ON PHYSICAL MECHANISMS RESPONSIBLE FOR EXCESS NOISE DUE TO JET-WING INTERACTION

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Outline

- Introduction
- Problem statement
- Method of solution
- Analysis of the results
- Conclusion

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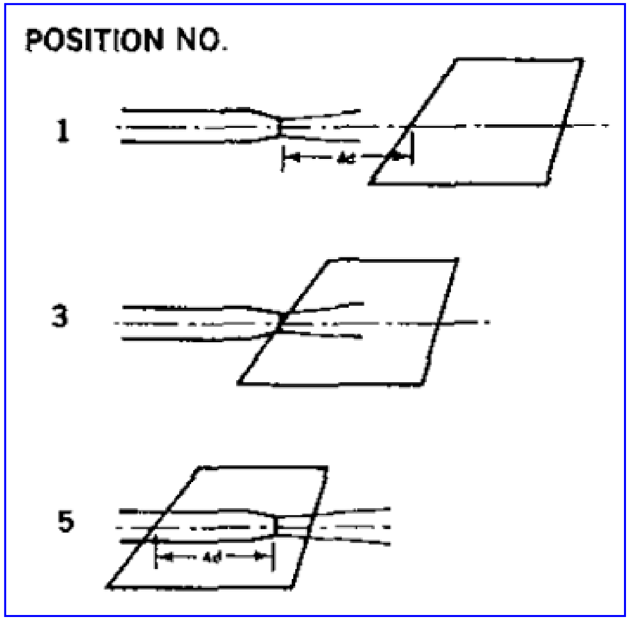
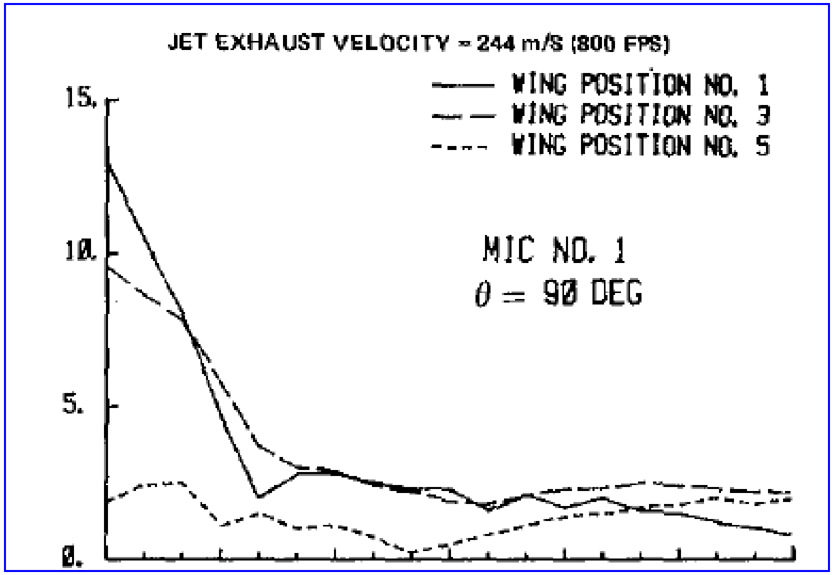
Jet-wing, jet-flap interaction

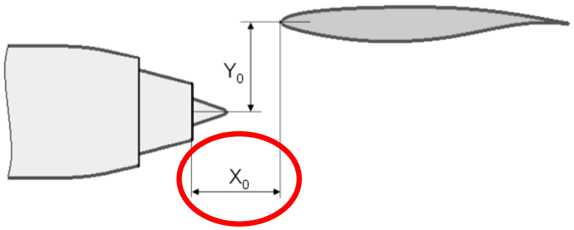
AIAA-80-1047

Wing Effect on Jet Noise Propagation

M. E. Wang







Noise intensification on approaching the nozzle edge plane to the wing trailing edge

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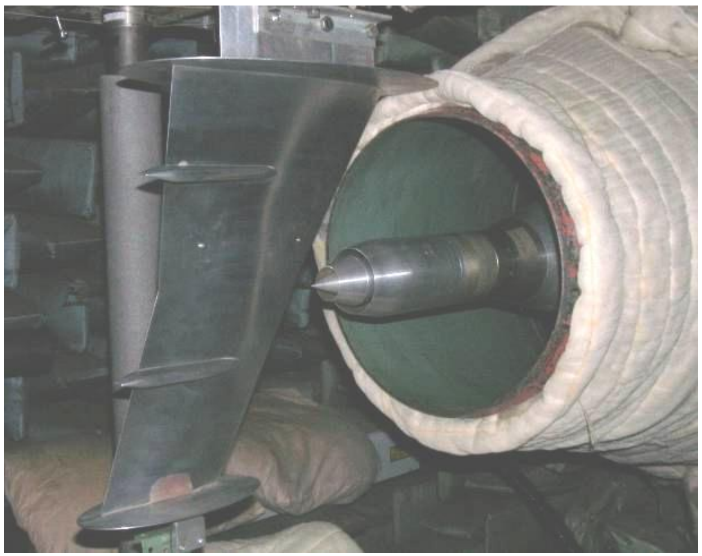
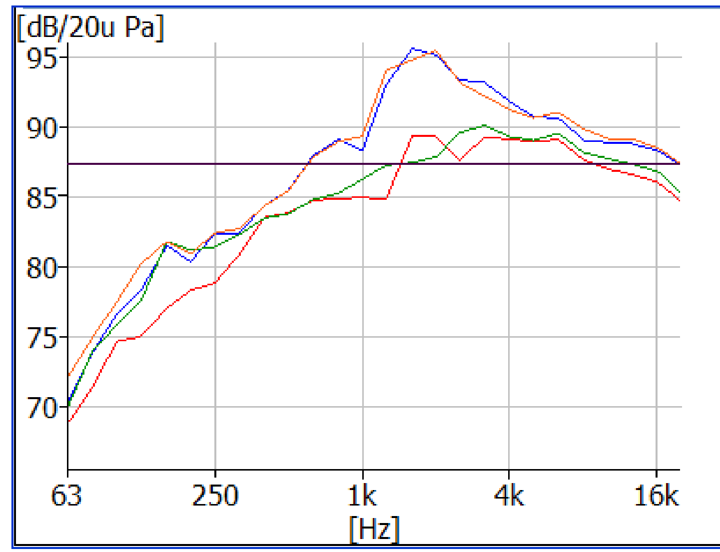
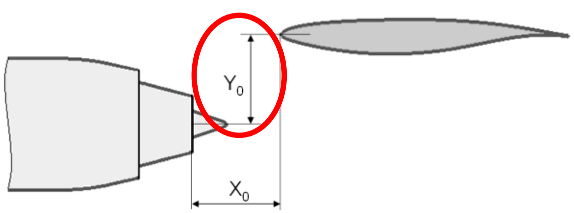
Intensification and suppression of jet noise sources in the vicinity of lifting surfaces

Victor F. Kopiev[1], Georgy A. Faranosov[2], Mikhail Yu. Zaytsev[3],
Evgeny V. Vlasov[4], Rudolf K. Karavosov[5], Ivan V. Belyaev[6], Nikolay N. Ostrikov[7]







Noise intensification on approaching the jet to the wing plane

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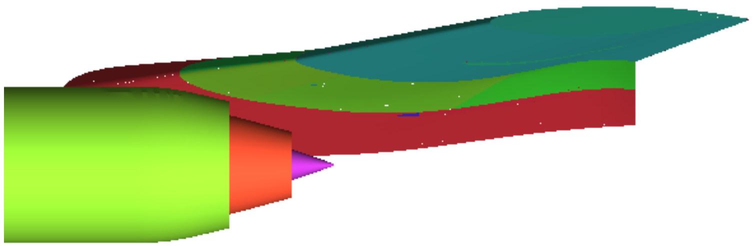
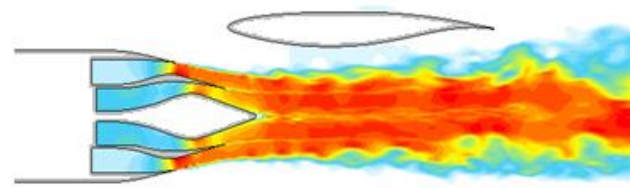
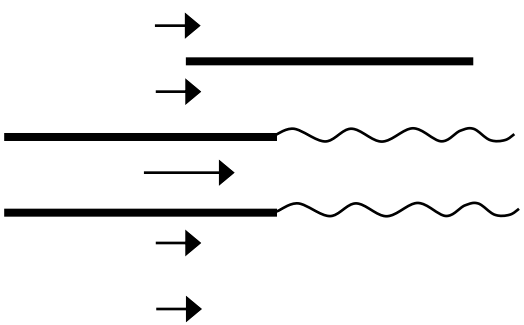
3D

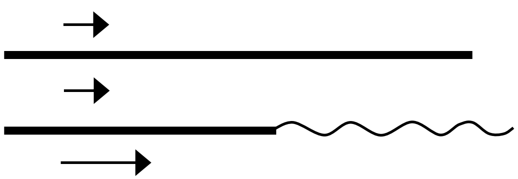


2D



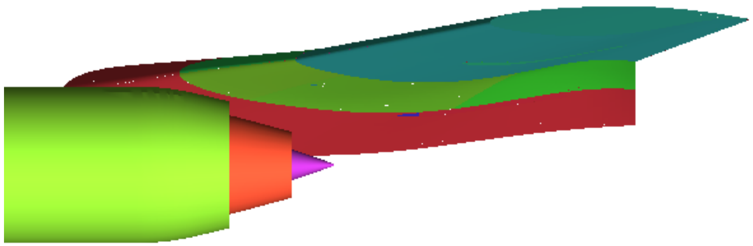


In-plane parallel flow

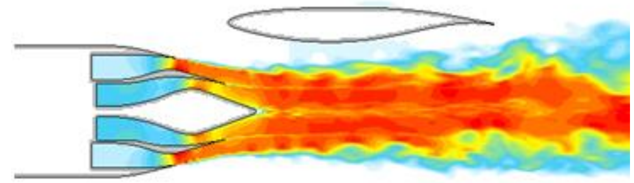


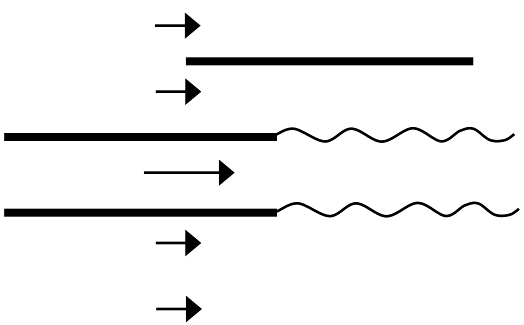
Trailing edge + nozzle edge

3D

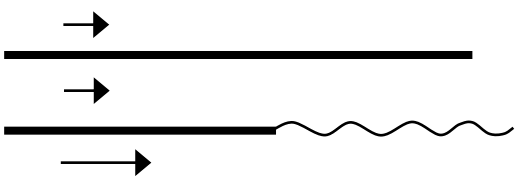


2D





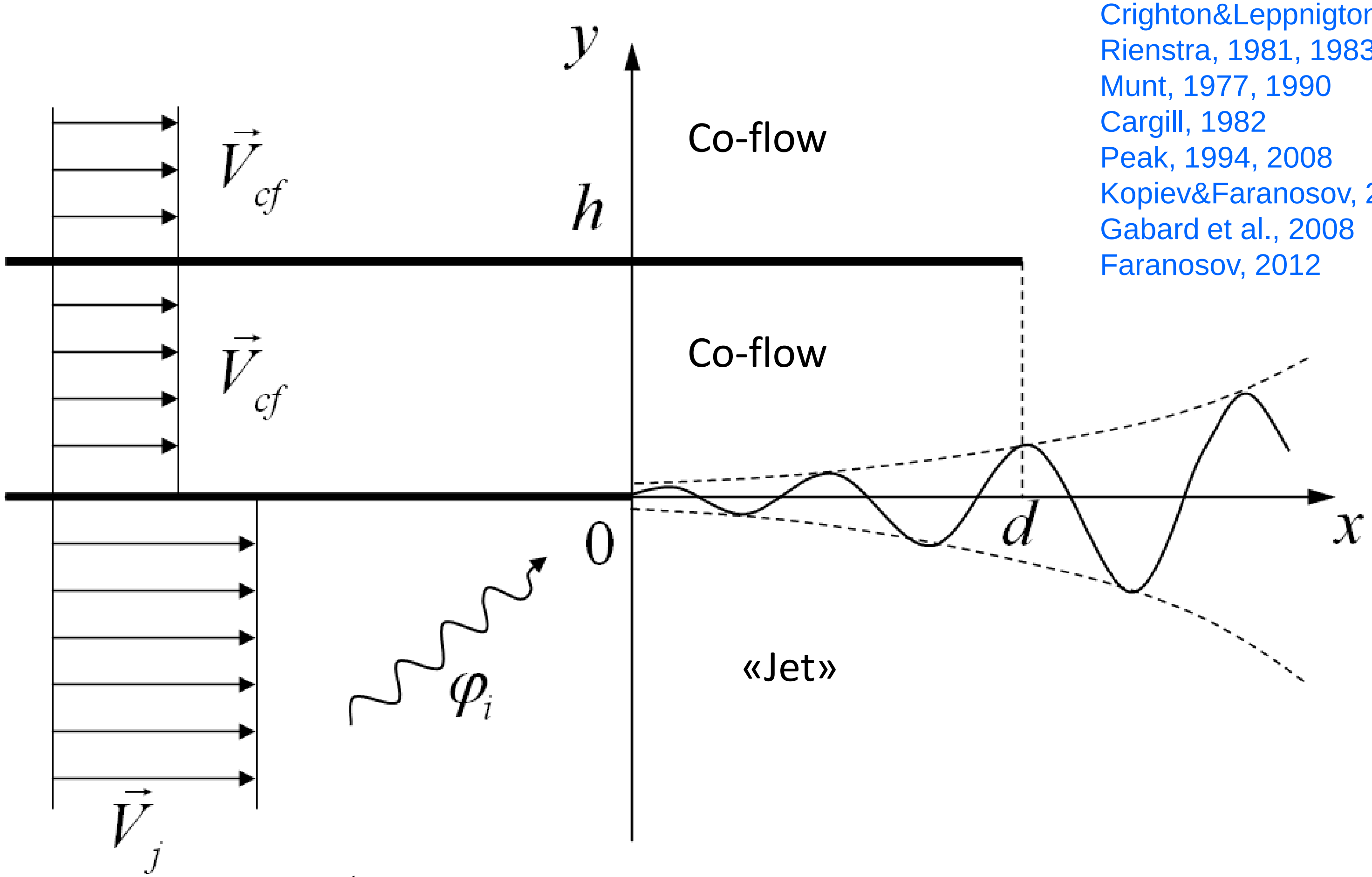
In-plane parallel flow



Trailing edge + nozzle edge

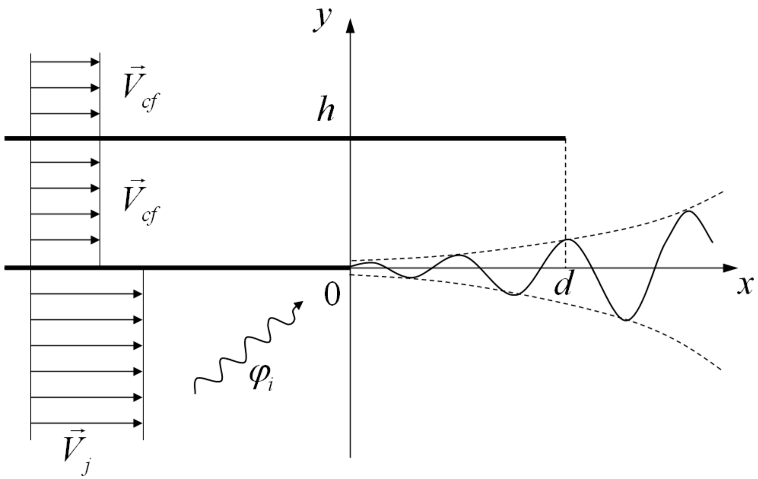
Model problem formulation

Morgan, 1974
Crighton&Leppnigton, 1974
Rienstra, 1981, 1983, 2006
Munt, 1977, 1990
Cargill, 1982
Peak, 1994, 2008
Kopiev&Faranosov, 2008
Gabard et al., 2008
Faranosov, 2012



$$\varphi_i = A\exp\left(-i\omega t - i\frac{\omega / c_j \cos\theta}{1 - M_j \cos\theta}x + i\frac{\omega / c_j \sin\theta}{1 - M_j \cos\theta}y\right)$$

Governing equations and boundary conditions



Equations

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)\varphi-\left(M_{cf}\frac{\partial}{\partial x}-i\frac{\omega}{c_{cf}}\right)^2\varphi=0\,,\quad y>0,$$

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)\varphi-\left(M_{j}\frac{\partial}{\partial x}-i\frac{\omega}{c_{j}}\right)^2\varphi=0\,,\quad y<0,$$

Boundary conditions

$y=h:$

$$\left.\frac{\partial\varphi}{\partial y}\right|_{h+0}=-i\omega\eta_{12}+V_{cf}\frac{d\eta_{12}}{dx},\quad \left.\frac{\partial\varphi}{\partial y}\right|_{h-0}=-i\omega\eta_{12}+V_{cf}\frac{d\eta_{12}}{dx};\quad \eta_{12}=0,\ x<d;$$

$$p_{12}=p|_{h+0}-p|_{h-0}=-i\omega\rho_{cf}\left(\varphi|_{h+0}-\varphi|_{h-0}\right)+\left(\rho_{cf}V_{cf}\left.\frac{\partial\varphi}{\partial x}\right|_{h+0}-\rho_{cf}V_{cf}\left.\frac{\partial\varphi}{\partial x}\right|_{h-0}\right);\ p_{12}=0,\ x>d;$$

$y=0:$

$$\left.\frac{\partial\varphi}{\partial y}\right|_{+0}=-i\omega\eta_{23},\quad \left.\frac{\partial\varphi}{\partial y}\right|_{-0}=-i\omega\eta_{23}+V_j\frac{d\eta_{23}}{dx};\quad \eta_{23}=0,\ x<0;$$

$$p_{23}=p|_{+0}-p|_{-0}=-i\omega\left(\rho_{cf}\varphi|_{+0}-\rho_j\varphi|_{-0}\right)+\left(\rho_{cf}V_{cf}\left.\frac{\partial\varphi}{\partial x}\right|_{+0}-\rho_jV_j\left.\frac{\partial\varphi}{\partial x}\right|_{-0}\right);\ p_2=0,\ x>0;$$

$y\to\pm\infty:$ Radiation condition

Matrix Wiener-Hopf equation

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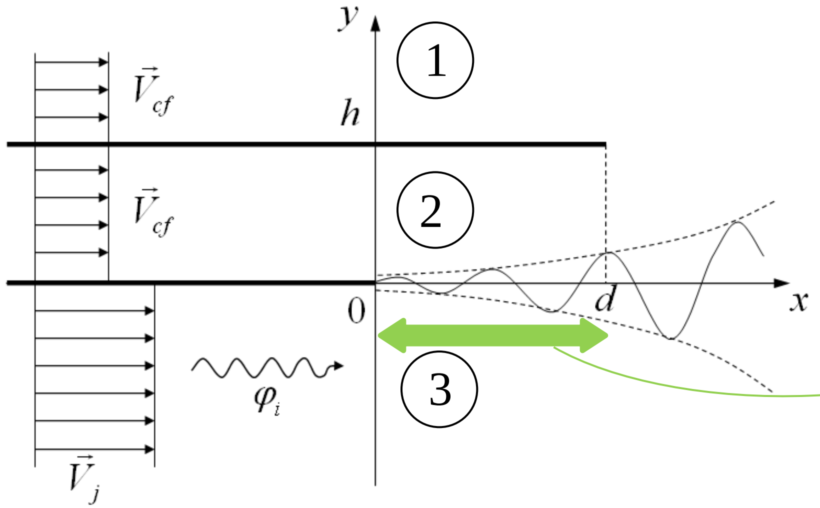
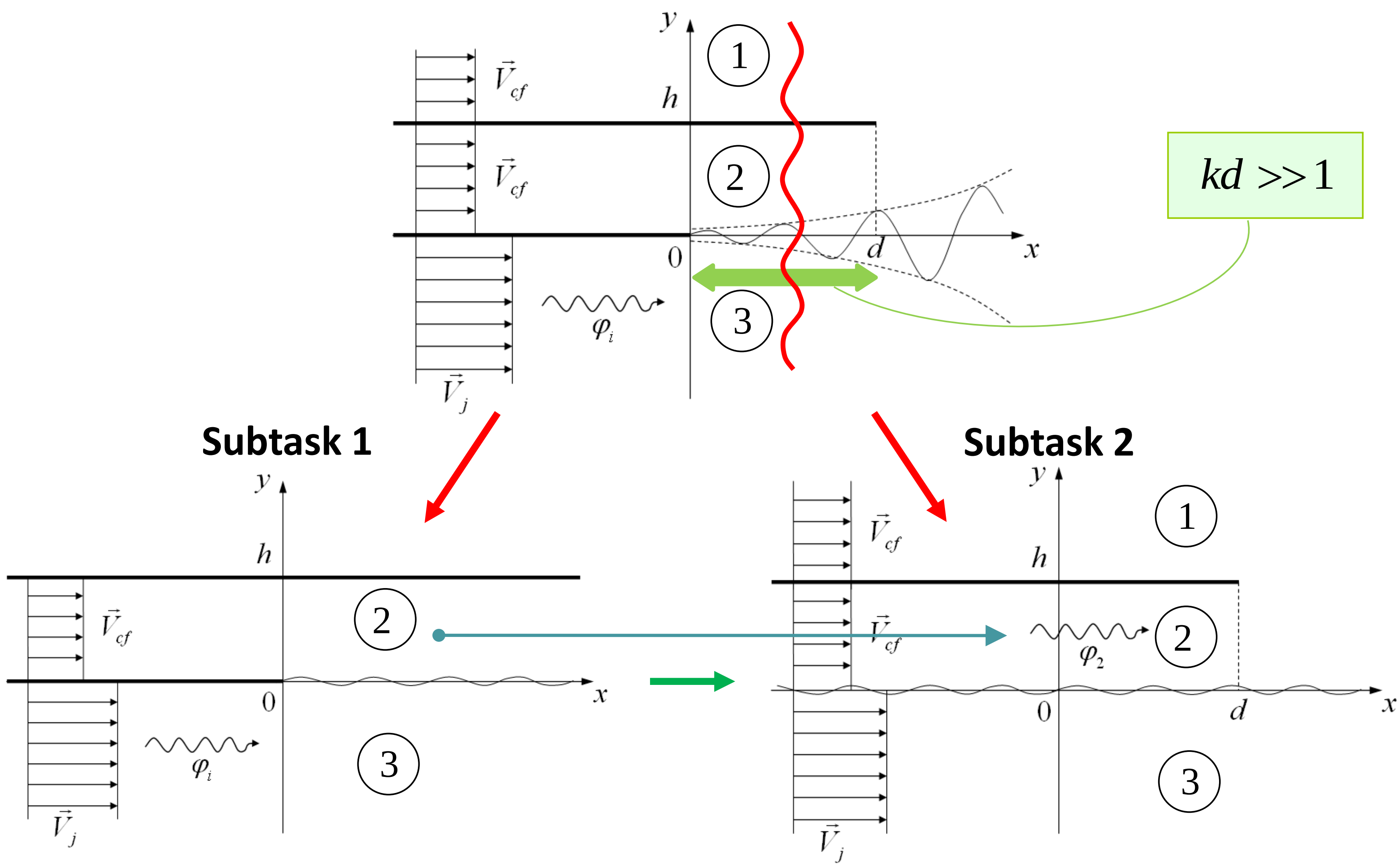
Approximate solution method



$$kd >> 1$$

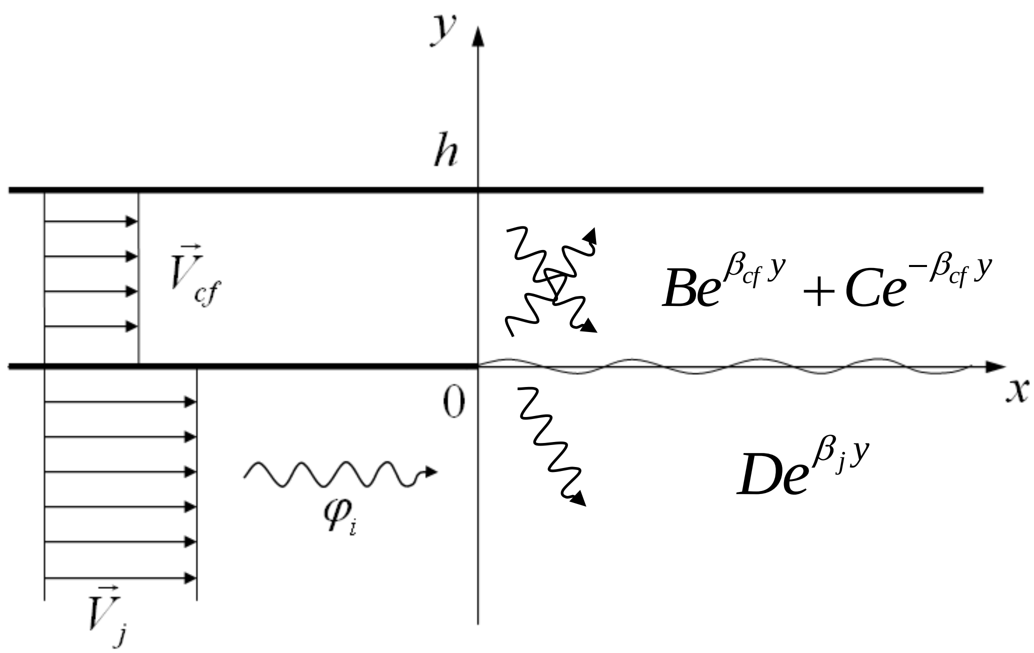
Approximate solution method



Subtask 1

After Fourier transform over x:

$$\begin{cases} \Phi_{yy} - \beta_{cf}{}^2\Phi = 0\,, \quad y > 0, \quad \beta_{cf} = \sqrt{(1-M_{cf}^2)\left(\alpha - \dfrac{k_{cf}}{1-M_{cf}}\right)\left(\alpha + \dfrac{k_{cf}}{1+M_{cf}}\right)}; \\ \Phi_{yy} - \beta_j{}^2\Phi = 0\,, \quad y < 0, \quad \beta_j = \sqrt{(1-M_j^2)\left(\alpha - \dfrac{k_j}{1-M_j}\right)\left(\alpha + \dfrac{k_j}{1+M_j}\right)}. \end{cases}$$



Subtask 1

$$\tilde{H}_+(\alpha)h_{23+}(\alpha)+i\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\Phi_{i+}(\alpha)=\frac{p_{23-}(\alpha)}{\tilde{H}_-(\alpha)}-i\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\Phi_{i-}(\alpha)$$

$$\tilde{H}(\alpha)=\frac{\rho_{cf}w_{cf}^2}{\beta_{cf}}\tanh(\beta_{cf}h)+\frac{\rho_j w_j^2}{\beta_j}=\tilde{H}_+(\alpha)\tilde{H}_-(\alpha)$$

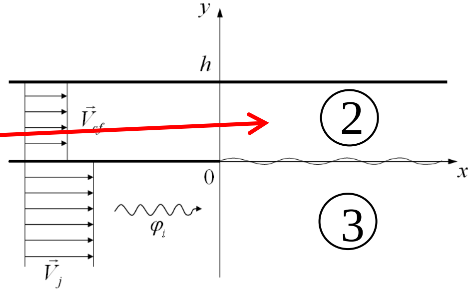
$$\Phi_i(\alpha)=\Phi_{i+}(\alpha)+\Phi_{i-}(\alpha)$$

$$w_j(\alpha)=\omega+V_j\alpha$$

$$w_{cf}(\alpha)=\omega+V_{cf}\alpha$$

Kutta-Zhukovsky condition is applied at the nozzle edge

$$\varphi_2=\frac{1}{2\pi}\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\int_C\frac{\Phi_{i+}(\alpha)}{\tilde{H}_+(\alpha)}\frac{\cosh(\beta_{cf}(y-h))}{\beta_{cf}\sinh(\beta_{cf}h)}e^{-i\alpha x}d\alpha$$



Subtask 2

After Fourier transform over x:

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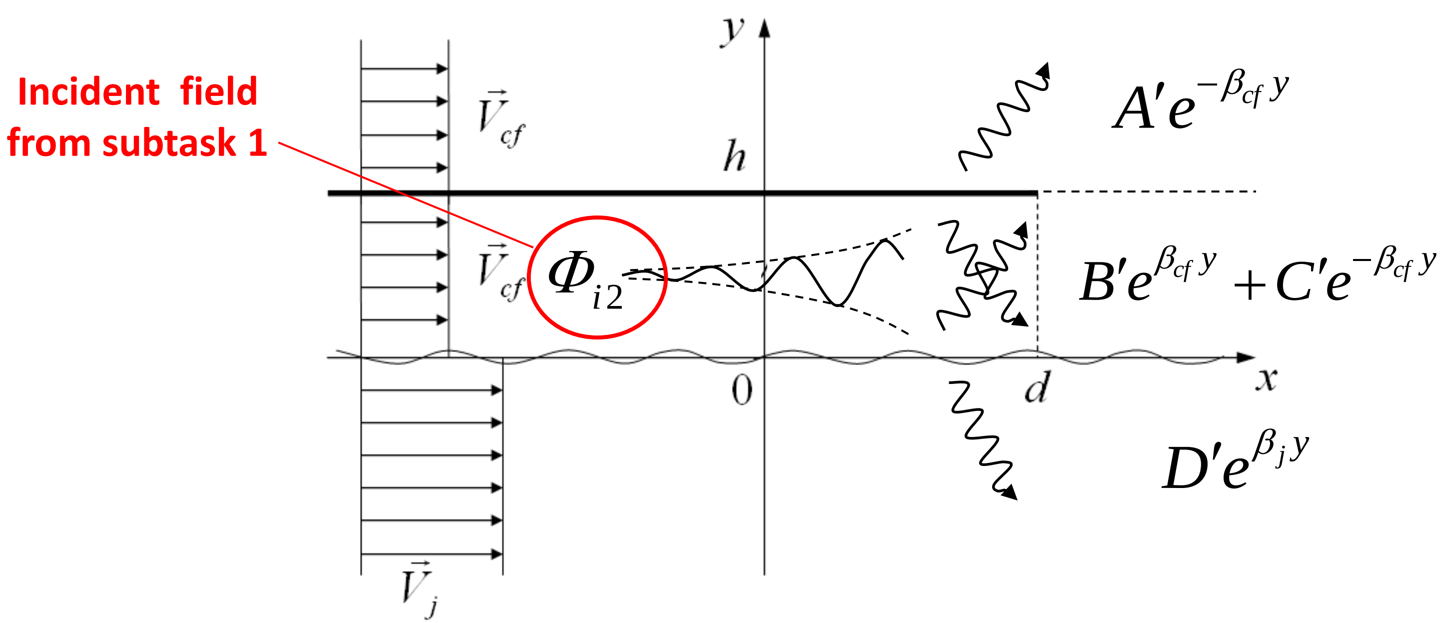

Subtask 2

$$F_+(\alpha)h_{12+}(\alpha)+i\frac{w_{cf}(\alpha_0)\rho_{cf}e^{-i\alpha_0 d}}{F_-(\alpha_0)}\Phi_{i2+}(\alpha)=\frac{p_{12-}(\alpha)}{F_-(\alpha)}-i\frac{w_{cf}(\alpha_0)\rho_{cf}e^{-i\alpha_0 d}}{F_-(\alpha_0)}\Phi_{i2-}(\alpha)$$

$$F(\alpha)=\frac{2\rho_{cf}w_{cf}^2}{\beta_{cf}}\frac{\Delta_{(+)}e^{\beta_{cf}h}}{\Delta_{(+)}e^{\beta_{cf}h}+\Delta_{(-)}e^{-\beta_{cf}h}}=F_+(\alpha)F_-(\alpha)$$

$$\Phi_{i2}(\alpha)=\Phi_{i2+}(\alpha)+\Phi_{i2-}(\alpha)$$

$$\Delta_{(\pm)}(\alpha)=\rho_{cf}w_{cf}^2\beta_j\pm\rho_j w_j^2\beta_{cf}$$

Kutta-Zhukovsky condition is applied at the trailing edge

$$\tilde{\varphi}_1=\frac{1}{2\pi}\frac{w_{cf}(\alpha_0)\rho_{cf}e^{-i\alpha_0 d}}{F_-(\alpha_0)}\int_C\frac{w_{cf}(\alpha)\Phi_{i2+}\big|_h(\alpha)}{F_+(\alpha)}e^{-i\alpha(x-d)-\beta_{cf}(y-h)}d\alpha$$

$$\tilde{\varphi}_3=-\frac{1}{4\pi}\frac{w_{cf}(\alpha_0)\rho_{cf}e^{-i\alpha_0 d}}{F_-(\alpha_0)}\int_C\frac{w_j(\alpha)\left(\Delta_{(+)}+\Delta_{(-)}\right)\Phi_{i2+}\big|_h(\alpha)}{\beta_j^2\tilde{H}(\alpha)F_+(\alpha)\beta_{cf}\sinh(\beta_{cf}h)}e^{-i\alpha(x-d)-\beta_{cf}y}d\alpha$$

Subtask 2

$$F_+(\alpha)h_{12+}(\alpha)+i\frac{w_{cf}(\alpha_0)\rho_{cf}e^{-i\alpha_0 d}}{F_-(\alpha_0)}\Phi_{i2+}(\alpha)=\frac{p_{12-}(\alpha)}{F_-(\alpha)}-i\frac{w_{cf}(\alpha_0)\rho_{cf}e^{-i\alpha_0 d}}{F_-(\alpha_0)}\Phi_{i2-}(\alpha)$$

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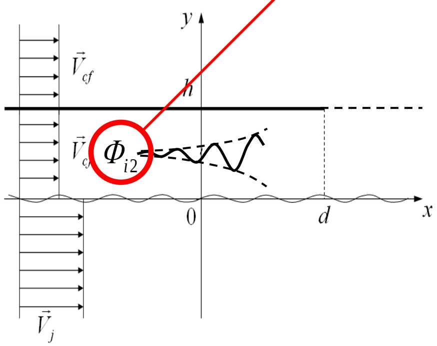
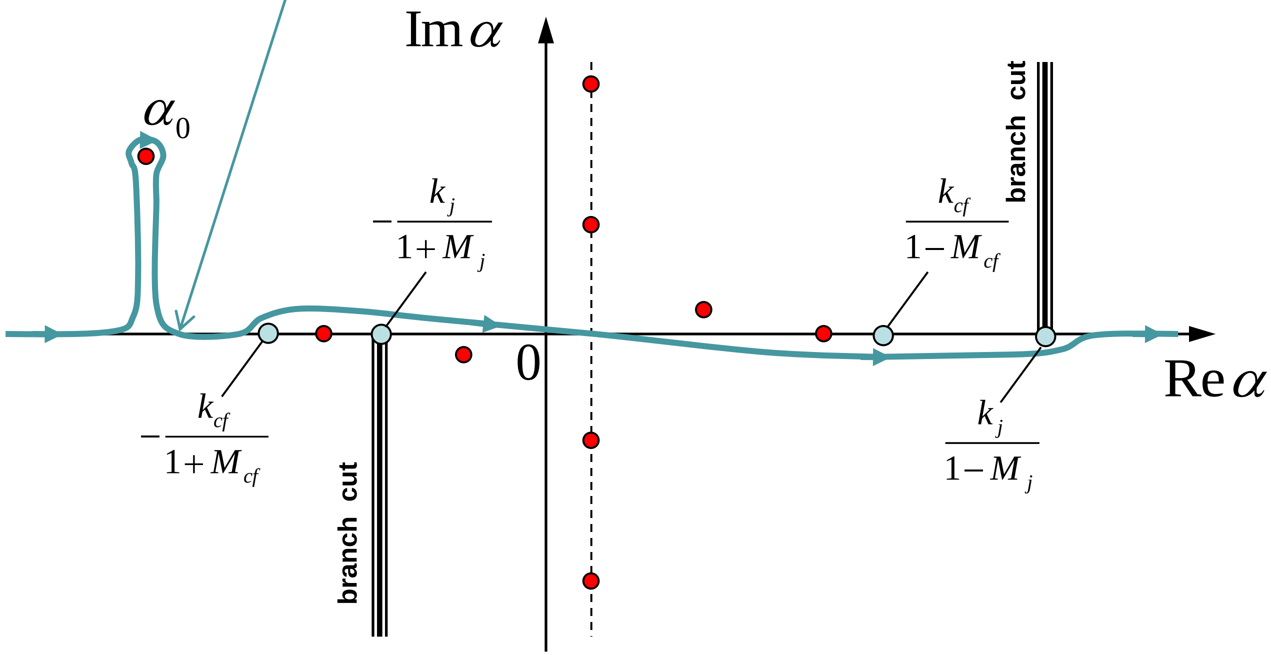
From Subtask 1 :

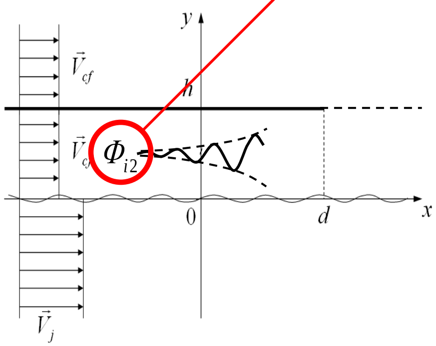
$$\varphi_2 = \frac{1}{2\pi}\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\int_C \frac{\Phi_{i+}(\alpha)}{\tilde{H}_+(\alpha)}\frac{\cosh(\beta_{cf}(y-h))}{\beta_{cf}\sinh(\beta_{cf}h)}e^{-i\alpha x}d\alpha$$

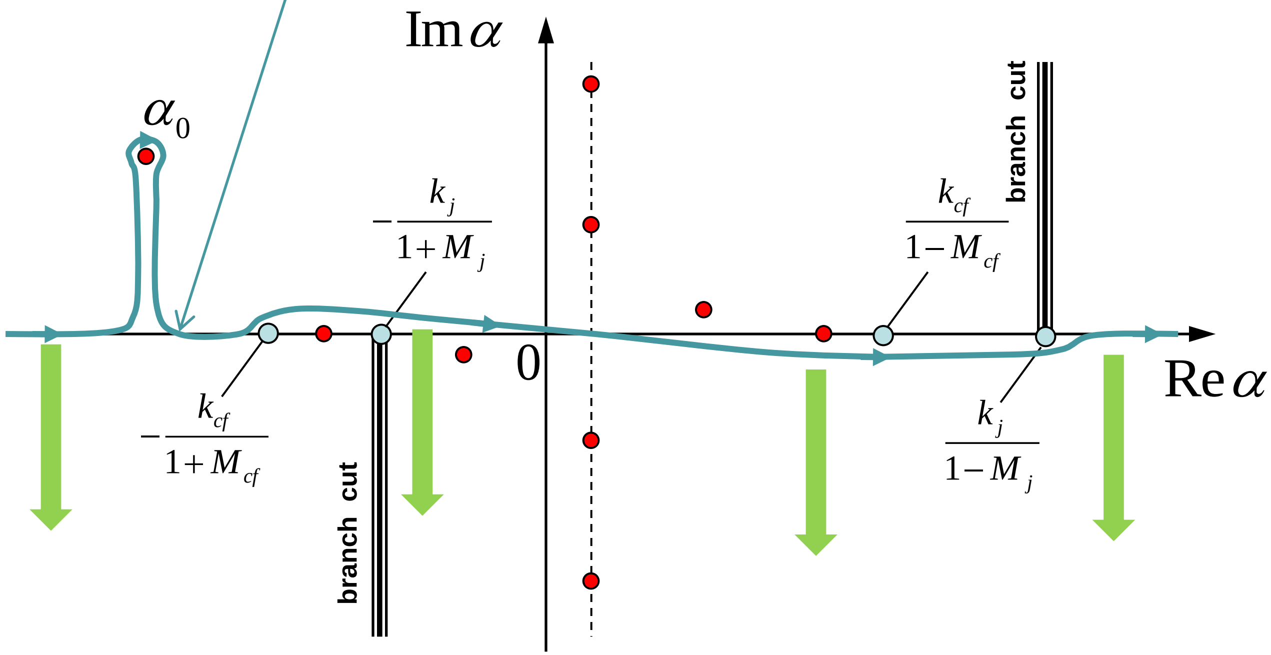




$x > 0$

$$\varphi_2 = \frac{1}{2\pi}\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\int_C \frac{\Phi_{i+}(\alpha)}{\tilde{H}_+(\alpha)}\frac{\cosh(\beta_{cf}(y-h))}{\beta_{cf}\sinh(\beta_{cf}h)}e^{-i\alpha x}d\alpha$$

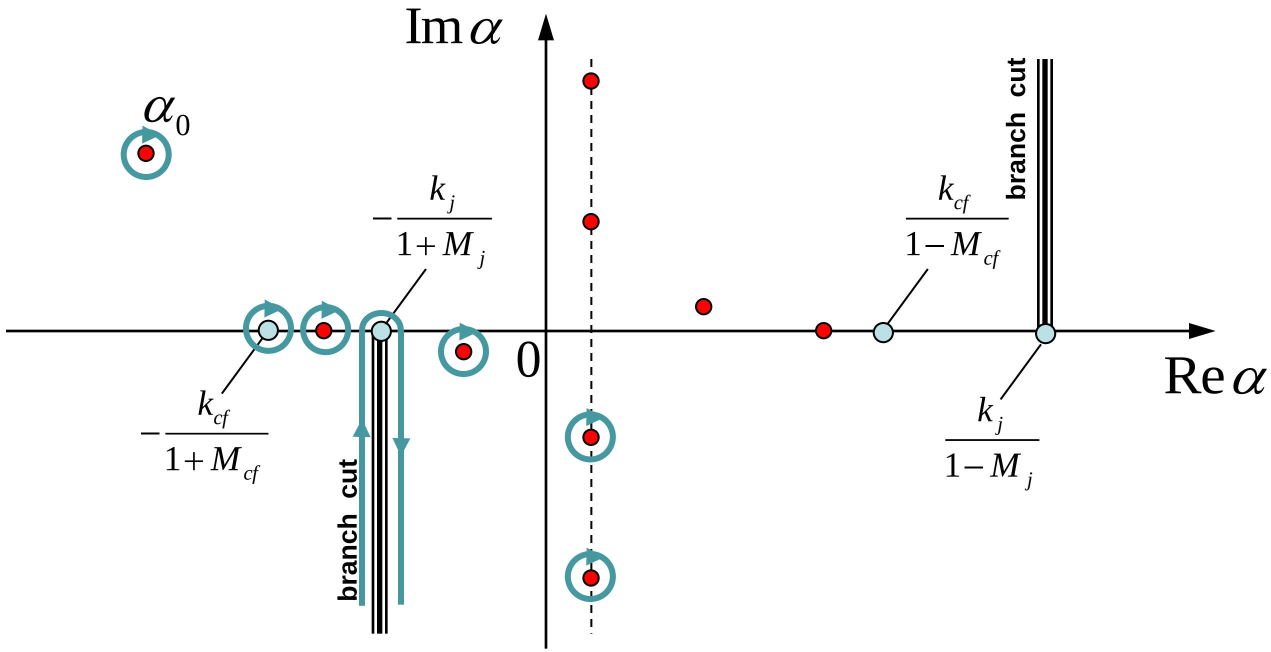




$x > 0$

$$\varphi_2 = \frac{1}{2\pi}\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\int_C \frac{\Phi_{i+}(\alpha)}{\tilde{H}_+(\alpha)}\frac{\cosh(\beta_{cf}(y-h))}{\beta_{cf}\sinh(\beta_{cf}h)}e^{-i\alpha x}d\alpha =$$

$$= -i\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\sum_{n=0}^{\infty}\underset{\alpha_n}{res}\left(\frac{\Phi_{i+}(\alpha)}{\tilde{H}_+(\alpha)}\frac{\cosh(\beta_{cf}(y-h))}{\beta_{cf}\sinh(\beta_{cf}h)}\right)e^{-i\alpha_n x} + \int_{\cap}$$



$x > 0$

$$\varphi_2 = \frac{1}{2\pi}\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\int_C \frac{\Phi_{i+}(\alpha)}{\tilde{H}_+(\alpha)}\frac{\cosh(\beta_{cf}(y-h))}{\beta_{cf}\sinh(\beta_{cf}h)}e^{-i\alpha x}d\alpha =$$

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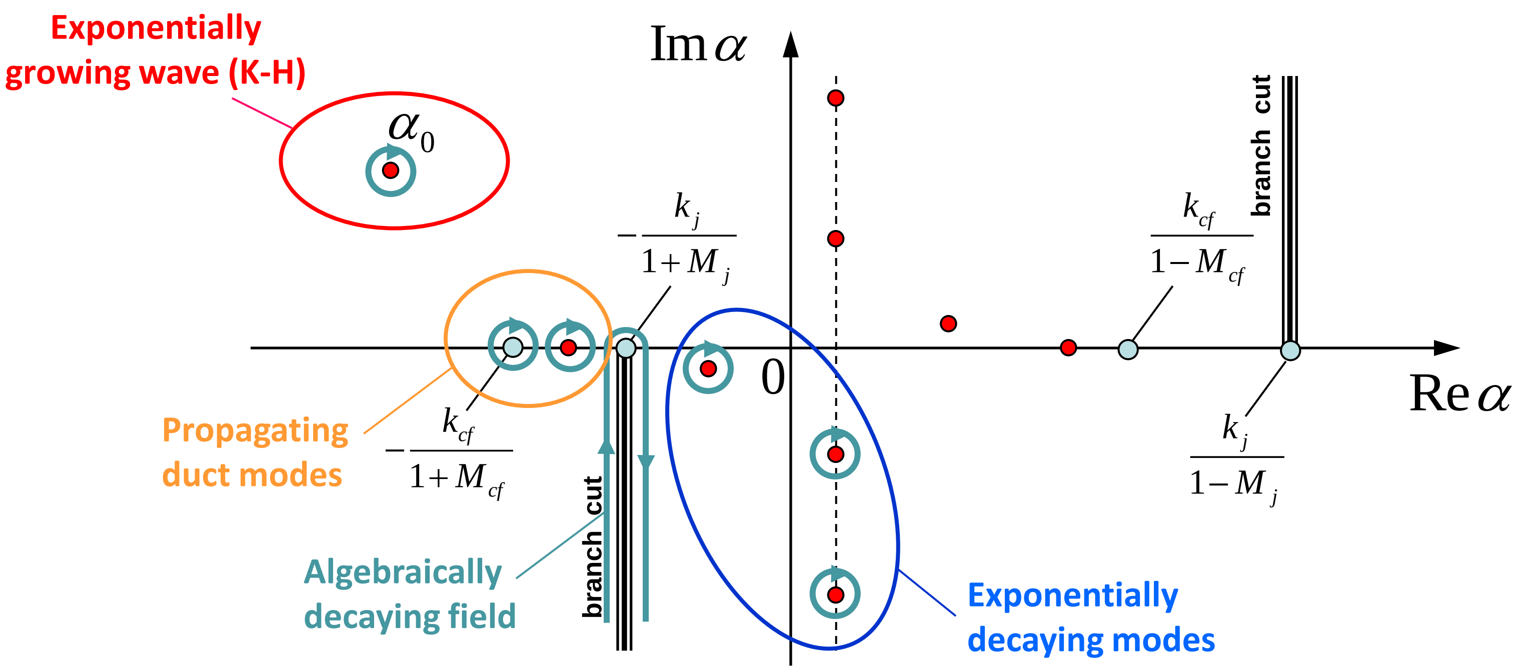
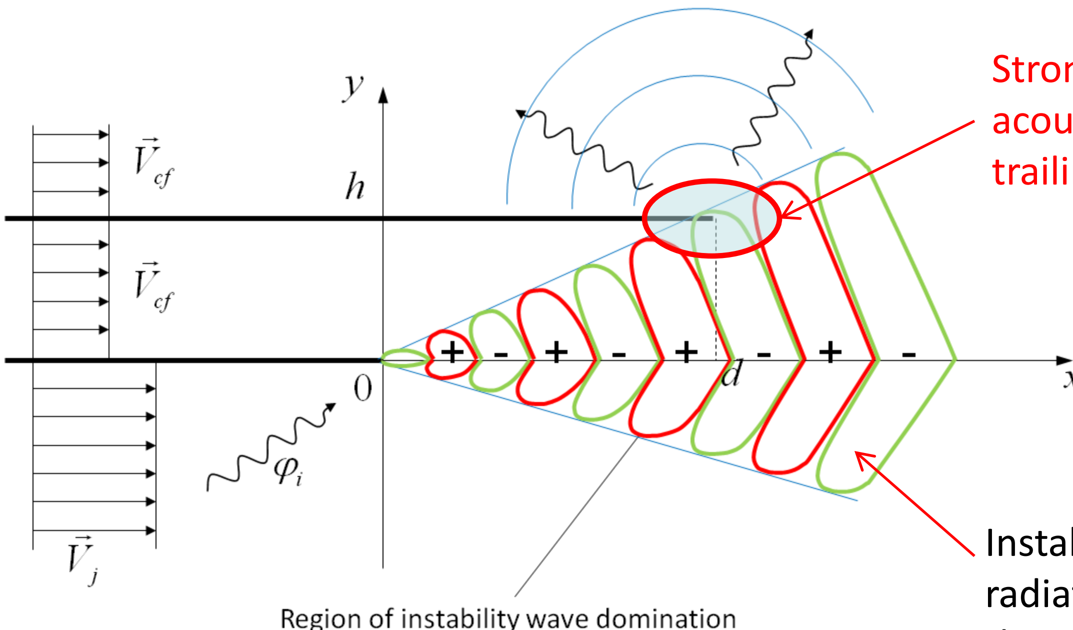


$x > 0$

$kx >> 1$

$$\varphi_2 = \frac{1}{2\pi}\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\int_C \frac{\Phi_{i+}(\alpha)}{\tilde{H}_+(\alpha)}\frac{\cosh(\beta_{cf}(y-h))}{\beta_{cf}\sinh(\beta_{cf}h)}e^{-i\alpha x}d\alpha \approx$$

$$\approx -i\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\underset{\alpha_0}{res}\left(\frac{\Phi_{i+}(\alpha)}{\tilde{H}_+(\alpha)}\frac{\cosh(\beta_{cf}(y-h))}{\beta_{cf}\sinh(\beta_{cf}h)}\right)e^{-i\alpha_0 x}$$



Strong scattering into acoustic waves by the trailing edge

Instability wave does not radiate sound without the wing trailing edge !

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Parameters values for numerical estimations

$$\rho_{cf} = \rho_j = 1.21\, kg/m^3$$

$$c_{cf} = c_j = 340\ m/s$$

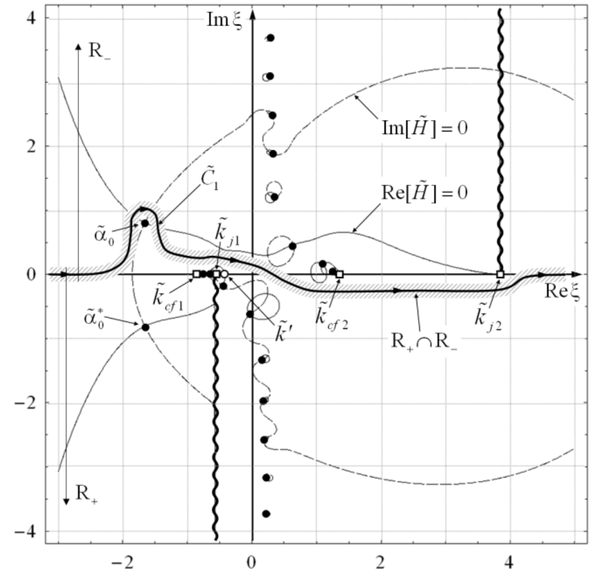
$$M_j = 0.74$$

$$M_{cf} = 0.235$$

$$f = 300\ Hz$$

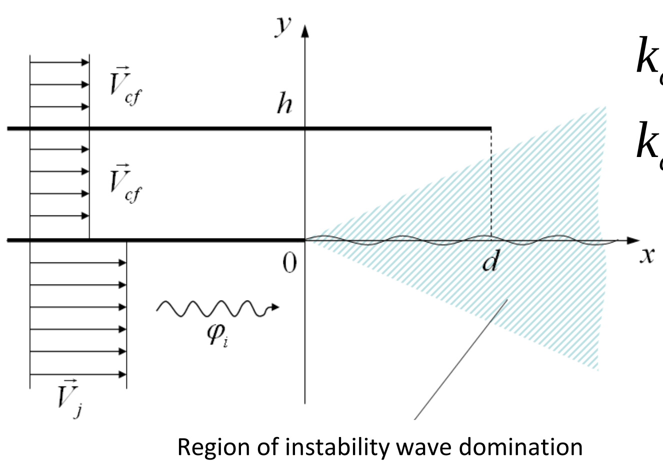
$$d = 4\ m$$

$$h = 0.15;\ 0.45;\ 1.05;\ 1.65\ m$$

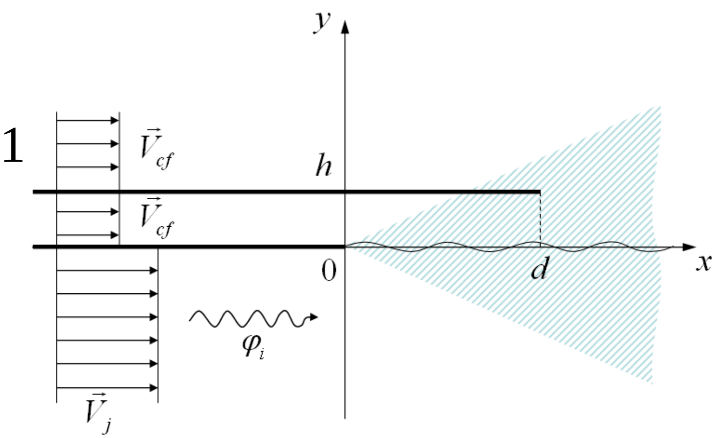


$$k_{cf}h \sim 0.8 \ldots 9$$

$$k_{cf}d \sim 22 >> 1$$



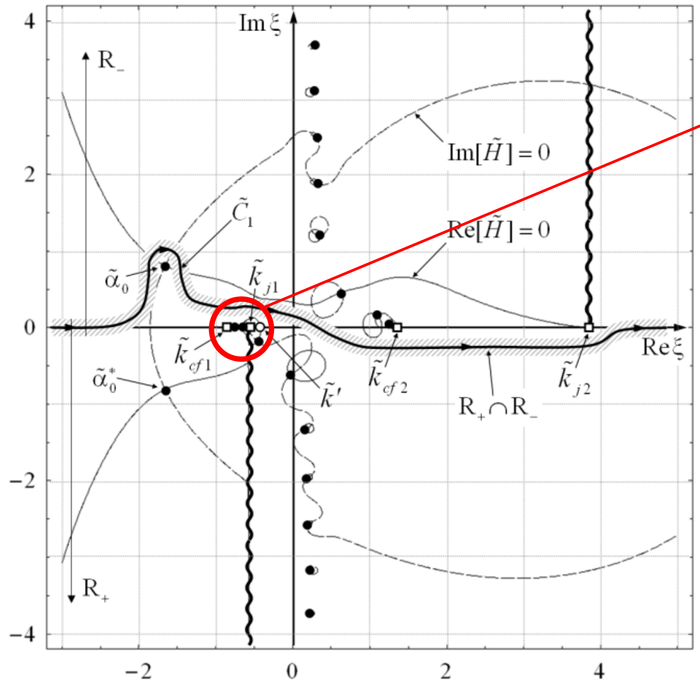
Large $k_{cf}h$



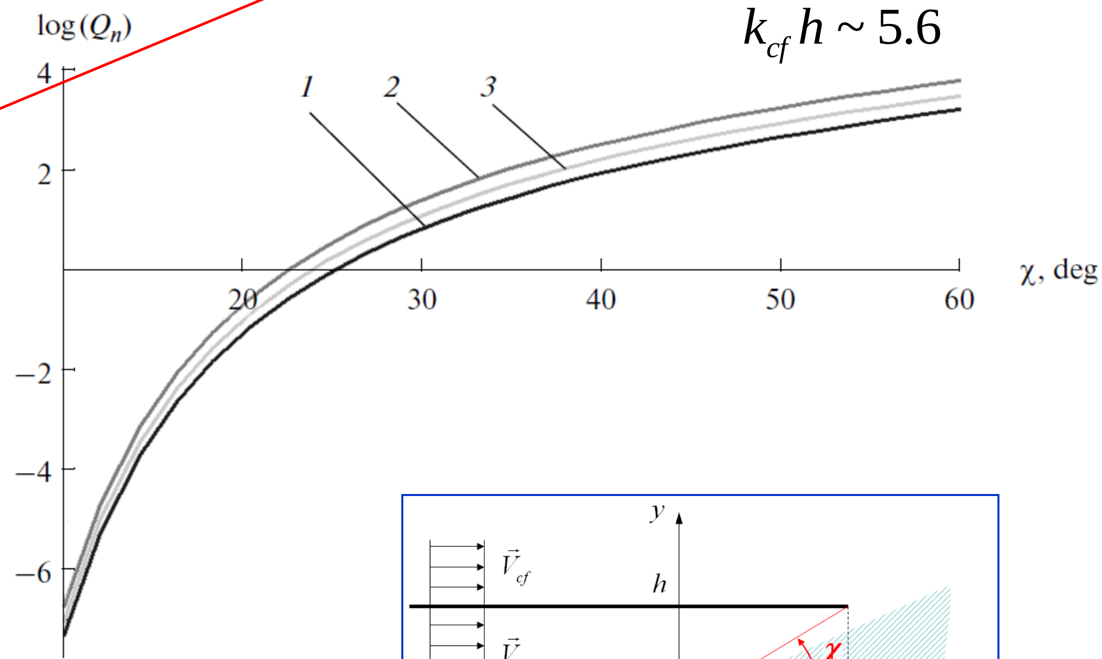
Small $k_{cf}h$

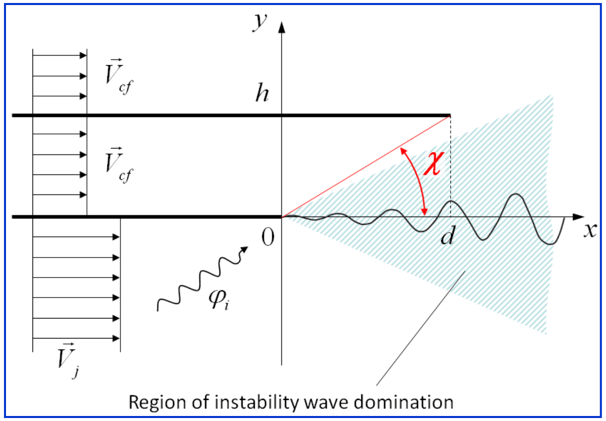
Relative contribution to the full solution of instability wave and duct propagating modes

$$Q_n = \left| A_n / A_0 \right| e^{\left(\mathrm{Im}[\alpha_n^-] - \mathrm{Im}[\alpha_0]\right)d}, \quad n = 1, 2, 3$$



$k_{cf}h \sim 5.6$





Directivity patterns of instability wave scattering at the wing trailing edge (distance to the origin is r=100m)

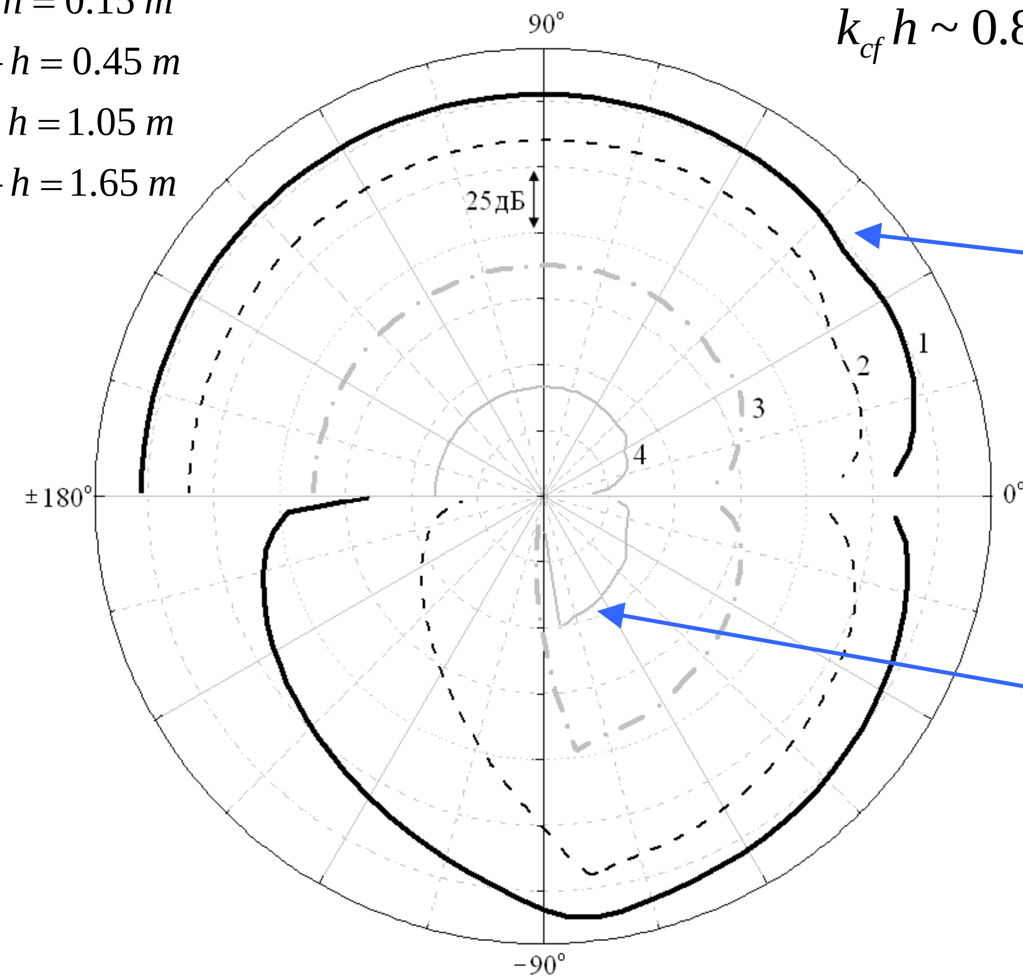
$1 - h = 0.15\ m$

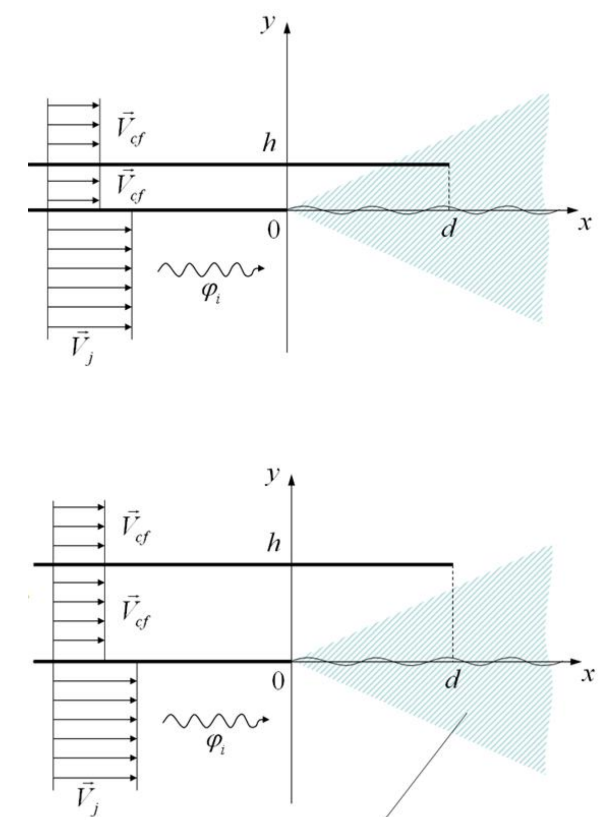
$2 - h = 0.45\ m$

$3 - h = 1.05\ m$

$4 - h = 1.65\ m$

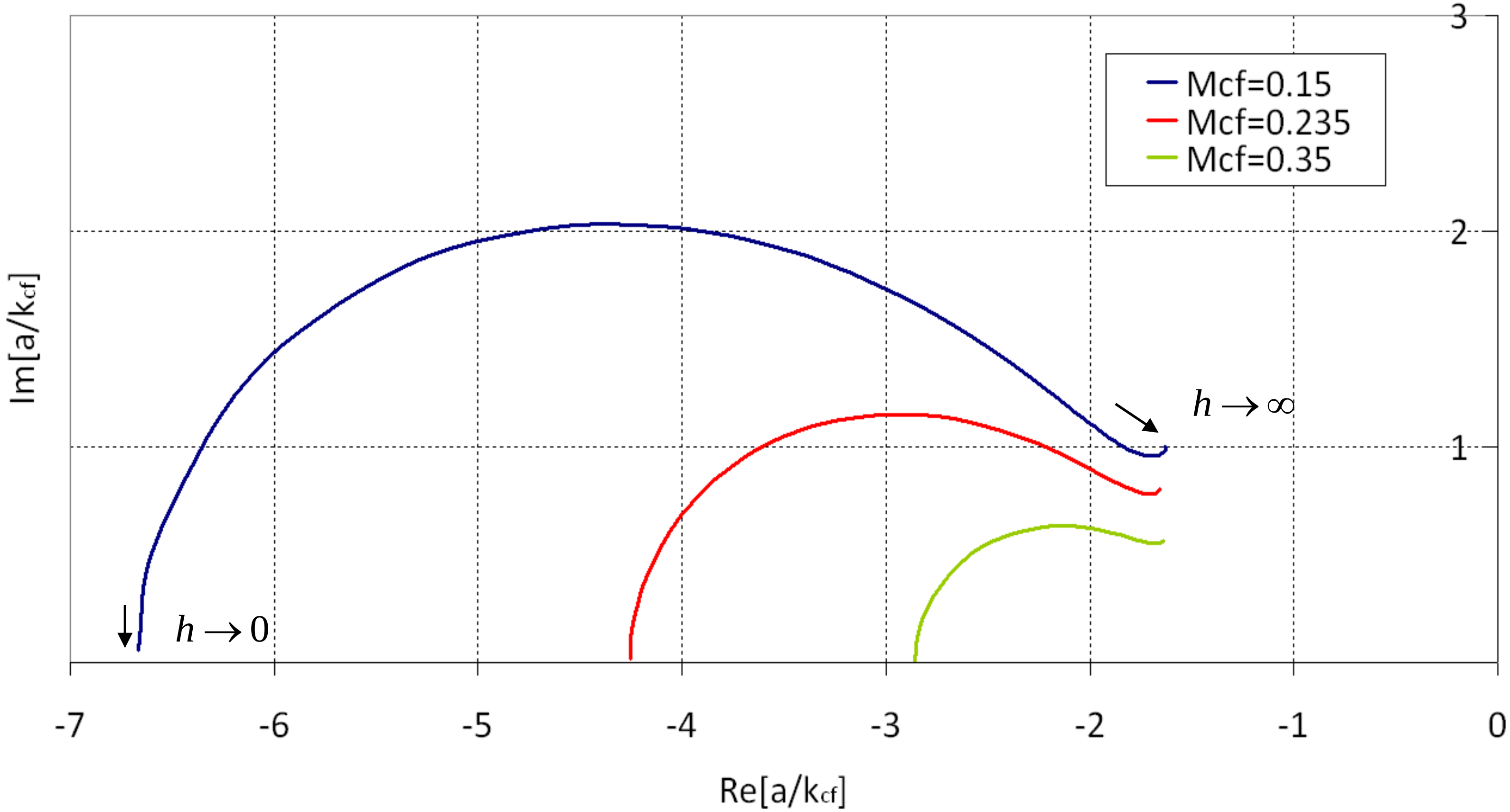
$k_{cf} h \sim 0.8 \ldots 9$





Region of instability wave domination

Instability wave increment and its phase speed dependence upon $k_{cf}h$ and M_{cf}



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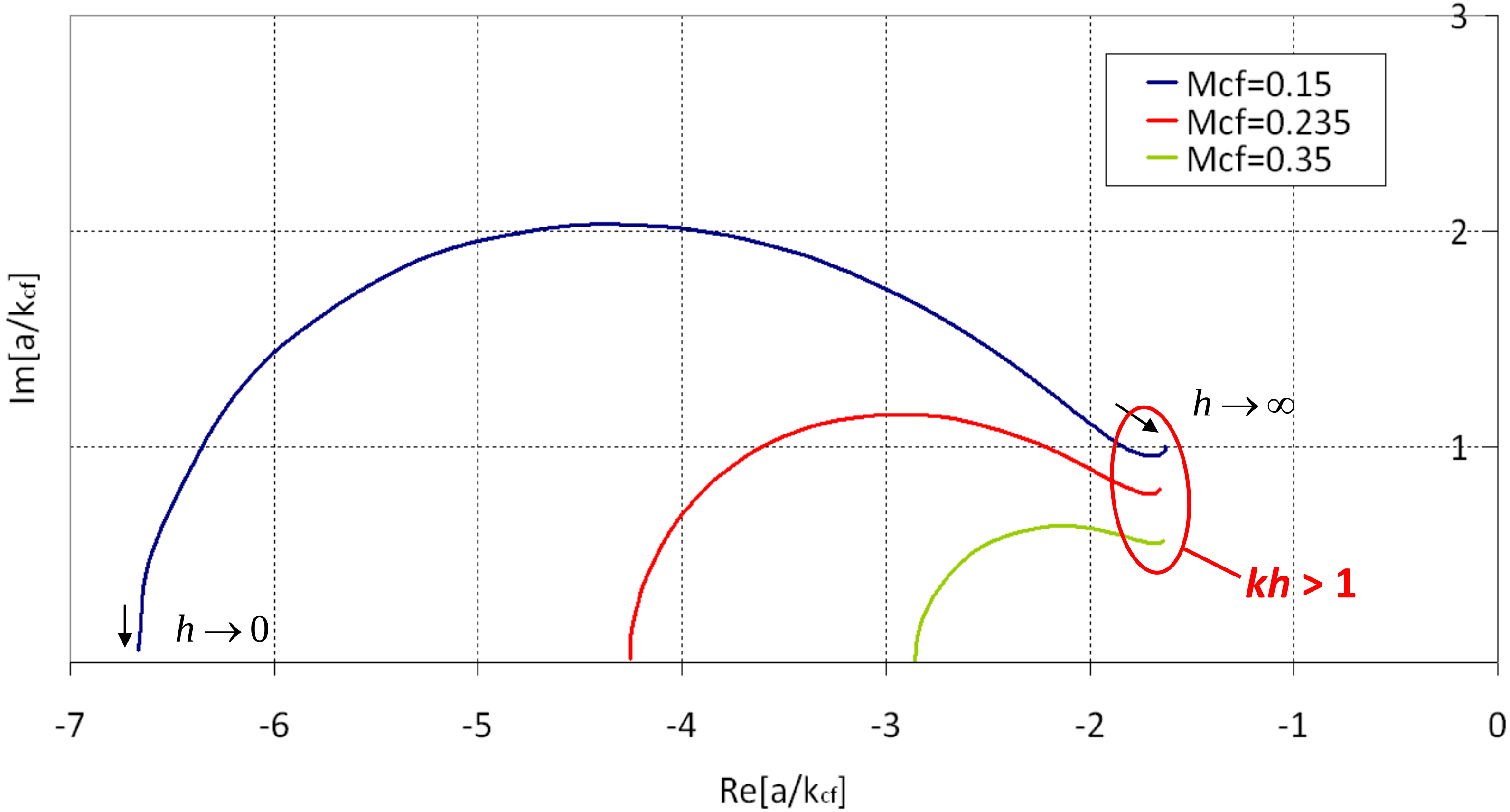

Stability properties of the jet shear layer are weakly dependent on *kh*

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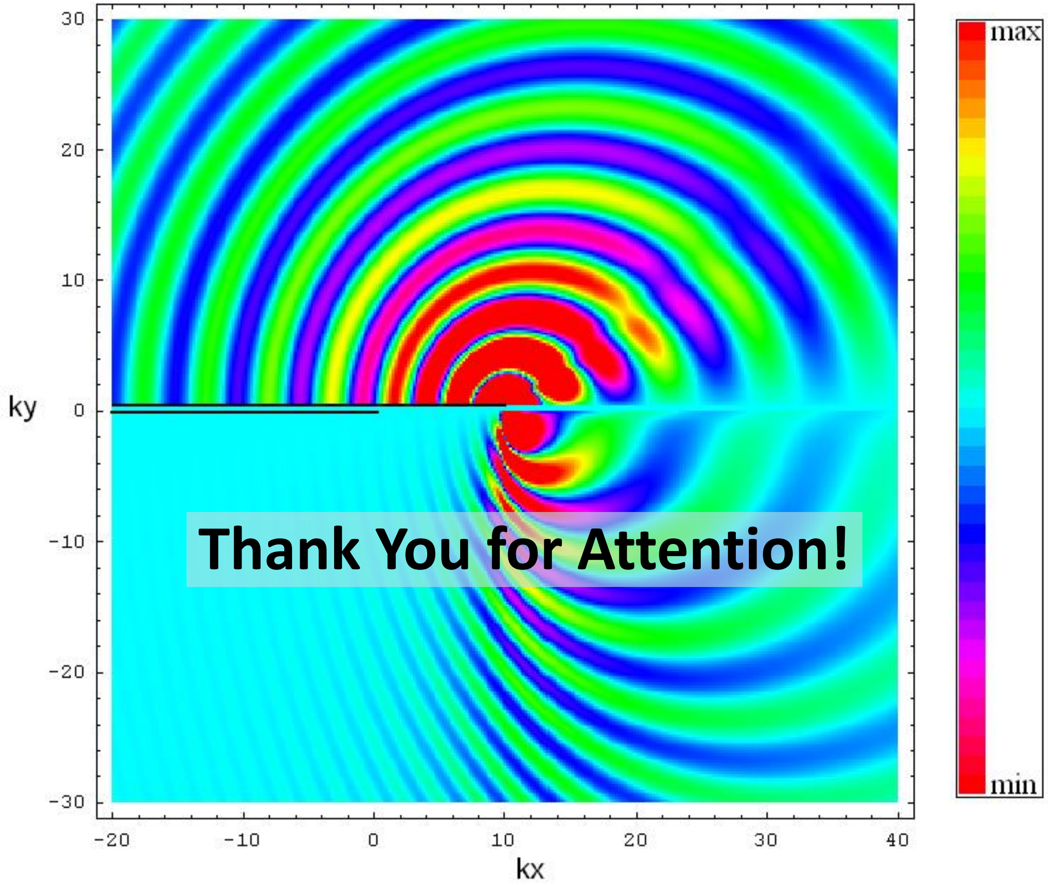
Conclusions

- Possible mechanism of jet noise amplification in the presence of the wing is proposed.
- 2-D model problem is formulated. The model problem is solved approximately by means of double use of the scalar Wiener-Hopf technique.
- It is shown that the scattering of the instability wave hydrodynamic field on the wing trailing edge leads to acoustic waves radiation, the amplitude of these waves being proportional to the incident instability wave amplitude, i.e. the higher the closer the jet shear layer to the wing.
- It is shown that the directivity pattern of the scattered field has maximums in the sideline directions (above and below the wing) and minimums – in longitudinal direction.
- Instability wave characteristics (increment and phase speed) is shown to be depended upon the location of the jet shear layer with relative to the wing. But for $kh>1$ this dependence is very weak. i.e. stability properties of the jet near clean wing can be considered almost identical to those of single jet in wide frequency range.
- In order to predict jet-wing interaction noise, it is necessary to model correctly not only single jet noise sources (including their distribution) but also near field hydrodynamic pulsations.



Thank You for Attention!

$x > 0$

$kx >> 1$

$$\varphi_2 = \frac{1}{2\pi}\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\int_C \frac{\Phi_{i+}(\alpha)}{\tilde{H}_+(\alpha)}\frac{\cosh(\beta_{cf}(y-h))}{\beta_{cf}\sinh(\beta_{cf}h)}e^{-i\alpha x}d\alpha \approx$$

$$\approx -i\frac{w_j(k')\rho_j}{\tilde{H}_-(k')}\operatorname*{res}_{\alpha_0}\left(\frac{\Phi_{i+}(\alpha)}{\tilde{H}_+(\alpha)}\frac{\cosh(\beta_{cf}(y-h))}{\beta_{cf}\sinh(\beta_{cf}h)}\right)e^{-i\alpha_0 x}$$