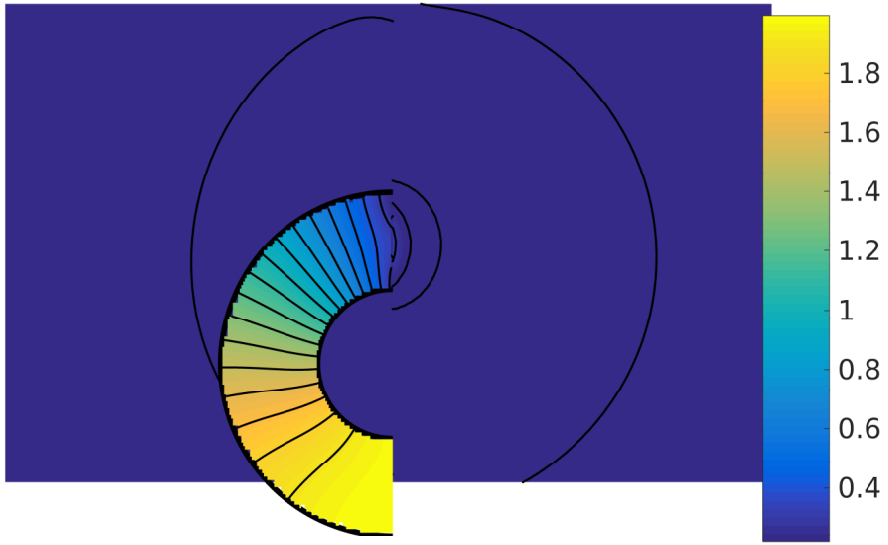
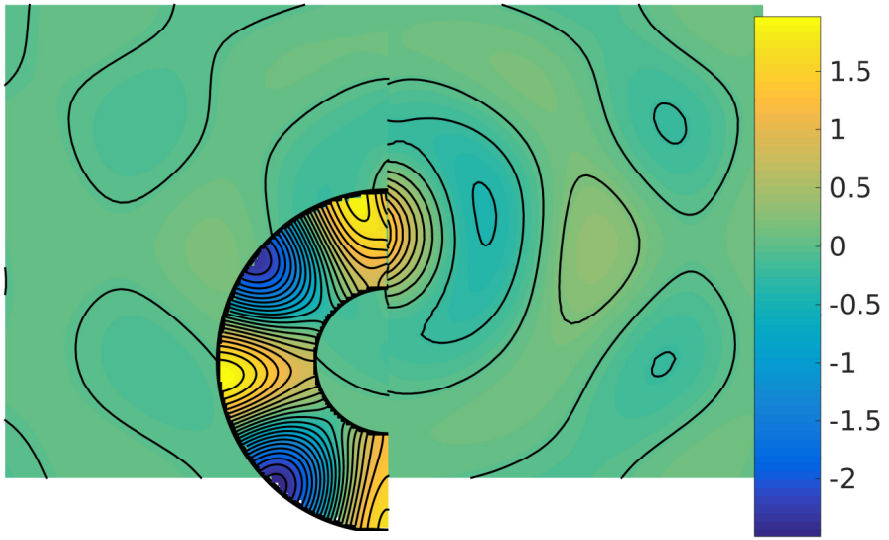
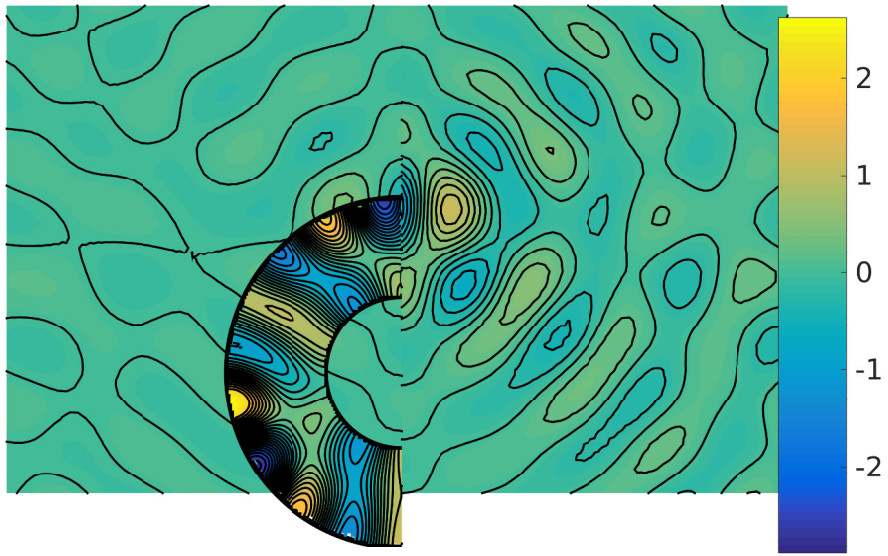
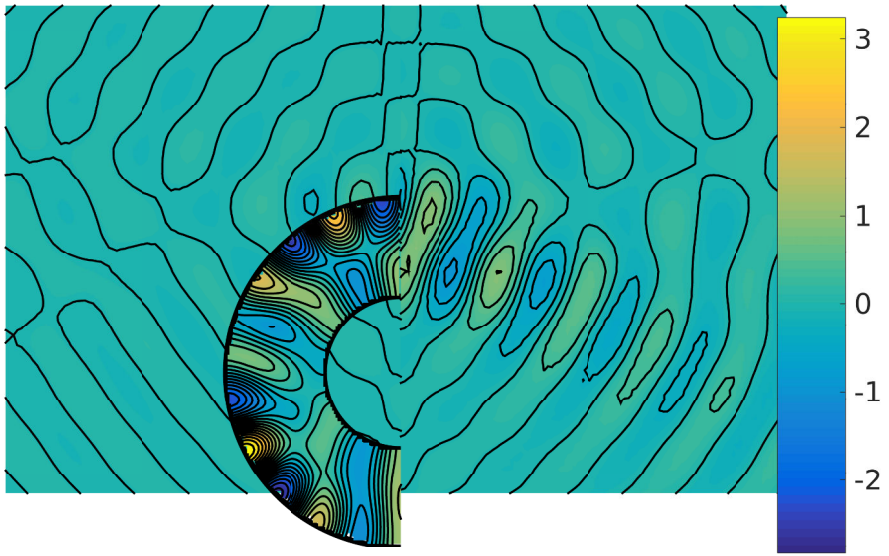
Curved cylindrical duct at resonance (1st, 5th, 10th and 12th)

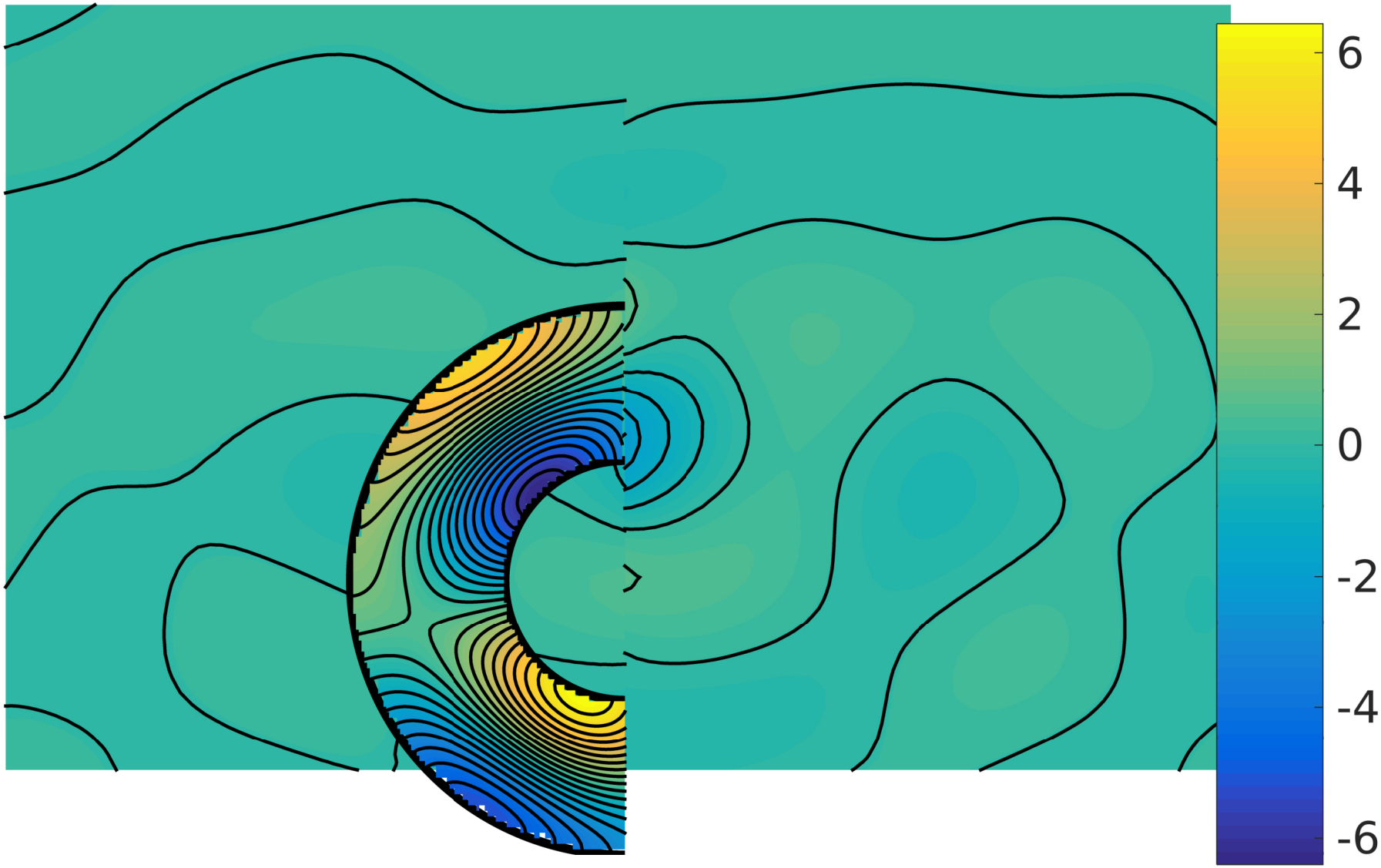




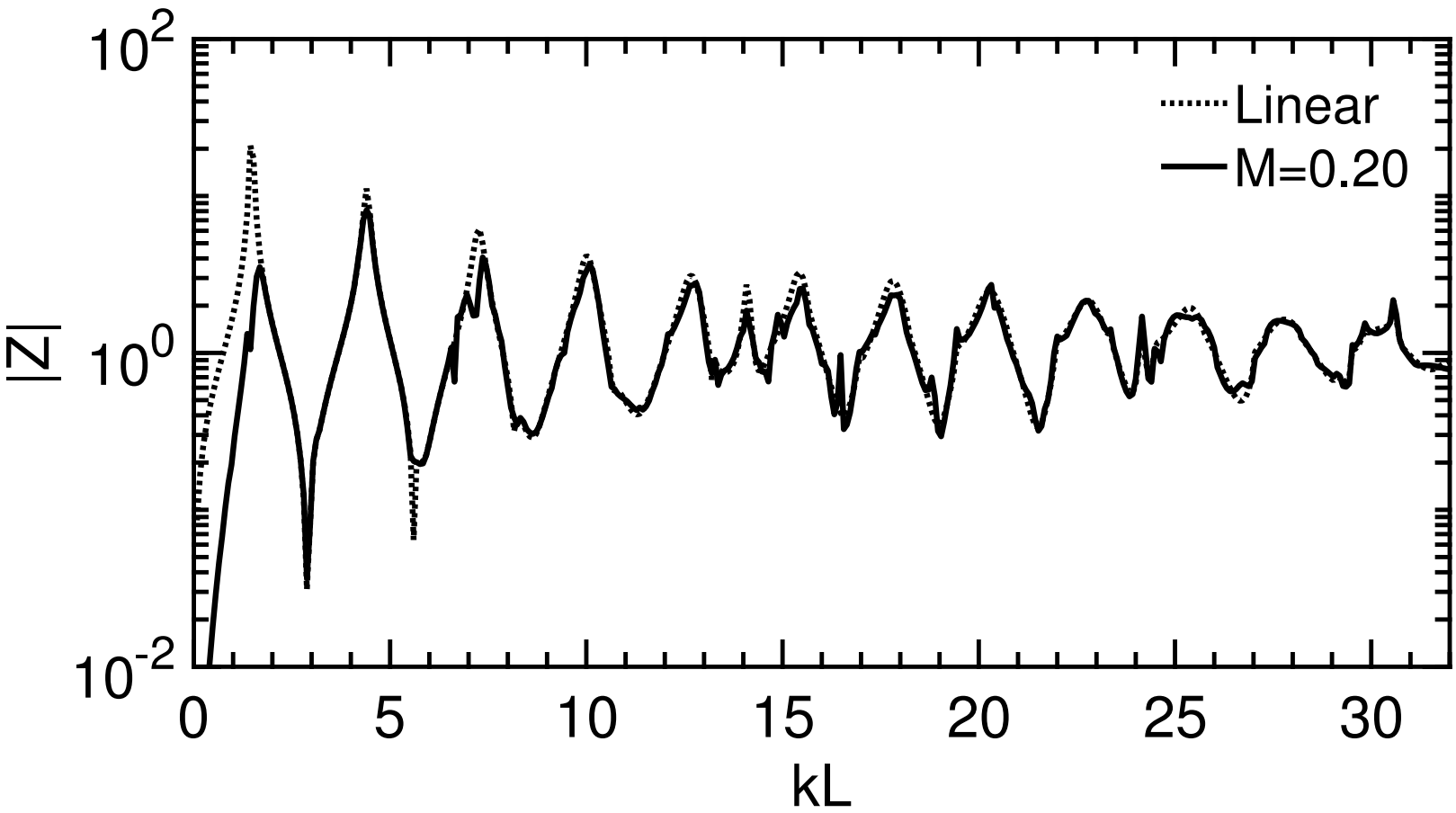




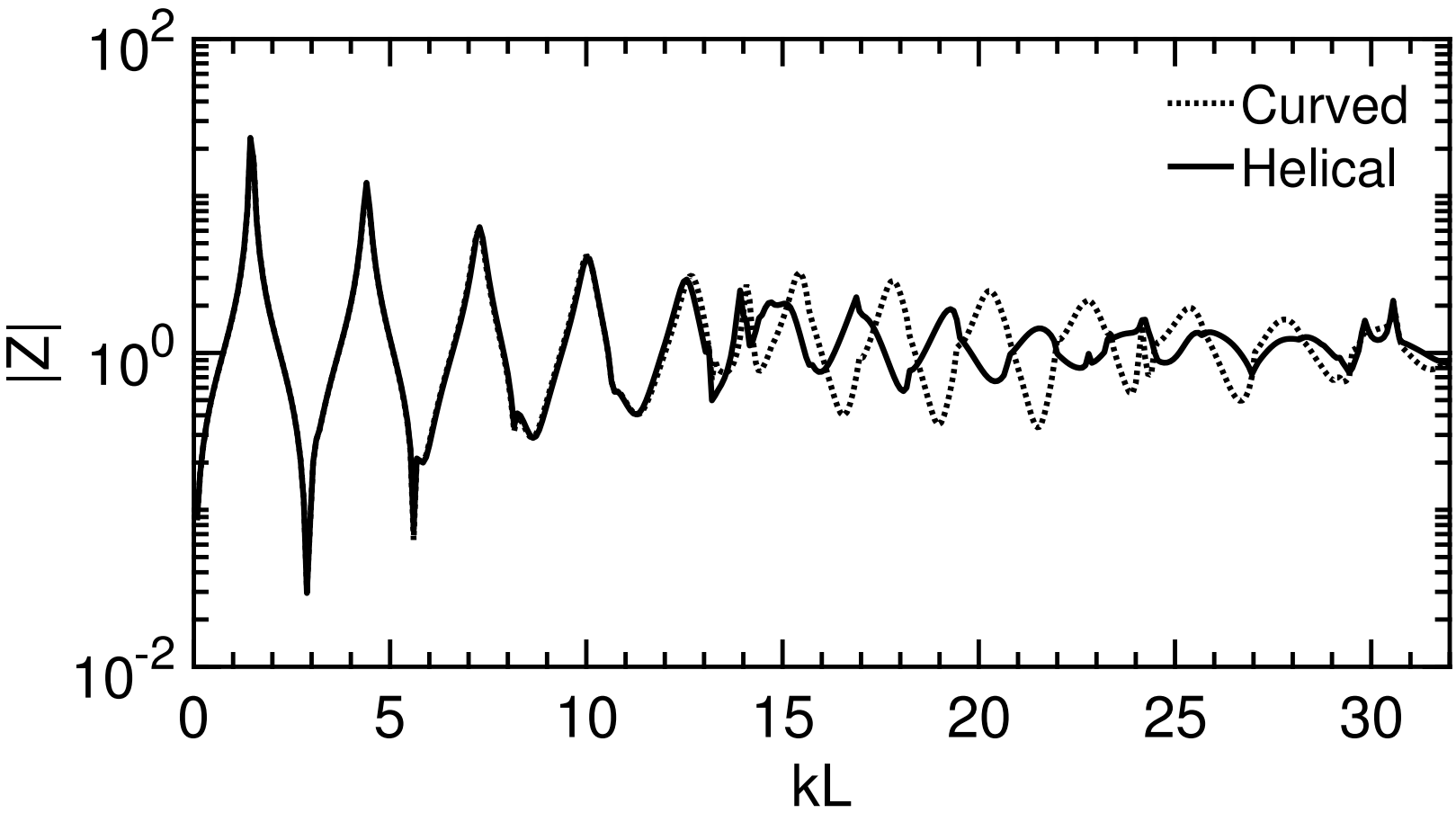
A non-plane-wave resonance of a curved cylindrical duct



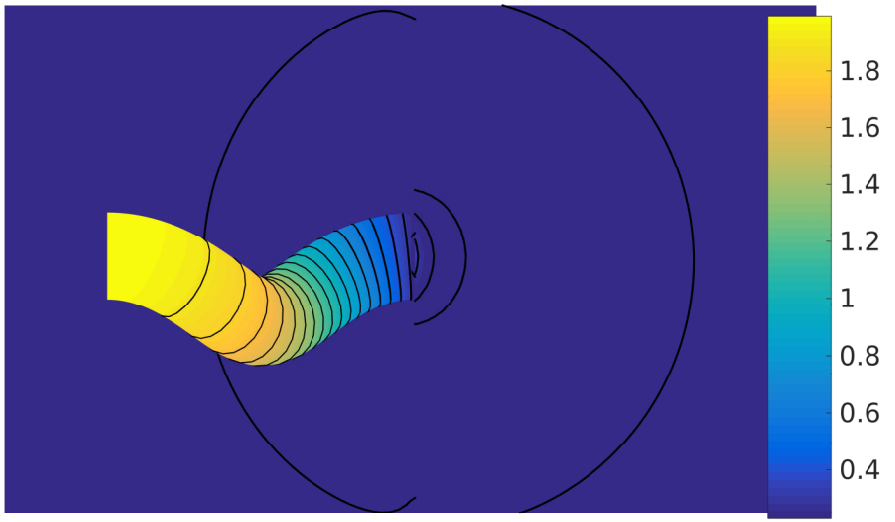
Linear vs nonlinear for a curved cylindrical duct

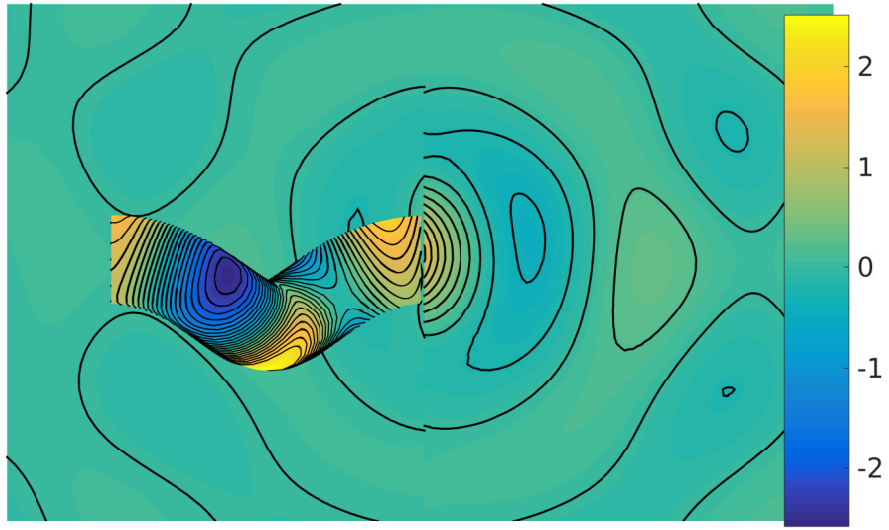


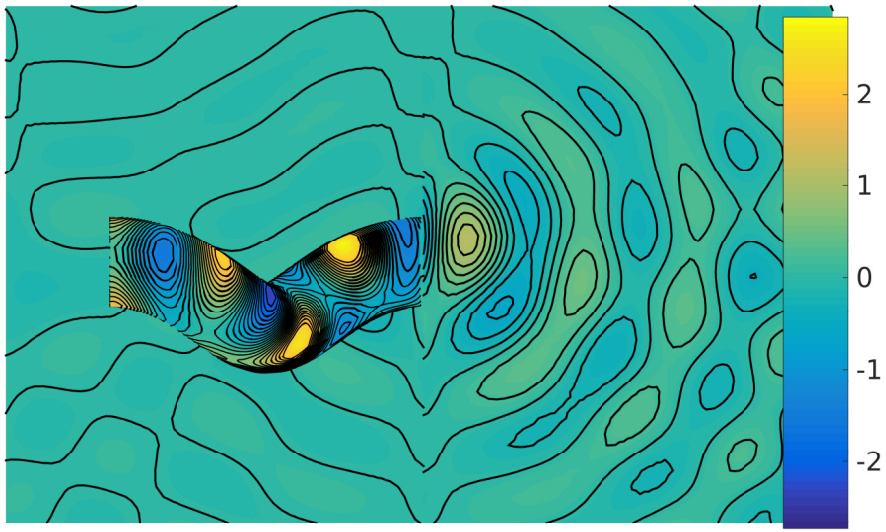
Helical vs equiv. length equiv. curvature non-helical duct



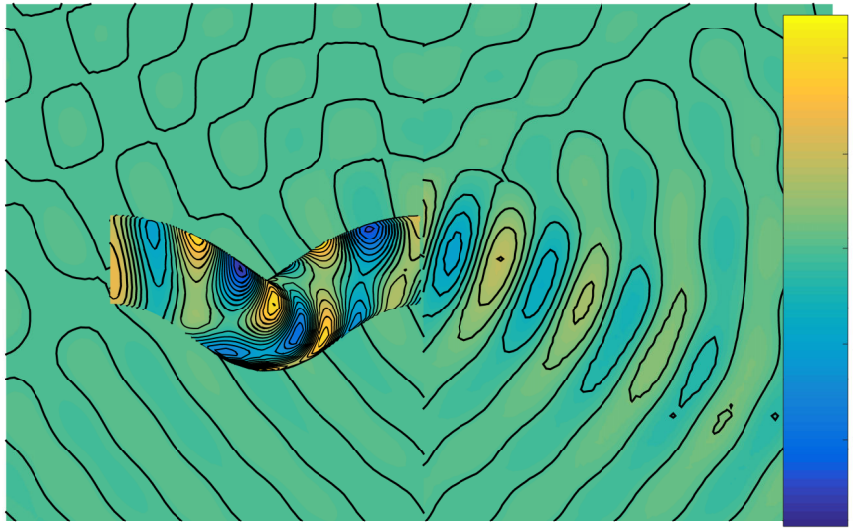
Resonances of a closed helical duct (1st, 5th and 10th)



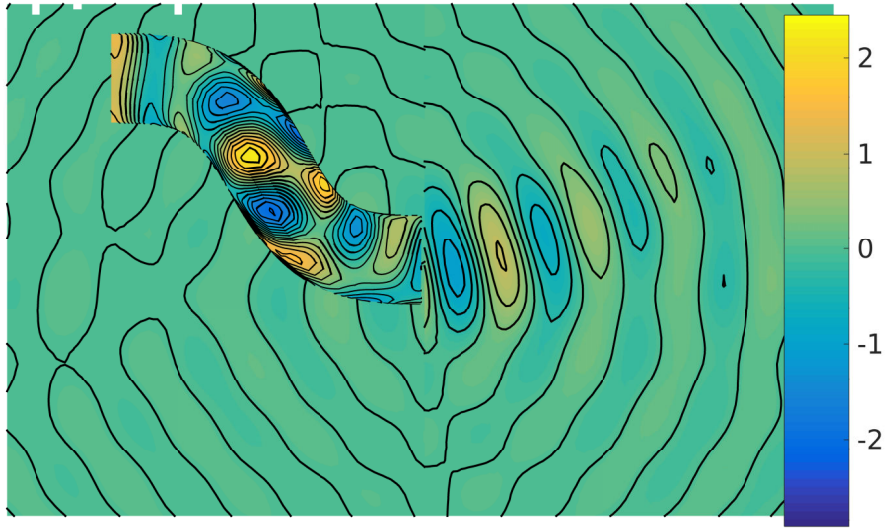




13th resonance of a closed helical duct

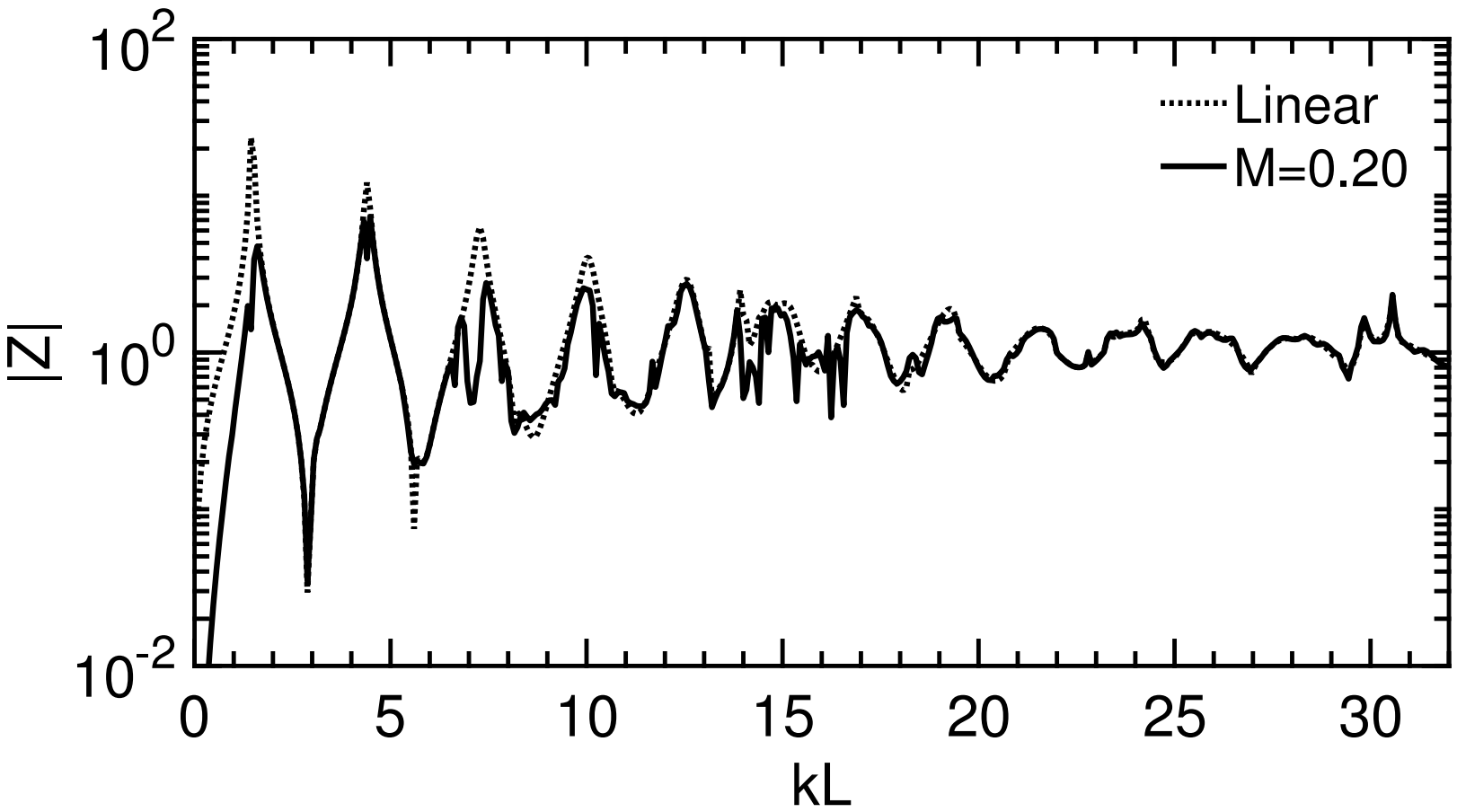


Binormal at exit into page

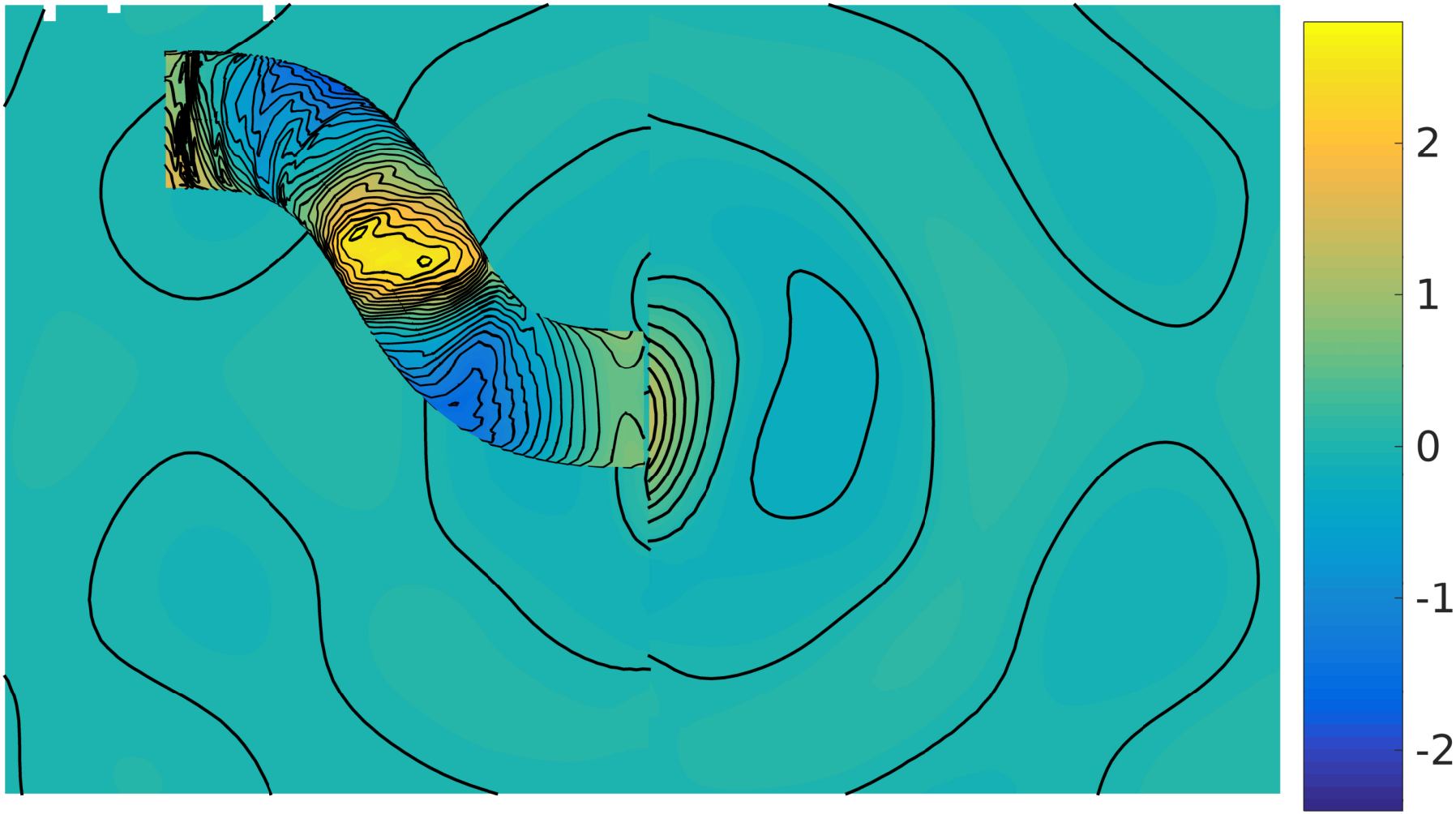


Normal at exit out of page

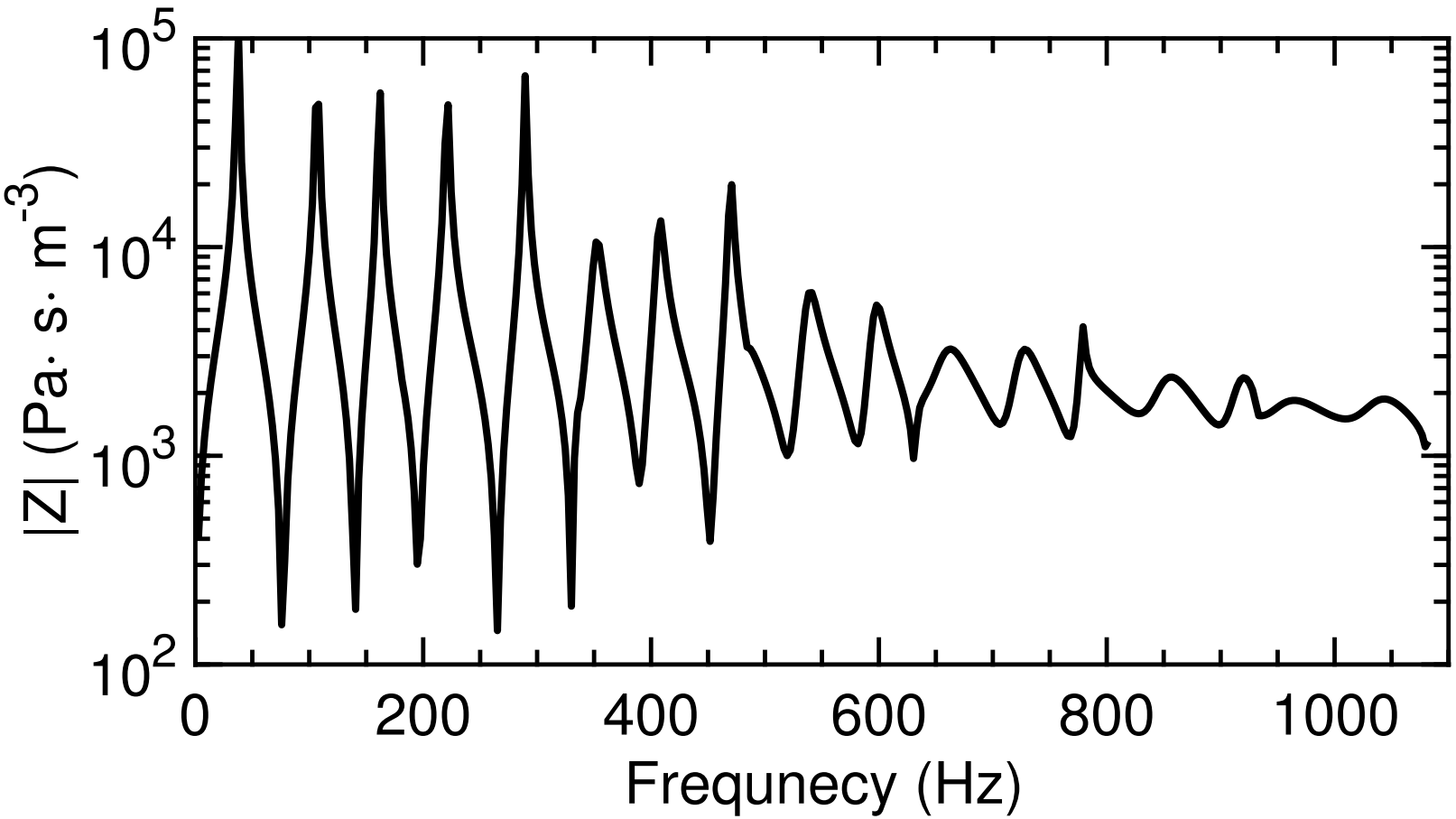
Linear vs nonlinear impedance for a helical duct



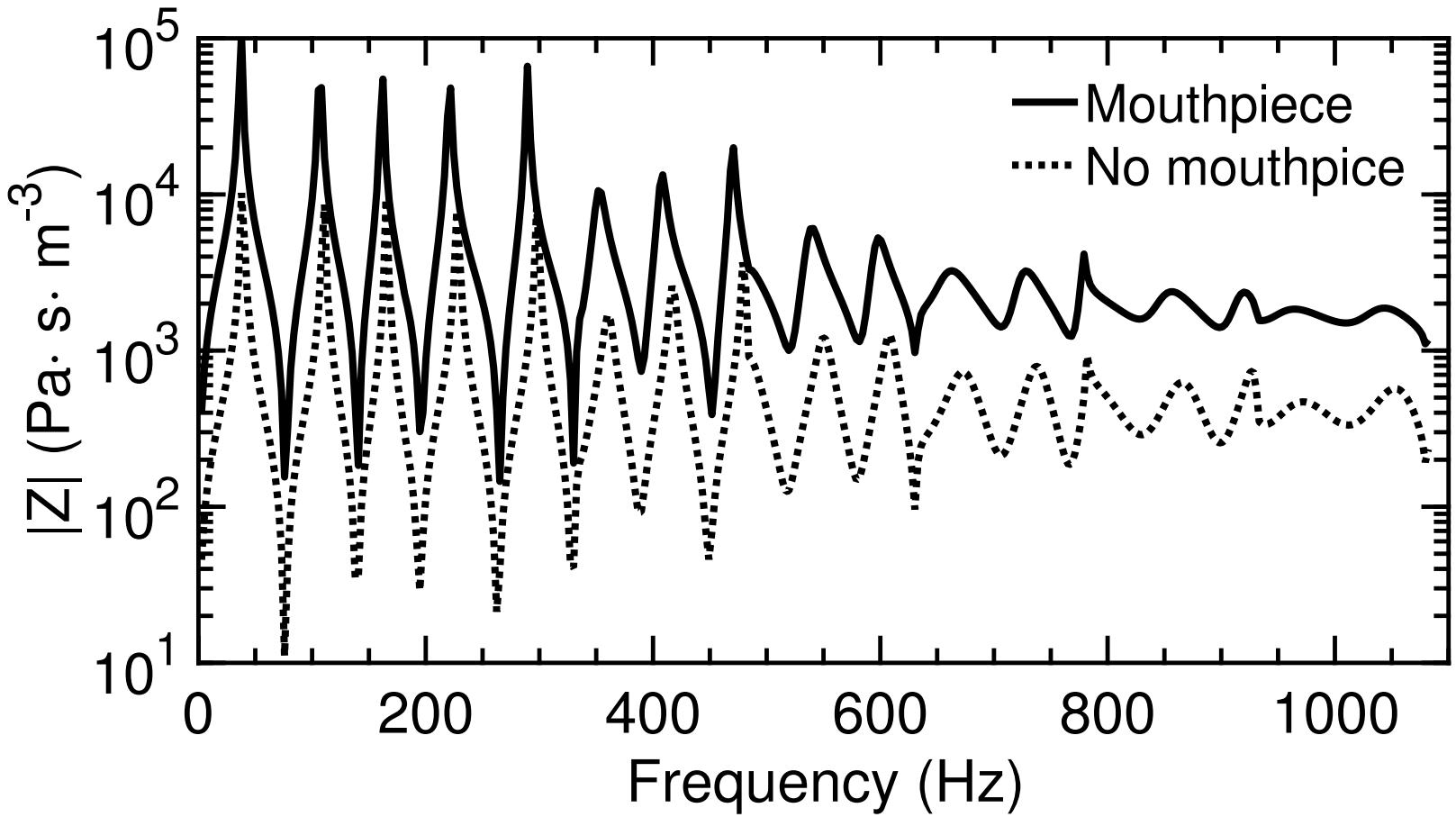
5th resonance of a closed helical duct ($M = 0.1$)



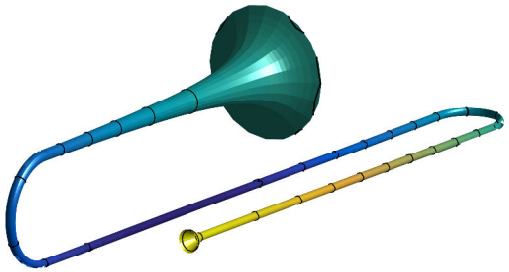
Impedance for a simplified trombone

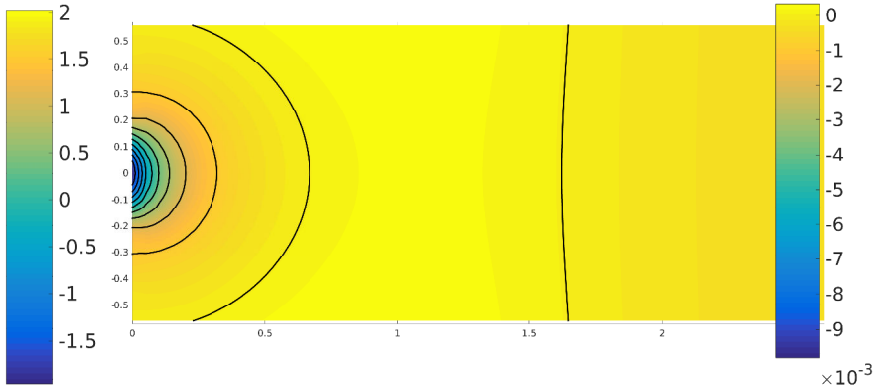


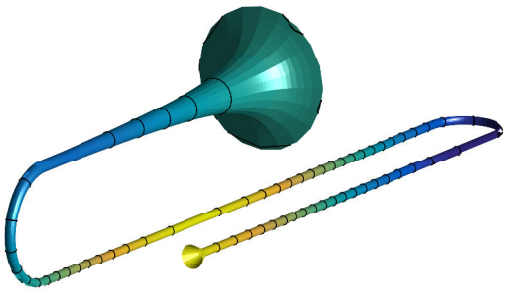
Trombone impedance with and without mouthpiece

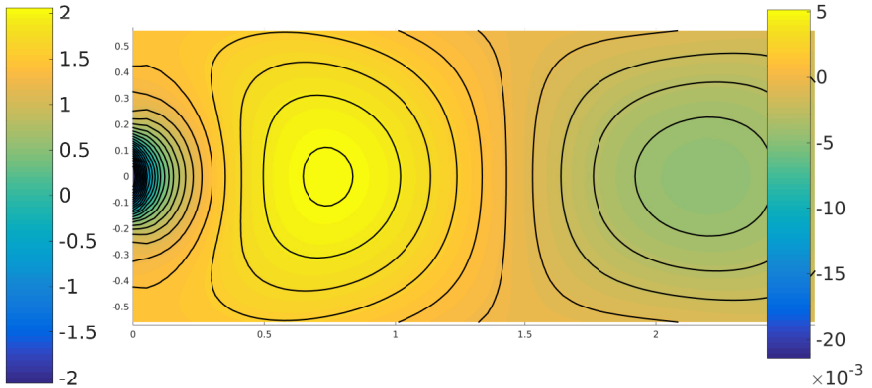


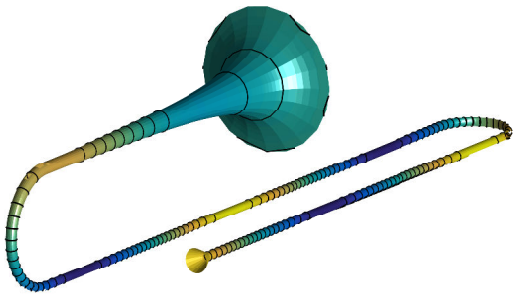
Simplified trombone at resonance (2nd, 4th and 8th)

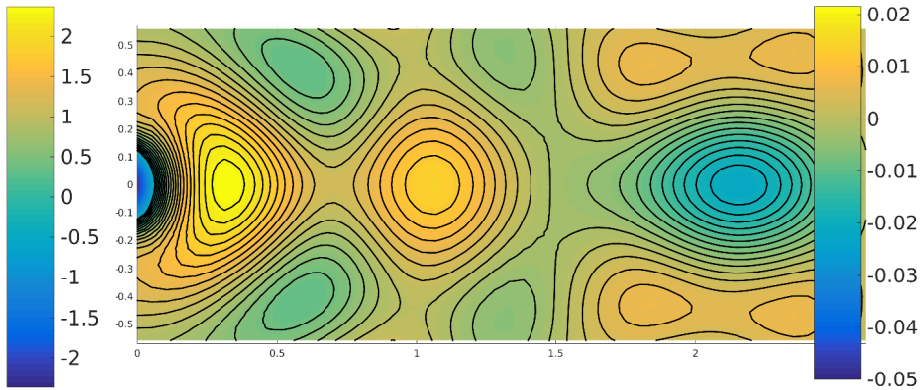




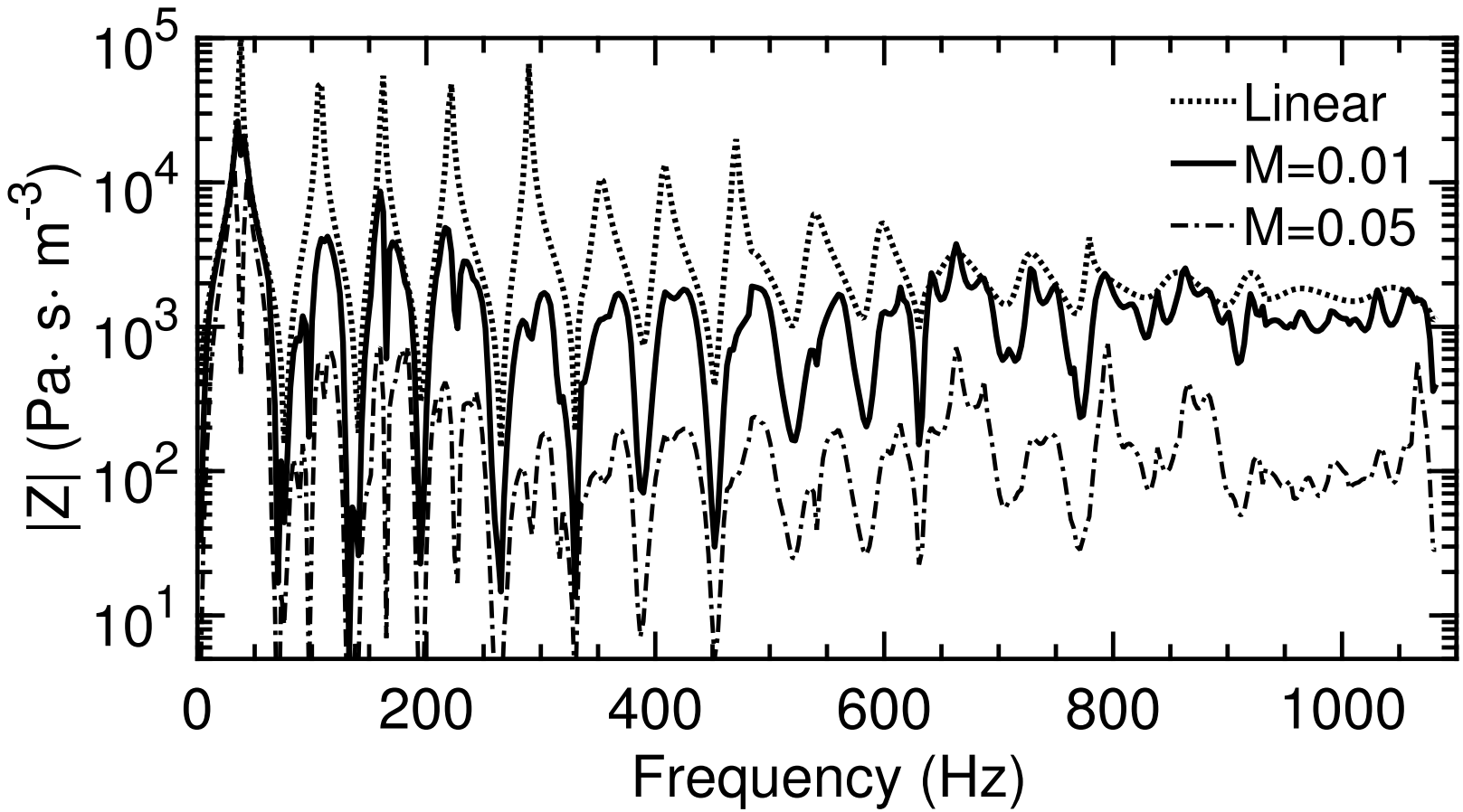




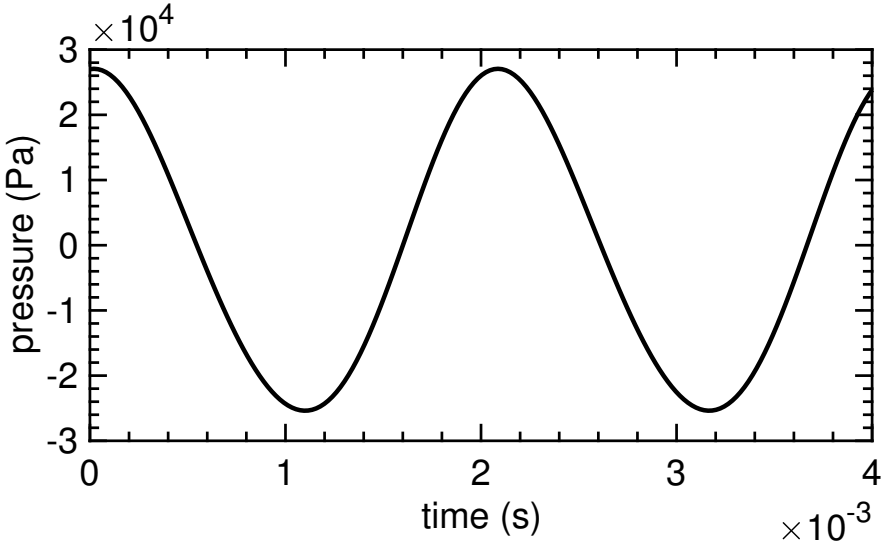




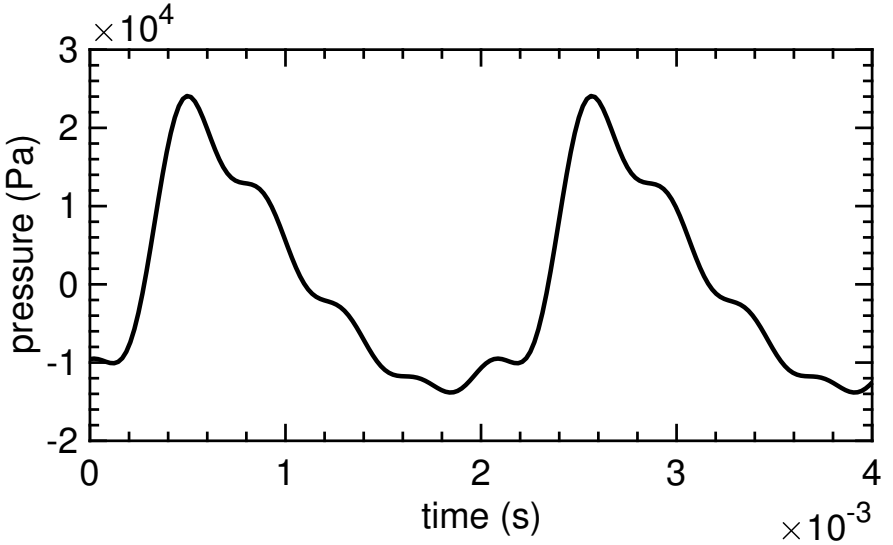
Nonlinearity in a simplified trombone



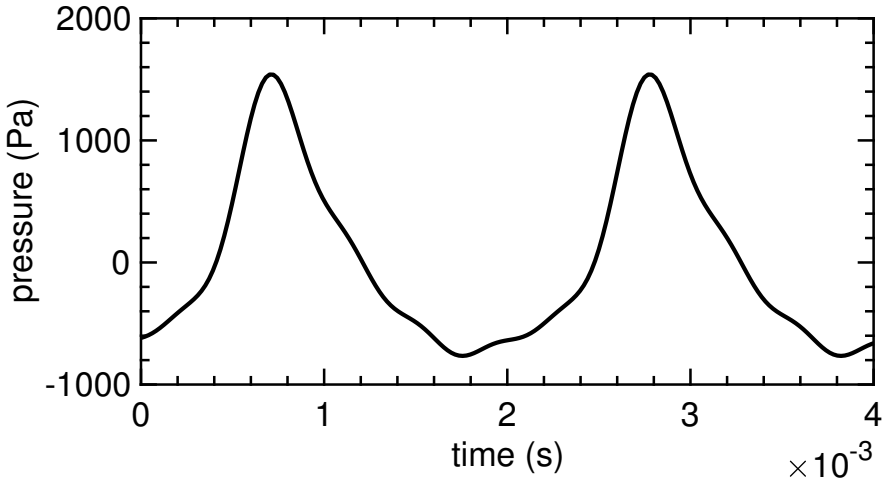
Pressure within a simplified trombone



Pressure in the mouthpiece

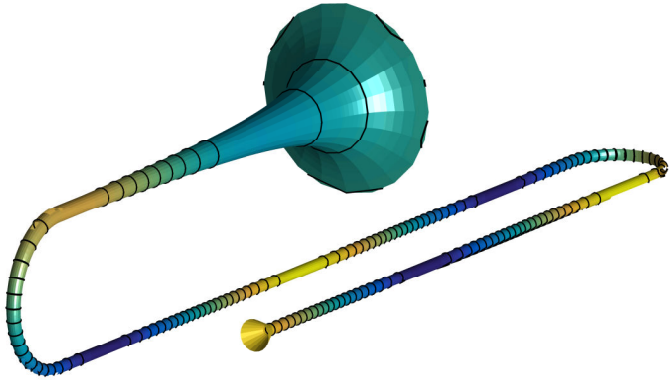


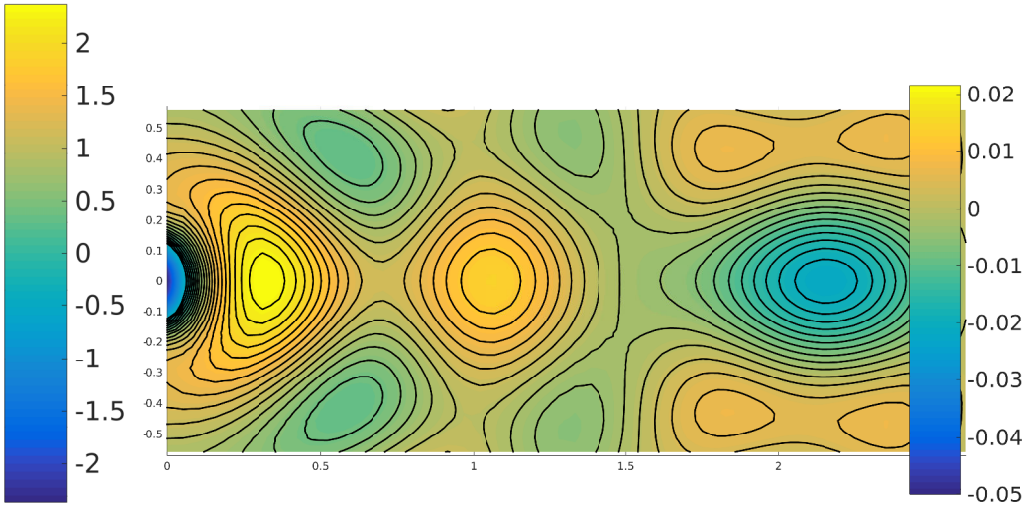
Pressure in the pipe just before the second bend

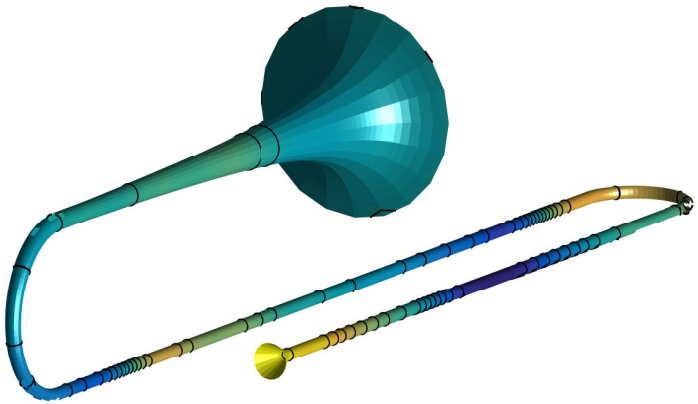


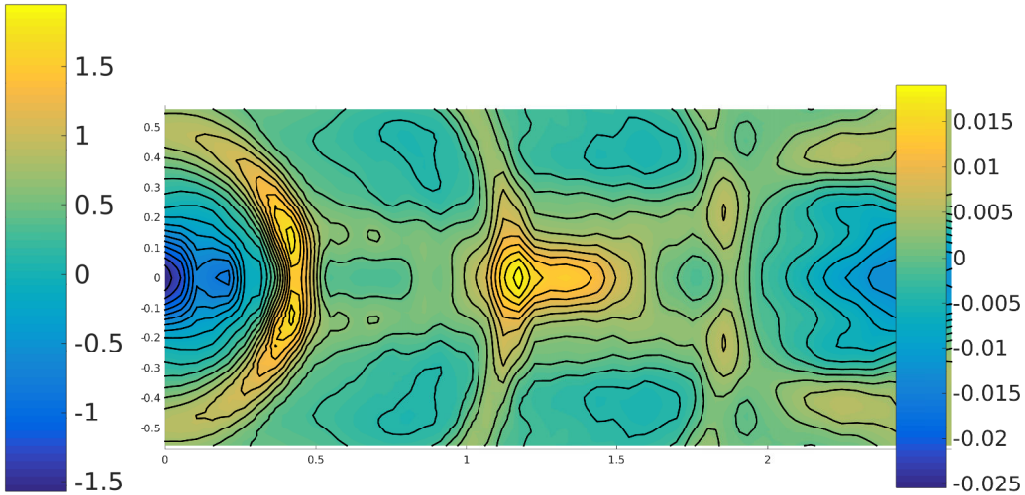
Pressure radiated at the bell

Simplified trombone at $M = 0$ and $M = 0.1$









Conclusion

- Generalization of Félix & Pagneux (2001 JASA; 2002 WM) to weak nonlinearity.
- Generalization of Fernando, Druon, Coulouvrat & Marchiano (2011 JASA) to non-straight ducts.
- New concept of weakly nonlinear reflectance, impedance, admittance, transmission coefficients, etc.
- New algebra (e.g. $\Psi_{[\alpha]\beta}[r]$, $\mathcal{R}[p,p]$) to handle complicated expressions.
- Expand in a basis of straight duct modes (from Félix & Pagneux):
  - Calculate linear and nonlinear admittance Y and $\mathcal{Y}$ at duct exit.
  - Solve ODE to find Y and $\mathcal{Y}$ throughout duct.
  - Use pressure at duct inlet to find pressure everywhere.
- Applied to curved and helical cylindrical ducts of varying width. Other duct shapes are also possible.
- Possible implications for brass and woodwind instruments.

- For details of 2D, see McTavish & Brambley (2019 JFM).
- For details of 3D, see future JFM paper (McTavish & Brambley).