Numerical investigation of normal mode radiation properties of ducts with low Mach number inlet flow

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Summary

Context

- Ducts are presents in a several acoustics components nowadays;
- Most of ducts have a inner mean flow;
- Study the acoustics properties of ducts with flow are important and there are so many works with outlet flow;
- But few works have presented concepts and informations internal acoustic about ducts with inlet flow;
- The numerical aproach by using the lattice Boltzmann method is a good choice to explore the acoustics parameters of dutcs with flow.

Goals

- Main goal: investigate the internal acoustic of unflanged ducts with normal mode and low Mach ($M \leq 0.2$) number inlet flow by using the lattice Boltzmann method.
- Specific goals:
  - implement and validate the internal acoustics parameters of unflanged duct without flow;
  - implement and validate the internal acoustics parameters of unflanged duct with outlet flow;
  - implement, validate and analyse the internal acoustics parameters of unflanged duct with inlet flow.

Summary

Internal Acoustics Parameters

- Magnitude of coeficient reflection in end of duct:

$$|R_r| = \left|\frac{Z_r - Z_0}{Z_r + Z_0}\right|, \tag{1}$$

- End correction:

$$l = \frac{1}{k}\arctan\left(\frac{Z_r}{Z_0\,\mathrm{j}}\right). \tag{2}$$

Related Works

- Levine and Schwinger (1948): $|R_r|$ and l/a without flow;
- Munt (1990): $|R_r|$ and l/a with outlet flow;
- Ingard and Singhal (1975) and Davies (1987): $|R_r|$ and l/a with inlet flow but only low frequencies ($ka < 0.25$). The values of l/a was suggested but not proved or measured;
- Ingard and Singhal (1975) and Davies (1987) related that inlet flow form a vena contracta with factor loss defined by

$$K_p = \frac{\Delta p}{0.5\rho(c_0 M)^2}. \tag{3}$$

Summary

Governing Equations

- lattice Boltzmann with MRT model according d'Humieres (1994):

$$f_i(\mathbf{x} + c_i\Delta t, t + \Delta t) = f_i(\mathbf{x}, t) - M^{-1}S(m_i - m_i^M). \quad (4)$$

- rigid wall: bounceback no-slip Viggen (2014);
- anechoic condition: Kam et al. (2006).

Element Structure

- D3Q19:

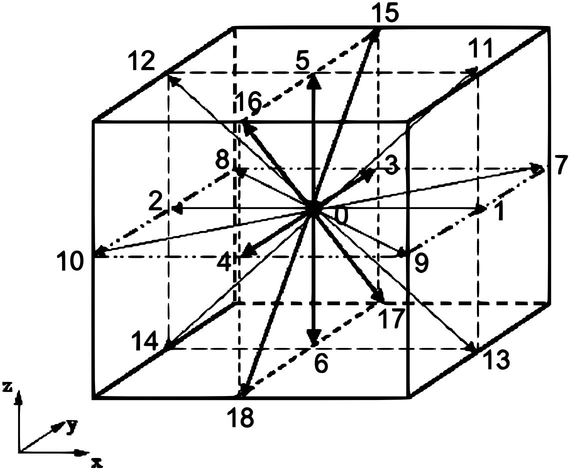


Figure 1: D3Q19 Model. Figure adapted from Premnath et al. (2013).

Numerical Model

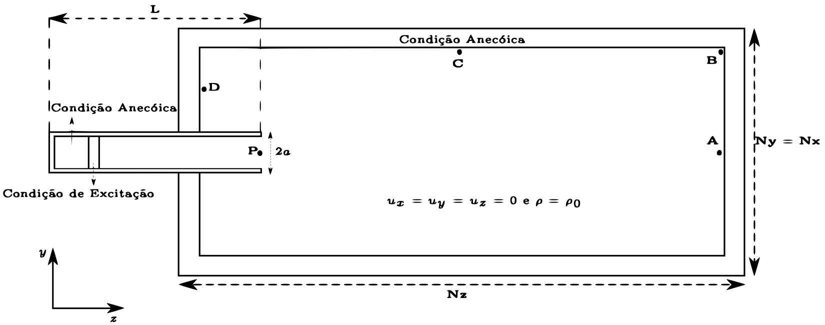
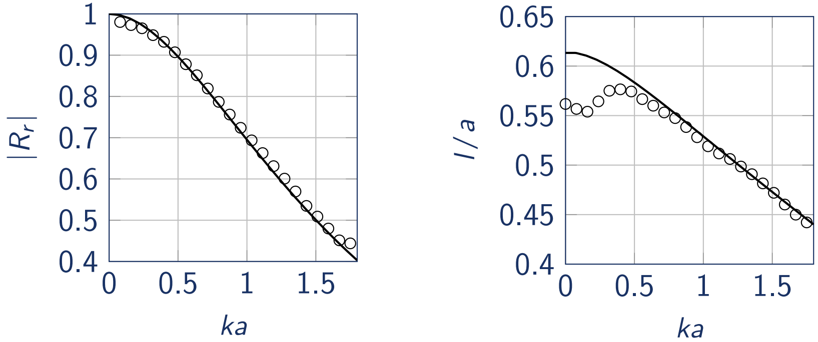


Figure 2: Numerical model: view of 3D lateral cut of the model.

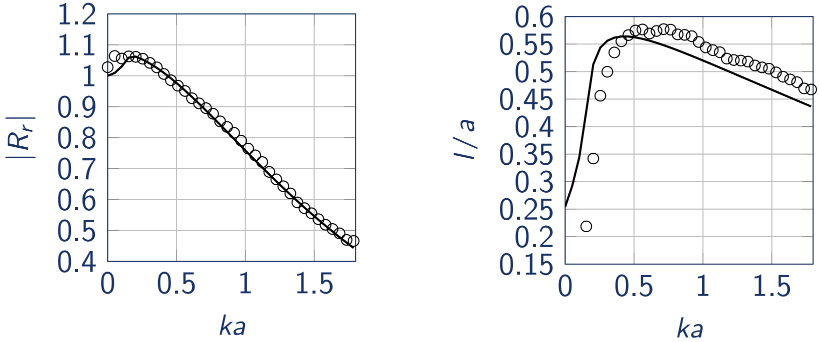
Summary

Without Flow



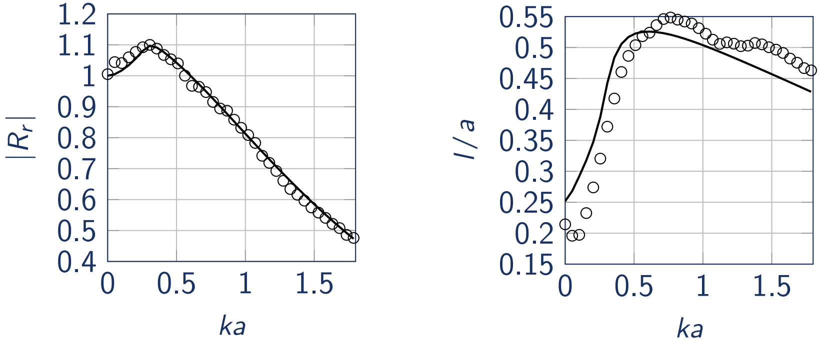
Solid lines represents Levine and Schwinger (1948) and circular points are the present study results.

With Outlet Flow: $M = 0.07$



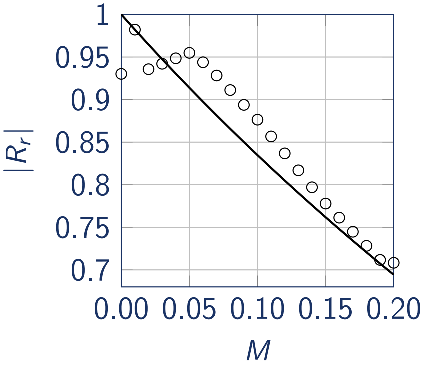
Solid lines represents Munt (1990) and circular points are the present study results.

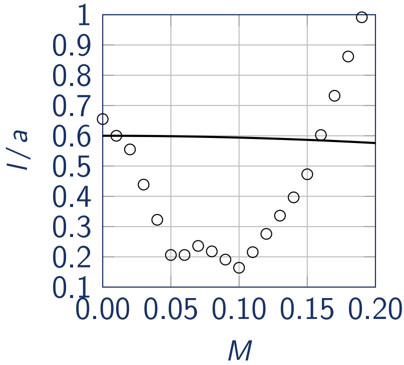
With Outlet Flow: $M = 0.15$



Solid lines represents Munt (1990) and circular points are the present study results.

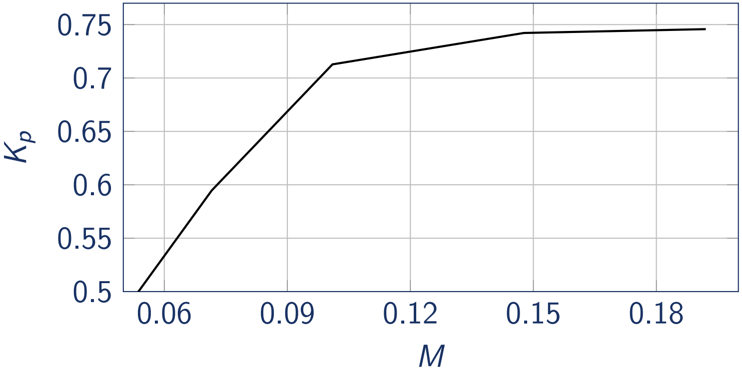
With Inlet Flow: $ka = 0.1$





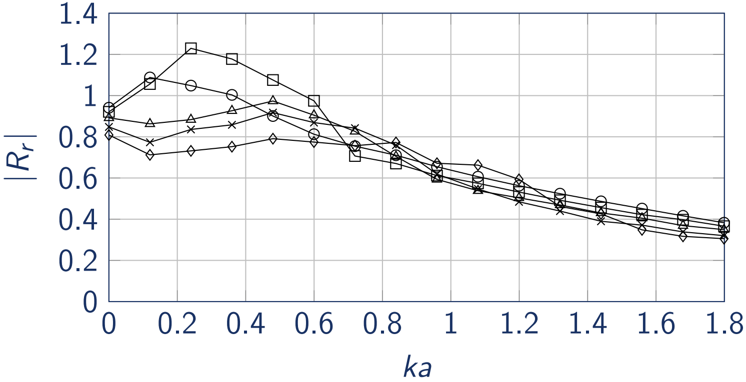
Solid lines represents Davies (1987) and circular points are the present study results.

With Inlet Flow: K_p X M



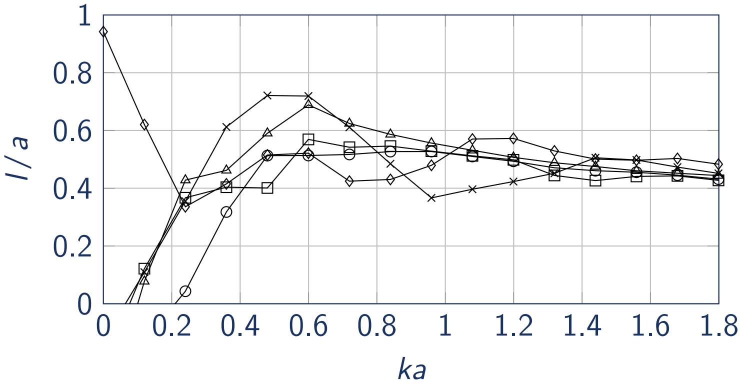
Loss factor formed by vena contracta increase with Mach number.

With Inlet Flow: R_r X ka



The results with $\bigcirc$ are $M = 0.05$, $\square$ are $M = 0.07$, $\triangle$ are $M = 0.1$, $\times$ are $M = 0.15$ and $\diamond$ are $M = 0.2$.

With Inlet Flow: l/a X ka



The results with $\bigcirc$ are $M = 0.05$, $\square$ are $M = 0.07$, $\triangle$ are $M = 0.1$, $\times$ are $M = 0.15$ and $\diamond$ are $M = 0.2$.

Summary

Conclusions

- Without flow: Good agreements were obtained among results from model in lattice Boltzmann method and Levine and Schwinger (1948);
- Outlet flow: Good agreements were obtained among results from model in lattice Boltzmann method and Munt (1990);
- Inlet flow: Good agreements were obtained among $|Rr|$ results from model in lattice Boltzmann method and Davies (1997). But there are divergences with values of l/a;
- Vena contracta was analyzed and your factor loss K_p increase with inlet flow Mach;
- In general $|R_r|$ decrease with increased values of K_p;
- In general l/a don't change with differents values of K_p;
- By increase values of M, $|R_r|$ increase with outlet flow and decrease with intlet flow.

Thank you!

Questions?