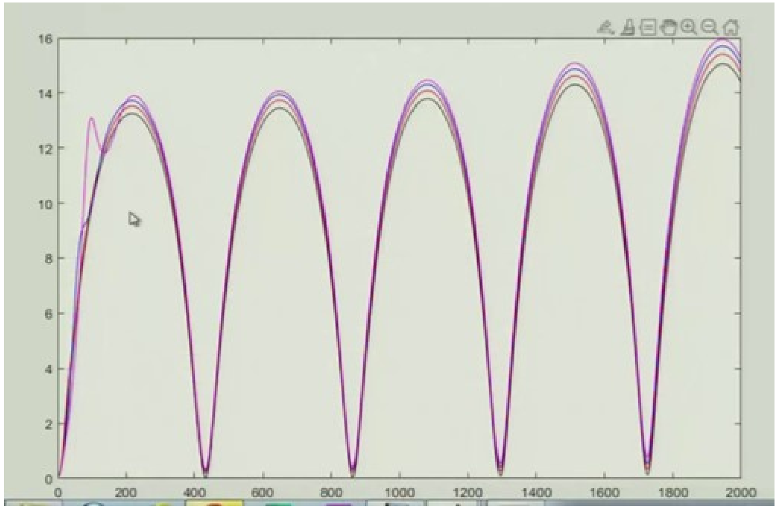




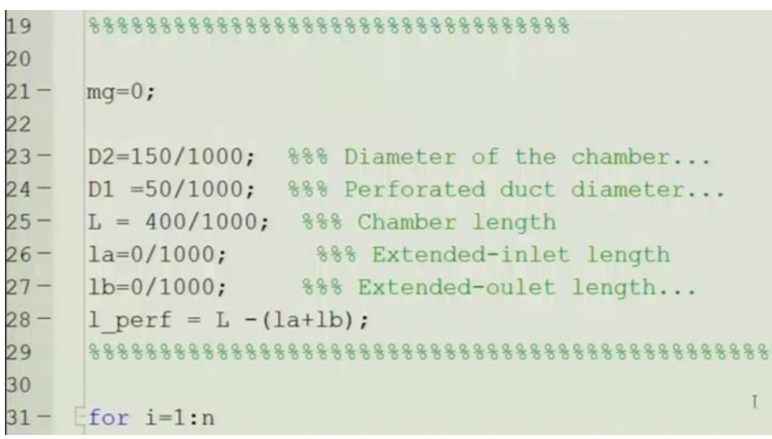
So, this can be your blue color. So, this tends to increase and you have certain wiggles here starts they start to show up.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

mg=0.15;

D2=150/1000;  %%% Diameter of the chamber...
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=0/1000;      %%% Extended-inlet length
lb=0/1000;     %%% Extended-oulet length...
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
```

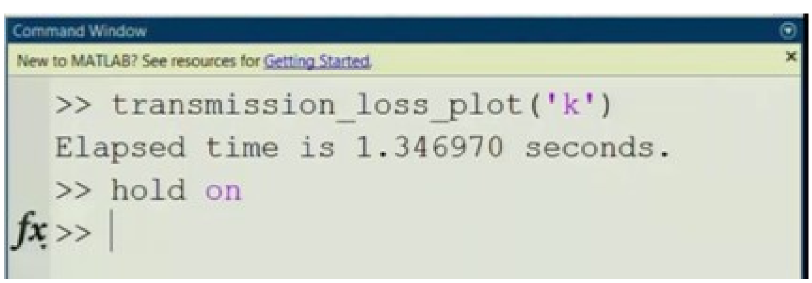
```
Command Window
New to MATLAB? See resources for Getting Started.
ans =

   13.0643

>> hold on
>> transmission_loss_plot('r')
Elapsed time is 1.356270 seconds.
>> transmission_loss_plot('b')
Elapsed time is 1.196289 seconds.
>> transmission_loss_plot('m')
Elapsed time is 1.159090 seconds.
```

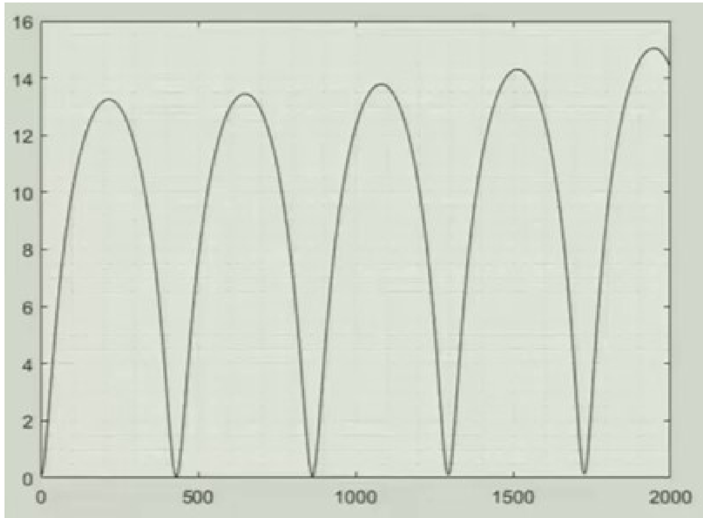


Let us do one more thing for 0.1 5 ok and then, let me use some other color magenta and we see these peaks happening due to the mean flow at very low frequencies alright. These are all characteristic of the mean flow thing. So, what I would suggest is that let me close this figure.



And let us get back to our basic figure for the case when we have a 0 flow; that is a stationary medium. Remember the code will work, because mean flow is already there, so, you just as a matter of setting things.



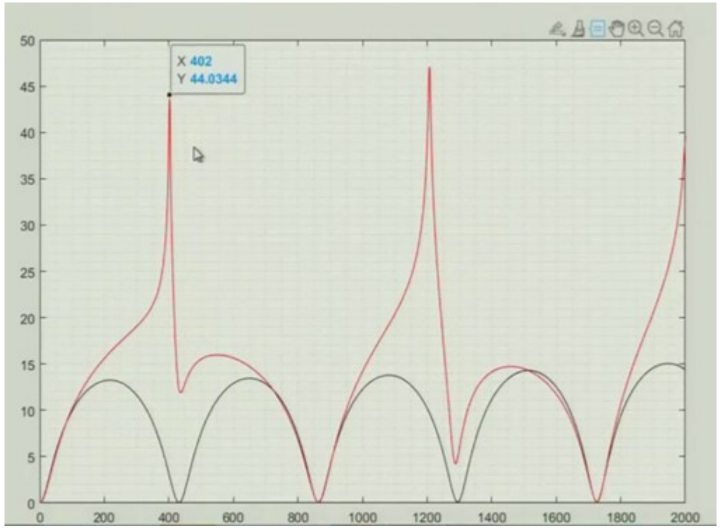


Now, once we do that let us simply generate this figure which we will have generated now, and hold on to it and now, play around with neck extensions.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

mg=0;

D2=150/1000;  %%% Diameter of the chamber...
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=200/1000;      %%% Extended-inlet length
lb=0/1000;     %%% Extended-oulet length...
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
```

Now, let us do it in a step-by-step manner. So, what is half of 400? 200. So, 0.5 L the other. So, extensions at the inlet, but there are no extensions at the outlet. Let see what we get?

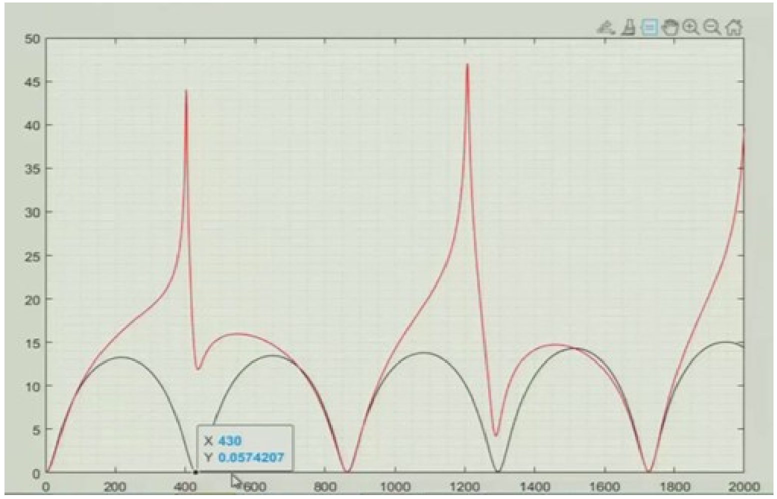
```
Command Window
New to MATLAB? See resources for Getting Started.
>> transmission_loss_plot('k')
Elapsed time is 1.346970 seconds.
>> hold on
>> transmission_loss_plot('r')
Elapsed time is 1.085002 seconds.
>> grid minor
fx >>
```



So, we will get this kind of a curve. That is a phenomenal increase we will do grid minor to have a greater insight. Before we you know start putting in a extension of the outlet, there are quite a few things I want to discuss. You know you see let us first put the data tip ok. So, forget about the peak.

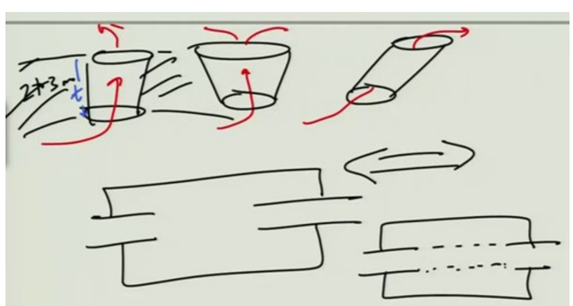
Peak can be anything peak theoretically, it is going to infinity. So, I do not really care about the amount of attenuation that is produced. The frequency at which it it is happening is important. We are we are doing the discrete frequency at 11 hertz so, 402. Now, the resonance of this chamber is 343 divided by you know basically, C_0 by C_0 divide by 2 l C_0 by l C_3 by 2 into C_0 by l.

Basically, when you equate k k naught l is equal to n pi you get the actual resonance. So, l is the complete length of the chamber including the extension. So, the first trough is observed at the first resonance frequency of the whole chamber; that is at k f is equal to C_0 by 2 l. So, you know 343 divide by 800 if you do, because l is your this thing or c 343 divided 0.8 if you do you will get about 428 or something like that ok.



You will get 428 if I have to click this something like this 428. Now, we remember for us extension concentric chamber with you know with extensions; you know with extensions at the inlet and outlet; if we just had tube with l by 2 length. Theoretically, it would have exactly tune the performance we saw that ok.

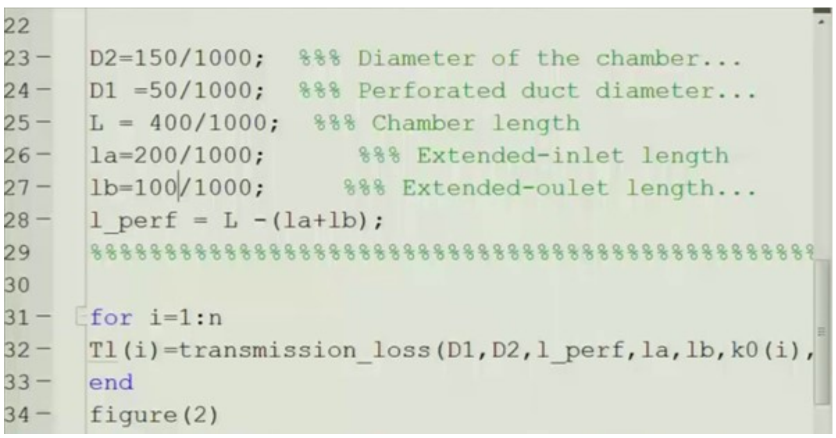
But then, the thing is does not really happen, because of end correction effects there were some end corrections you would also have done some assignments related to that in the last couple of weeks or so, but here we are we are deliberately choosing at *l* by 2 and assuming only plane wave still they are able to tune the performance ok and that is really because of the perforated impedance. So, that is one point I want to tell; that just by looking at the configuration shown here, you would see that this is very much similar to your extension.



So, basically if I were to use let me use the space here. So, theoretically, it is looking all very much sort of similar to this one. So, this is sort of equivalent to your this configuration, but because you have perforate, it plays a major major role and you have very different looking. Conceptually they are the same, but then you have quite different results ok. So, we have this sort of a thing ok.

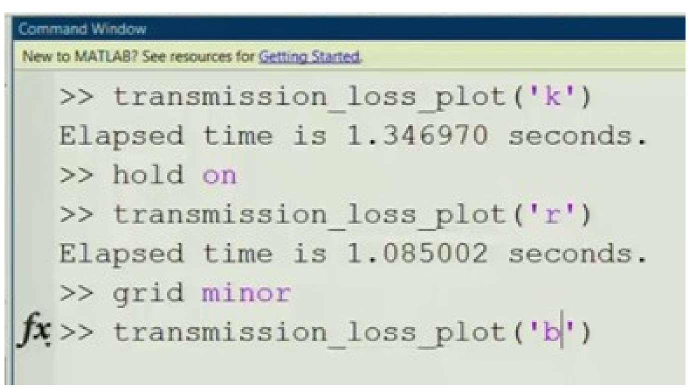
Now, we have the peaks here. So, what do we do with this? We have this thing here. So, basically by l by 2 we cannot really just unit we have to do some kind of a tuning we have to tune the length and anyways these are all based on plane wave model. So, this will; obviously, fail.

There will be some high order mode generated at the interface between the inlet pipe at the extensions and the annular cavity. There will be high order mode generated due to the inductive effects of the evaluation modes, the effective length of the acoustic length of the pipes will increase. So, in order to tune that we have to consider the geometrically smaller length so, let me explain, but before we do that.



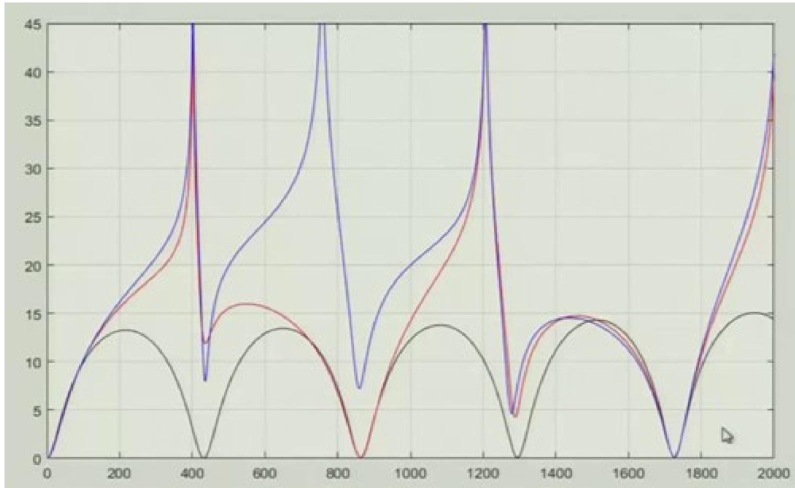
```
D2=150/1000;  %%% Diameter of the chamber...
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=200/1000;       %%% Extended-inlet length
lb=100/1000;      %%% Extended-oulet length...
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),
end
figure(2)
```

Let us also set this as 120 well 100; that is your 1 by fourth.



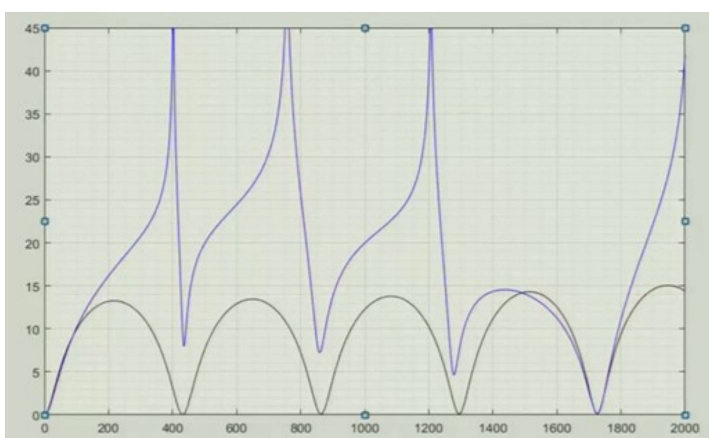
```
Command Window
New to MATLAB? See resources for Getting Started.
>> transmission_loss_plot('k')
Elapsed time is 1.346970 seconds.
>> hold on
>> transmission_loss_plot('r')
Elapsed time is 1.085002 seconds.
>> grid minor
fx >> transmission_loss_plot('b')
```

And at least draw the curve obtain the curve. This is blue color.

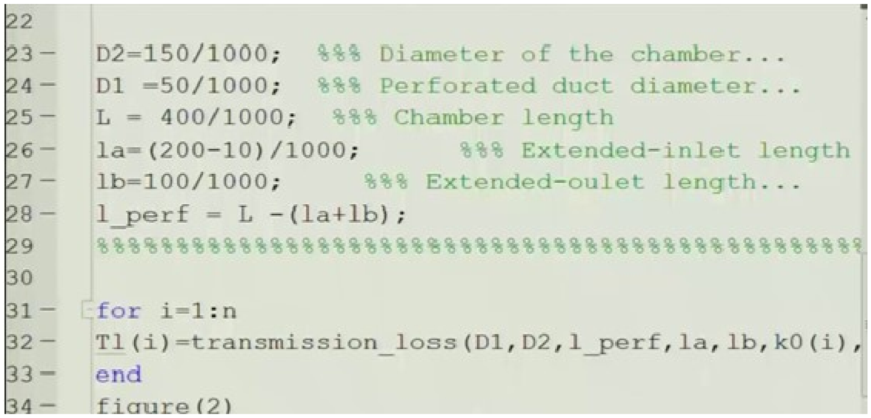


We see we have just readjusted the scale then, what we see. Now, is that your this peaks this peak definitely, again happens at where it used to happen just when you have l by 2 and lb 0. But now, when we have extensions at both inlet and outlet, you know 0.5 l and 0.25 l, the performance kind of enhances in the at higher frequencies I mean beyond this thing.

Although, we would still see a trough here, the trough is lifted significantly, but you know another interesting thing is that even by choosing *l* by 4, we are not able to cancel the second trough; what we vary able to cancel for a simple expansion chamber with extension. So, these are definitely the doings of the perforate ok. So, let us have some fun with it. What I would do is that basically, get rid of the red curve ok

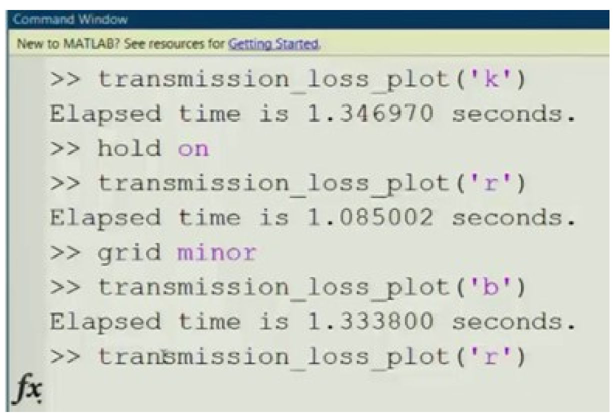


And keep this thing intact and you know vary this thing. So, remember based on the plane wave model, we are having the peak at this value at you know at this particular this particular value ok. So, and this is happening slightly before the trough; that means, perforate the. What perforate is doing, is that it is trying to you know kind of; its effect is to basically, increase the acoustic length. So, the resonance will occur a bit before. So, if you were to add the geometric length that is if you were to I am sorry.

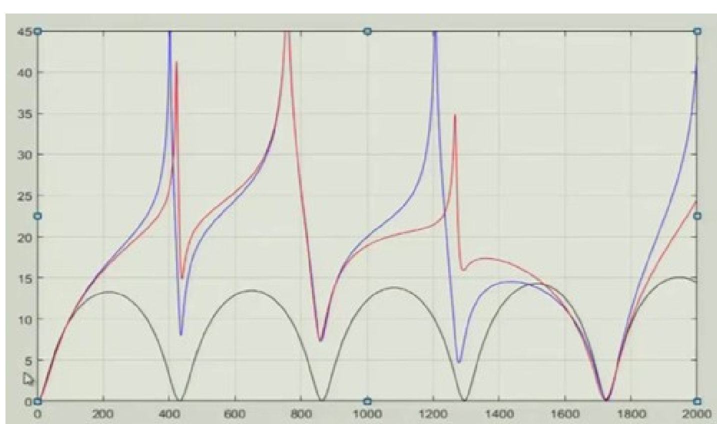


```
D2=150/1000;  %%% Diameter of the chamber...
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=(200-10)/1000;       %%% Extended-inlet length
lb=100/1000;     %%% Extended-oulet length...
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),
end
figure(2)
```

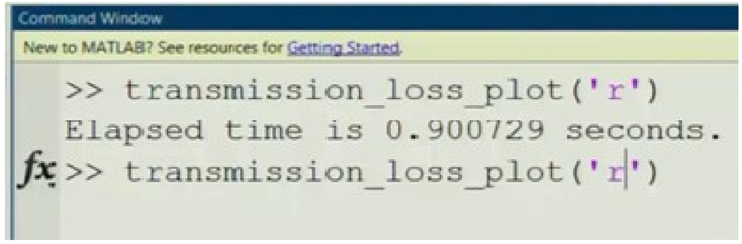
If you were to subtract or reduce the geometric length in such a manner that your net length; your net acoustic length will be such that it cancels the trough, then we can sort of uplift the thing. Let us reduce it by a small amount 10 let say 10.



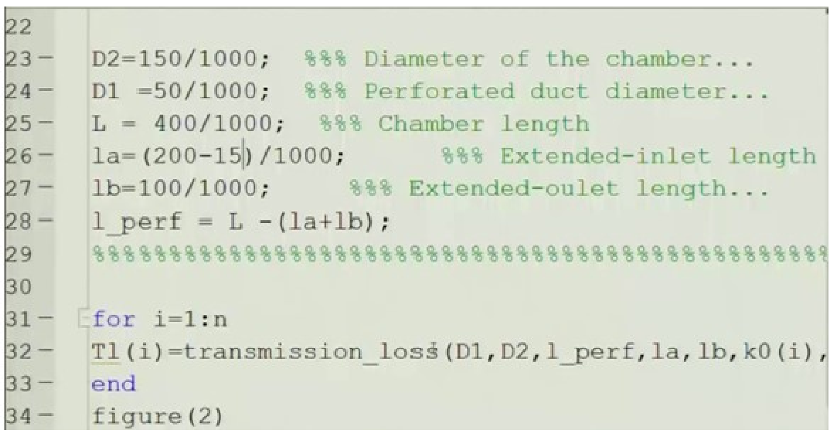
```
Command Window
New to MATLAB? See resources for Getting Started.
>> transmission_loss_plot('k')
Elapsed time is 1.346970 seconds.
>> hold on
>> transmission_loss_plot('r')
Elapsed time is 1.085002 seconds.
>> grid minor
>> transmission_loss_plot('b')
Elapsed time is 1.333800 seconds.
>> transmission_loss_plot('r')
fx
```

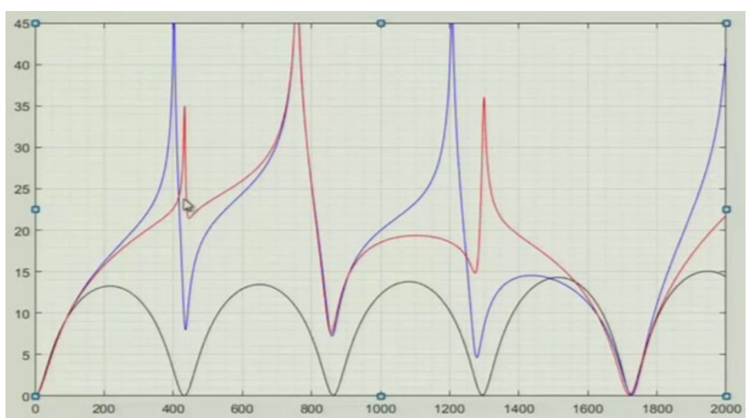


So, let us do it with the red colored plot and we will get this kind of a thing.

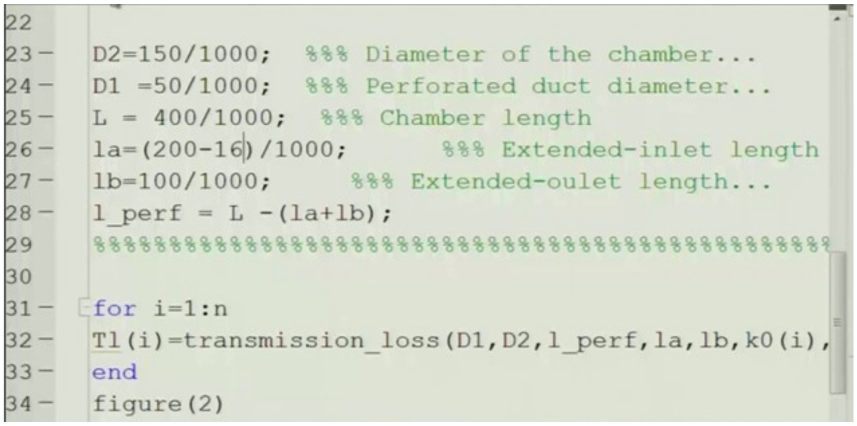


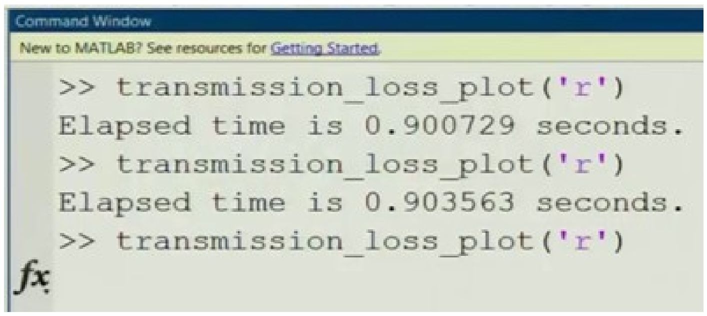
So, it is there its approaching and then, if we were to you know let me use another color or perhaps red only, but sort of get rid of this thing and put 15 here ok.

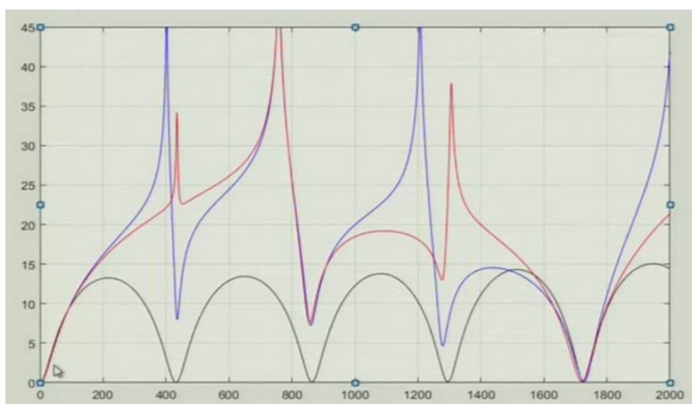




And it is almost nullified the trough ok. And if I were to maybe, takes a little bit more. Say, 16 if I do.







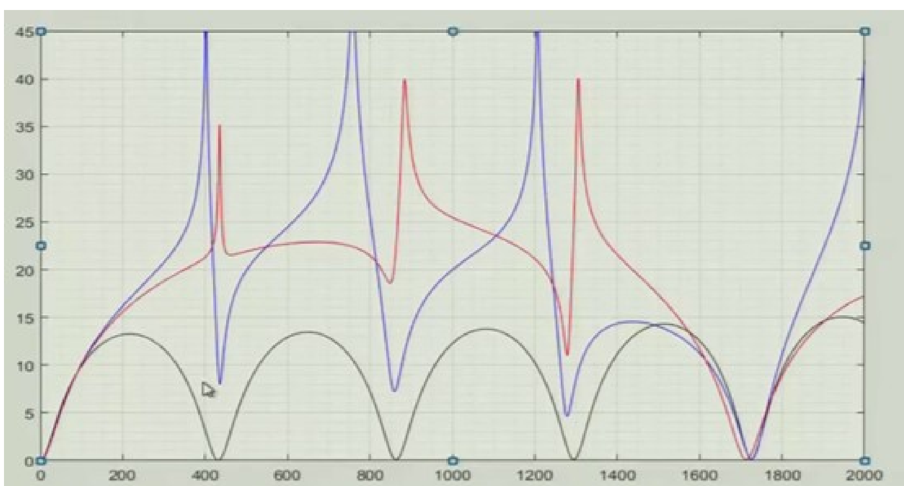
So, it is almost cancelled. So, basically what it means is that; it is possible to you know account for the to tune the length tune the extension length in such a manner that really your first peak attenuation peak to the resonator form at the inlet cancels as a trough.

And you see a dramatic increase you know this. If you come by this was only 13 now, this is much more 18, 5 db attenuation and this was trough, you are getting more than 20 25 db at attenuation. So, this is a fantastic performance. Now, another thing that I want to point out is that; whatever extensions you are seeing.

```
D2=150/1000;   %%% Diameter of the chamber...
D1 =50/1000;   %%% Perforated duct diameter...
L = 400/1000;   %%% Chamber length
la=(200-16)/1000;       %%% Extended-inlet length
lb=(100-16)/1000;      %%% Extended-oulet length..
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),
end
figure(2)
```

Corrections or tuning you are seeing at the inlet, will also hold for the outlet. It does not plane wave kind of does not distinguish.

```
Command Window
New to MATLAB? See resources for Getting Started.
>> transmission_loss_plot('r')
Elapsed time is 0.900729 seconds.
>> transmission_loss_plot('r')
Elapsed time is 0.903563 seconds.
>> transmission_loss_plot('r')
Elapsed time is 0.906085 seconds.
>> transmission_loss_plot('r')
fx
```



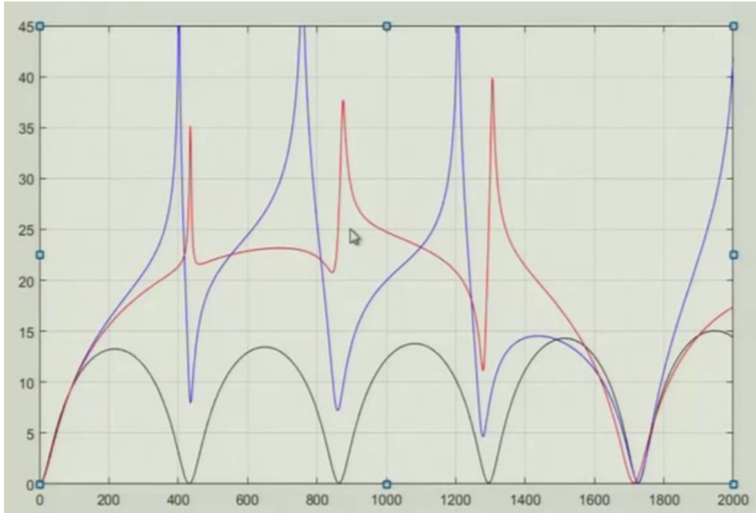
So, we can sort of demonstrate this thing well slightly more, but it is much better.

```
D2=150/1000;  %%% Diameter of the chamber...
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=(200-16)/1000;      %%% Extended-inlet length
lb=(100-14)/1000;     %%% Extended-oulet length..
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),
end
figure(2)
```

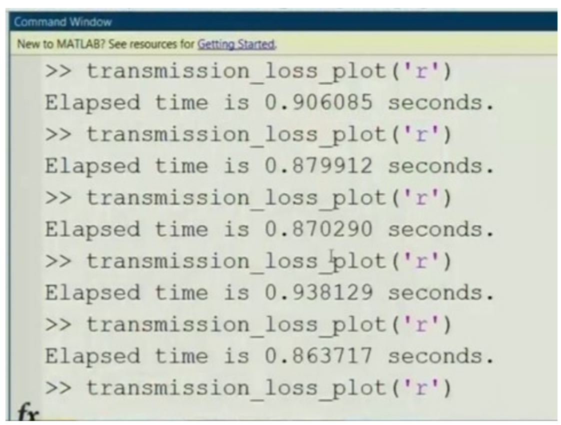
```
D2=150/1000;  %%% Diameter of the chamber...
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=(200-16)/1000;      %%% Extended-inlet length
lb=(100-15)/1000;     %%% Extended-oulet length..
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),
end
figure(2)
```

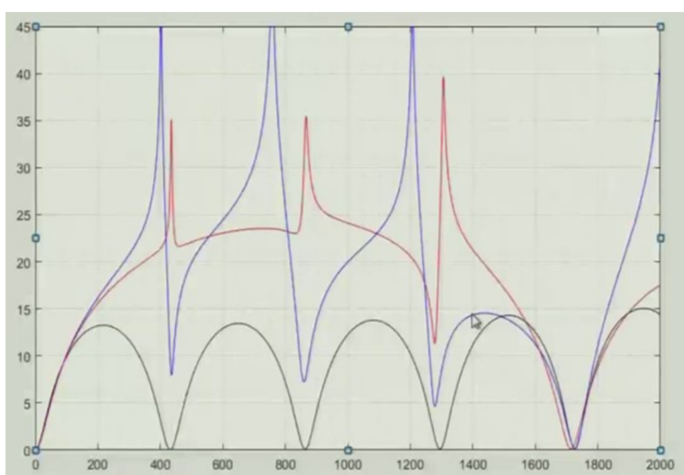
So, if we were to; if we were to slightly modify it by taking 14. So, this was 16 just take a bit less maybe, we can try with 15 as well.

```
Command Window
New to MATLAB? See resources for Getting Started.
>> transmission_loss_plot('r')
Elapsed time is 0.903563 seconds.
>> transmission_loss_plot('r')
Elapsed time is 0.906085 seconds.
>> transmission_loss_plot('r')
Elapsed time is 0.879912 seconds.
>> transmission_loss_plot('r')
Elapsed time is 0.870290 seconds.
>> transmission_loss_plot('r')
Elapsed time is 0.938129 seconds.
>> transmission_loss_plot('r')
fx
```



It would not be too different that is all I am saying. So, you are nearly there, but if you make it like 15 so, this is all done by hit and trial or trial and error.





So, if you have to do it 14 and do the calculations. So, you have nearly you know this the attenuation here, due to the resonator formed at the outlet has almost nullified the trough. So, basically what is happened is that, because of the perforate impedance, the exact tuning.

If you choose *l* by 2, you know la is equal to *l* by 2, it does not really tune it based on the plane wave theory you know. It is it kind of mismatches the trough. So, by choosing an appropriate length, we can actually tune the performance and this happens by trial and error, but then we have to wait and watch.

So, what happens is that; in the for experimental results, there will be full contribution by the three-Dimensional modes ok. There will be evanescent waves that are generated at the interface port chamber interface. So, the at the you know interface of the where the perforated pipe starts and where the extension ends. So, at the interface, there will be high order mode generated. So, all the tuning that we just talking about.

These are just based on the plane wave analysis, but one really has to do either a finite element analysis of such perforated mufflers new based on things like advanced techniques maybe, we can discuss it in a different course called numerical mode matching or analytical mode matching where we find out the performance of such mufflers incorporating three-Dimensional arm effects.

And then choosing the length in such a manner that the 1-D peak matches with a three-Dimensional p peak and then, we can; we then we can do all those tuning business. So, basically, what I am trying to say is that; the acoustic performance of a E-CTR will be different from a expansion chamber with extensions and this and that is largely, because of perforates. Now, we will keep these results aside and what we will do is that. Let me make a simple change in the code.

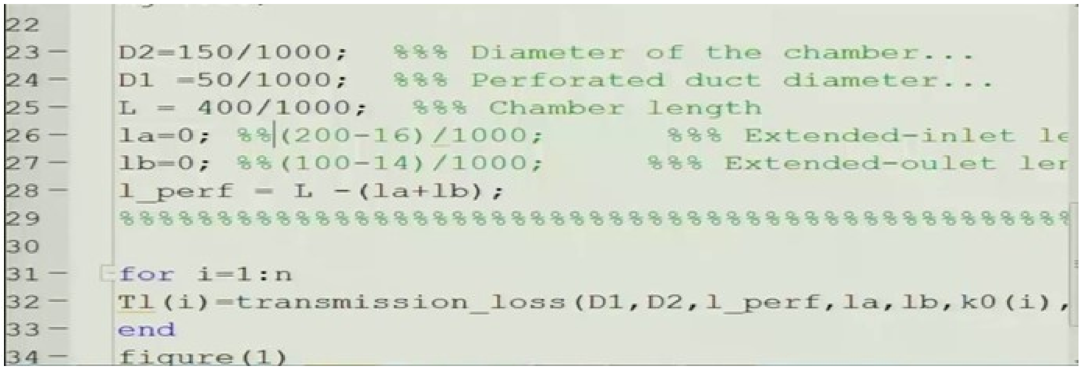
```
D1 =50/1000;   %%% Perforated duct diameter...
L = 400/1000;   %%% Chamber length
la=(200-16)/1000;       %%% Extended-inlet length
lb=(100-14)/1000;      %%% Extended-oulet length..
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),
end
figure(1)
plot(f,Tl,ch)
grid minor
toc
```

```
n1=size(f); n=n1(1,2);
c0=343.1382;
%%%%
k0=(2*pi*f)/c0;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

mg=0.10;

D2=150/1000;   %%% Diameter of the chamber...
D1 =50/1000;   %%% Perforated duct diameter...
L = 400/1000;   %%% Chamber length
la=(200-16)/1000;       %%% Extended-inlet length
lb=(100-14)/1000;      %%% Extended-oulet length..
l_perf = L -(la+lb);
```

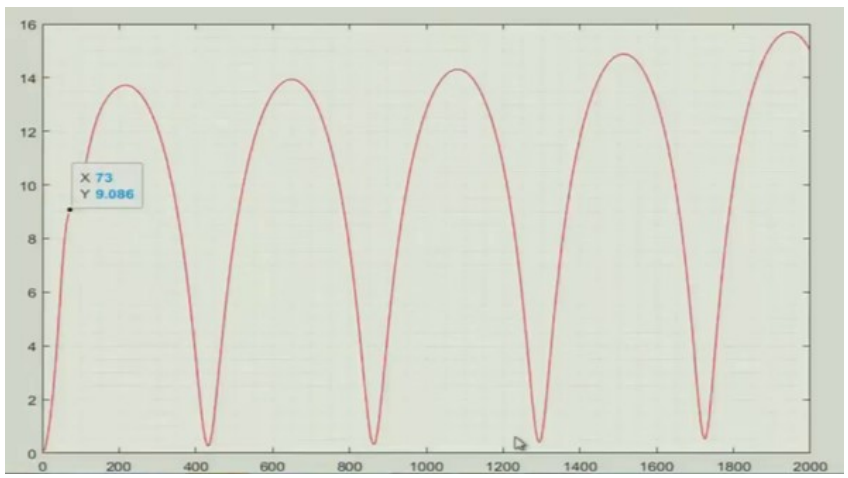
Let me use figure 1 and you know put a some; put some significant value of the mean flow 0.1 say ok. So, it is hard to now start tuning the performance when you have flow.

```
Command Window
New to MATLAB? See resources for Getting Started.
Elapsed time is 0.906085 seconds.
>> transmission_loss_plot('r')
Elapsed time is 0.879912 seconds.
>> transmission_loss_plot('r')
Elapsed time is 0.870290 seconds.
>> transmission_loss_plot('r')
Elapsed time is 0.938129 seconds.
>> transmission_loss_plot('r')
Elapsed time is 0.863717 seconds.
>> transmission_loss_plot('r')
Elapsed time is 0.966524 seconds.
```

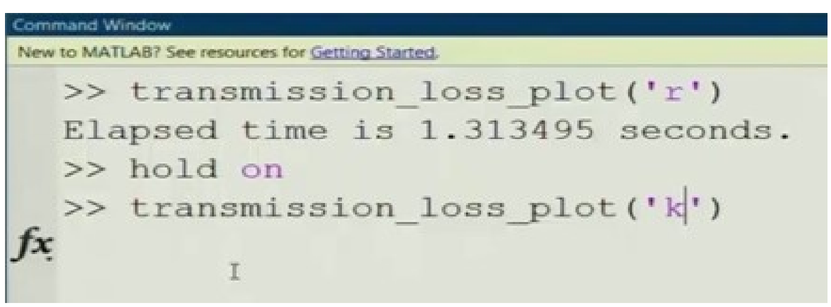
```
Command Window
New to MATLAB? See resources for Getting Started.
>> transmission_loss_plot('r')
Elapsed time is 1.313495 seconds.
fx >>
```



So, but we will try to do something. So, I will initially, to begin with, put 0 here, and 0 here, and see what happens?

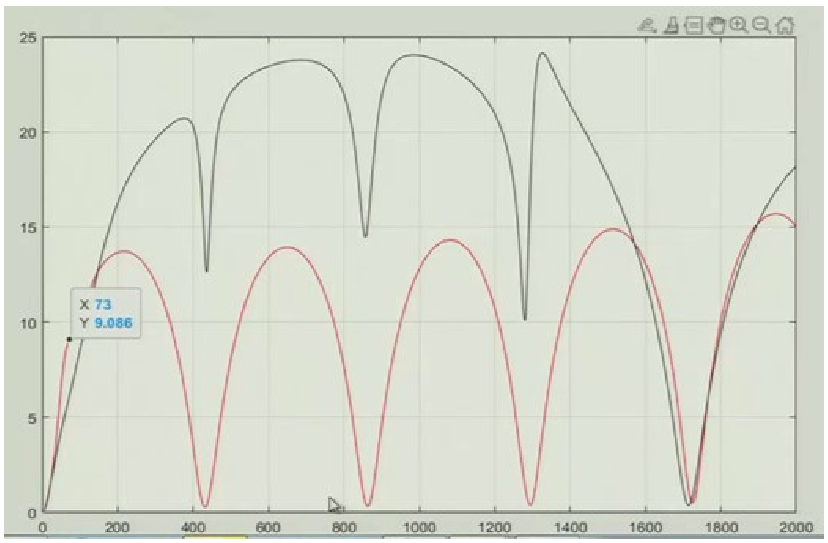


So, we get this. We already started getting these kind of things that we are seeing here. Let me maximize the screen and I will do hold on.



```
mg=0.10;

D2=150/1000;   %%% Diameter of the chamber...
D1 =50/1000;   %%% Perforated duct diameter...
L = 400/1000;   %%% Chamber length
la=(200-16)/1000;        %%% Extended-inlet length
lb=(100-14)/1000;       %%% Extended-oulet length..
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),
end
figure(1)
```

And now, with the same value, I will just uncomment it ok and see what happens.




```
Command Window
New to MATLAB? See resources for Getting Started.
>> transmission_loss_plot('r')
Elapsed time is 1.313495 seconds.
>> hold on
>> transmission_loss_plot('k')
Elapsed time is 0.978931 seconds.
>> grid on
fx >>
```

So, the performance definitely has increased. So, how about I do grid on and do this kind of a business. So, we see the one effect of mean flow definitely is that it basically, increases the trough. You know it increases the trough as we can see here, but it also you know brings down the peak. So, all the peaks attenuation peaks that were happening that were occurring in these things; they have come down and the mismatch definitely is there.

But, what I am saying is that attenuation is even at the lowest point, it is no it is fairly significant 12 db or 12.5 db, but the peaks have come down. So, the mismatch is there. If we were to you know sort of keep doing this iterations a few more time.

```
mg=0.10;

D2=150/1000;  %%% Diameter of the chamber...
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=(200-14)/1000;       %%% Extended-inlet length
lb=(100-14)/1000;      %%% Extended-oulet length..
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),
end
figure(1)
```

```
Command Window
New to MATLAB? See resources for Getting Started.
>> transmission_loss_plot('r')
Elapsed time is 1.313495 seconds.
>> hold on
>> transmission_loss_plot('k')
Elapsed time is 0.978931 seconds.
>> grid on
>> transmission_loss_plot('k')
Elapsed time is 0.968385 seconds.
fx >>
```

So, this can be a little annoying for the people who do not really want to do this. Let us put this as 14 and kind of go back to our figure and plot it again.

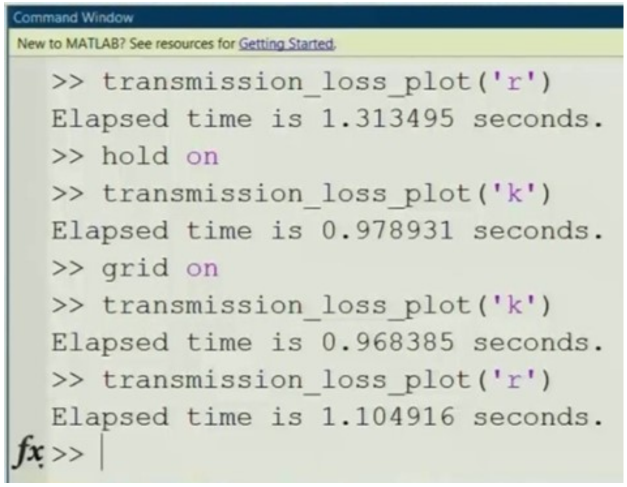
So, you know we would want this peak really to completely cancel out the trough for a non-zero value. So, we what we can do is that; we can have a still higher value and do this exercise.

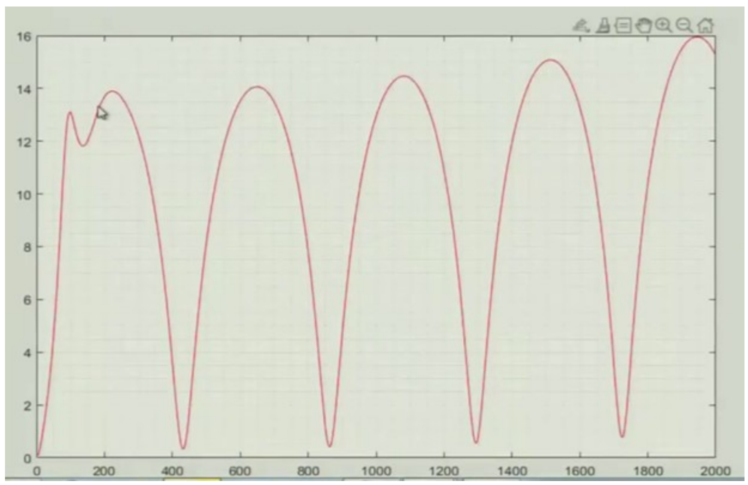
```
n1=size(f); n=n1(1,2);
c0=343.1382;
%%%%
k0=(2*pi*f)/c0;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

mg=0.15;

D2=150/1000;  %%% Diameter of the chamber...
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=(200-14)/1000;      %%% Extended-inlet length
lb=(100-14)/1000;     %%% Extended-oulet length..
l_perf = L -(la+lb);
```

So, I will say I will set the grazing flow value to 0.15.

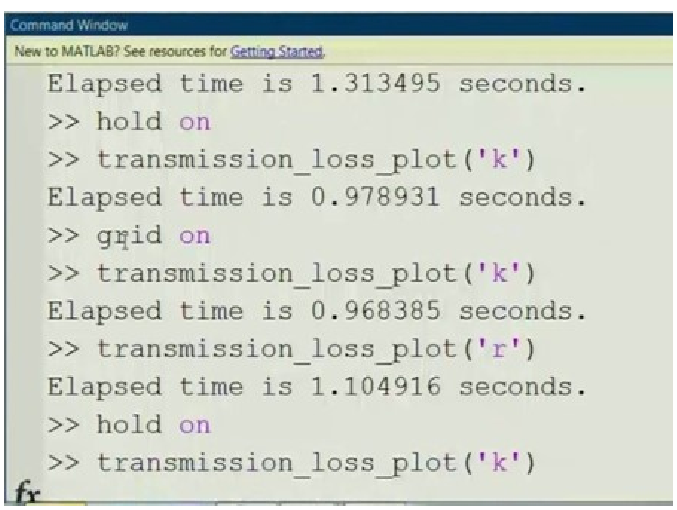
```
D1 =50/1000;  %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=0; %%(200-14)/1000;      %%% Extended-inlet le
lb=0; %%(100-14)/1000;     %%% Extended-oulet len
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),
end
figure(1)
plot(f,Tl,ch)
grid minor
toc
```

And the extensions, extension length could be 0 to get a baseline case.



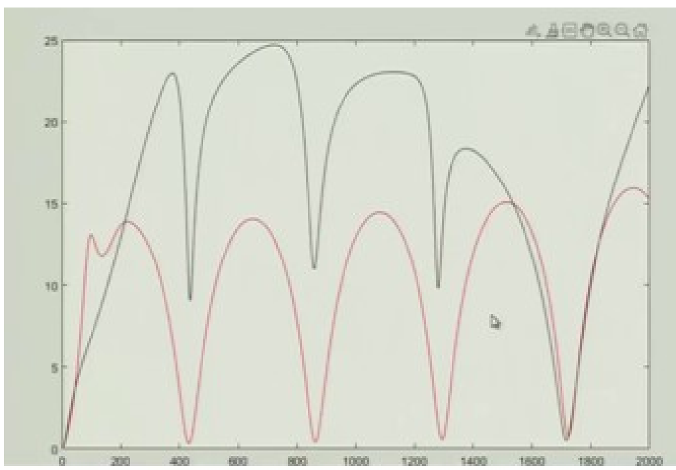


And see what happens? We get start getting these wiggles or these peaks.



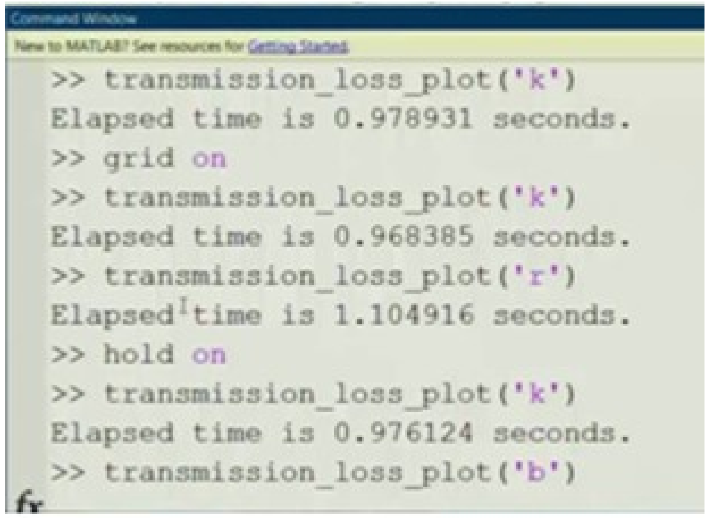
```
D1 =50/1000;   %%% Perforated duct diameter...
L = 400/1000;   %%% Chamber length
la=(200-10)/1000;       %%% Extended-inlet length
lb=(100-10)/1000;      %%% Extended-oulet length..
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),
end
figure(1)
plot(f,Tl,ch)
grid minor
toc
```

I will put this hold on say put hold on and. I will sort of put this as 10 and 10 and see what happens. These are all hit and trial really.

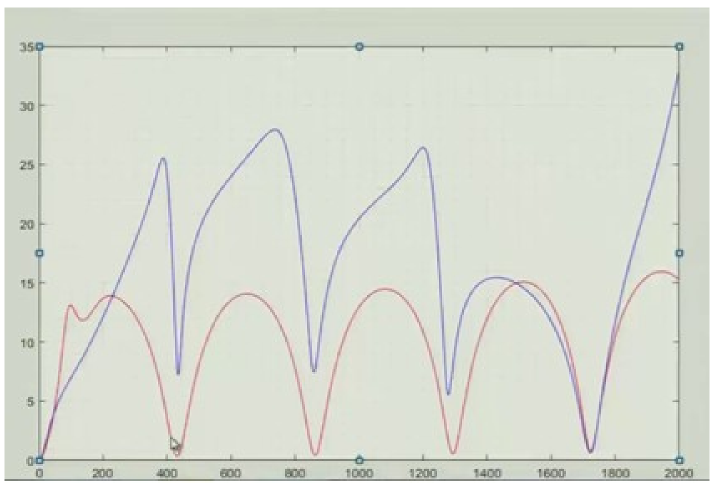



```
D1 =50/1000;   %%% Perforated duct diameter...
L = 400/1000;  %%% Chamber length
la=(200-5)/1000;       %%% Extended-inlet length
lb=(100-5)/1000;      %%% Extended-oulet length...
l_perf = L -(la+lb);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:n
Tl(i)=transmission_loss(D1,D2,l_perf,la,lb,k0(i),
end
figure(1)
plot(f,Tl,ch)
grid minor
toc
```

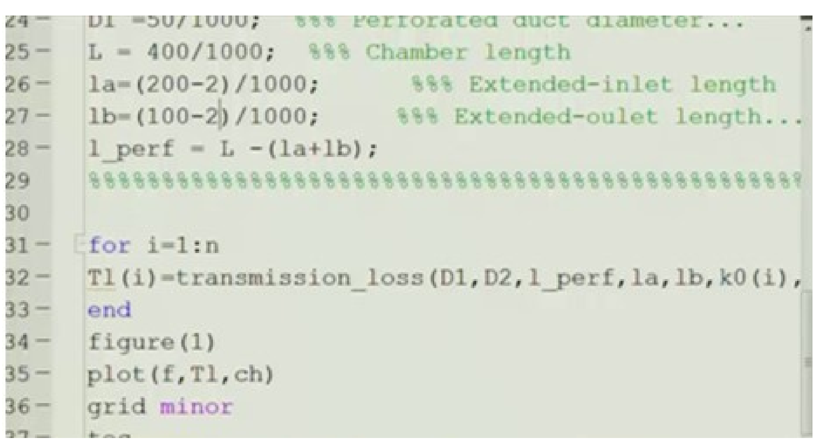
So, the peak is tending to this value, but what happens if we choose if we choose say another values. Let say, if we choose a 5 or some 5, let say we choose 5 ok.



And see what we are tending to get.



So, we are getting this kind of a thing. So, basically mean flow tends to reduce or decrease the end correction kind of a thing.



So, we are nearly there. So, basically, the point I am going to make is that the mean flow definitely reduces that attenuation peaks that are present, but it still kind of tends to produce you know it tends to produce some kind of increased attenuation at frequency range where normally trough would occur.

So, basically what I was saying is that then, this mean flow will have only a small effect on the end correction, but then in presence of mean flow, it is you know rather hard bit difficult to tune the performance at least in the context of 1-Dimensional analysis. But specially, when you have a large porosity like you know the ones that we have considered, we have considered almost 30 percent porosity which is like you know acoustically transparent as we can see from here; 30 percent porosity.

```
frange1=5;
frange2=2000;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
sigma=30;
sigma=sigma/100;

th=3/1000;
dh=3/1000;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

f=frange1:1:frange2;
n1=size(f); n=n1(1,2);
c0=343.1382;
```

So, for such a case end correction will be very small. End correction really is kind of significant, when you have a very low porosity ok like something like less than 15 percent or things like that. And other thing that we also must note that impedance perforate impedance is a function of many variables; which include you know, hole diameter thickness and your mean flow of course.

So, they also have to be investigated and porosity of course. So, you know if we do it ah. Systematically, if we were to do it, we can find out the generalized curve fit based on a number of basically expressions for end corrections as function of all these parameters. So, that will require a lot of you know trial and error to find out things.

So, what I would suggest is that, we leave these things here and what we will do in the next week that is week 9. We are really getting into the business end of the things and seeing things what happens practically. For the first time in this week, we have investigated. We just seen a glimpse of what mean flow can do in terms of very realistic configuration.

This configuration has the lowest back pressure, because flow just goes through a straight pipe. It has the least back pressure minimal. Now, what it could do is basically, this sets the scene for analysis of more complicated mufflers like for example, cross flow chambers. You know when you have the flow has to necessarily come out of the pipes and your it has to go through the pipes and leave the chain from the other pipe and do all the business.

And then, we have to there are different approaches; what we could do and then, we will probably look at three pass mufflers; a bit more complicated and discuss things when you have multi-path propagation multi different path the waves can take and how do we do a network analysis of such a configuration. So, this probably will be the subject matter of week 9 and possibly you know spilling over to week 10 and then, we will see how we go with it so, till that time.

Thanks a lot.