

Aerodinâmica Computacional

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Bibliografia

1. Anderson Jr., J.D., *Computational Fluid Dynamics: The Basics with Applications*, McGraw-Hill, 1995.
2. Anderson, D.A., Tannehill, J. C., Pletcher, R. H., *Computational Fluid Mechanics and Heat Transfer*, Hemisphere, 1984.
3. Fletcher, C.A.J., *Computational Techniques for Fluid Dynamics*, Springer-Verlag, 1992.

A indústria aeronáutica e as ferramentas de CFD

Motivação:

- Evolução dos computadores;
- Redução de custo;
- Engenharia reversa;
- Flexibilidade/aplicabilidade.



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Aplicações em análises aerodinâmicas

- Cálculo das forças e momentos aerodinâmicos;
- Projeto de superfícies aerodinâmicas;
- Dispositivos de hiper-sustentação;
- Propulsão;
- Sistemas pneumáticos;
- Jatos;
- Escoamentos hipersônicos;
- Redução da intensidade de ondas de choque;
- Aeroelasticidade;
- Etc.

Modelo matemático do escoamento:

- Conservação de massa (continuidade);
- Conservação da quantidade de movimento (momentum);
- Conservação da energia.

$$\left\{ \begin{array}{l} \frac{D\rho}{Dt} = -\rho \nabla \cdot \vec{V} \\ \frac{D\vec{V}}{Dt} = \frac{1}{\rho} (\nabla \cdot \vec{\tau} - \nabla p) + \vec{f} \\ \frac{DE}{Dt} = \frac{1}{\rho} \nabla \cdot (\vec{\tau} \cdot \vec{V} - p\vec{V} + \kappa \nabla T) + \vec{f} \cdot \vec{V} + \dot{q} \end{array} \right.$$

onde

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + (\vec{V} \cdot \nabla)$$

Equações constitutivas:

Gás ideal: $p = \rho RT$

Energia total: $E = e + \frac{|\vec{V}|^2}{2}$

Gás caloricamente perfeito: $T = c_v e$

Tensões viscosas: $\tau_{ij} = \mu \left(\frac{\partial V_i}{\partial x_j} + \frac{\partial V_j}{\partial x_i} \right) + \lambda (\nabla \cdot \vec{V}) \delta_{ij}$

Hipótese de Stokes: $\lambda = -\frac{2}{3}\mu$

Métodos de discretização das equações:

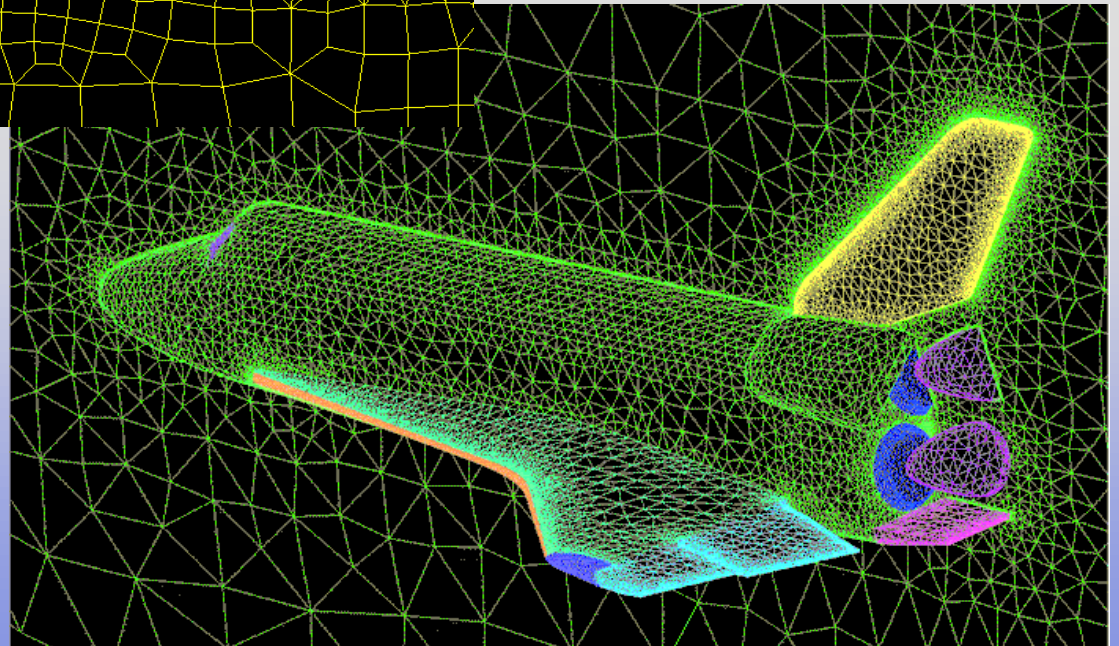
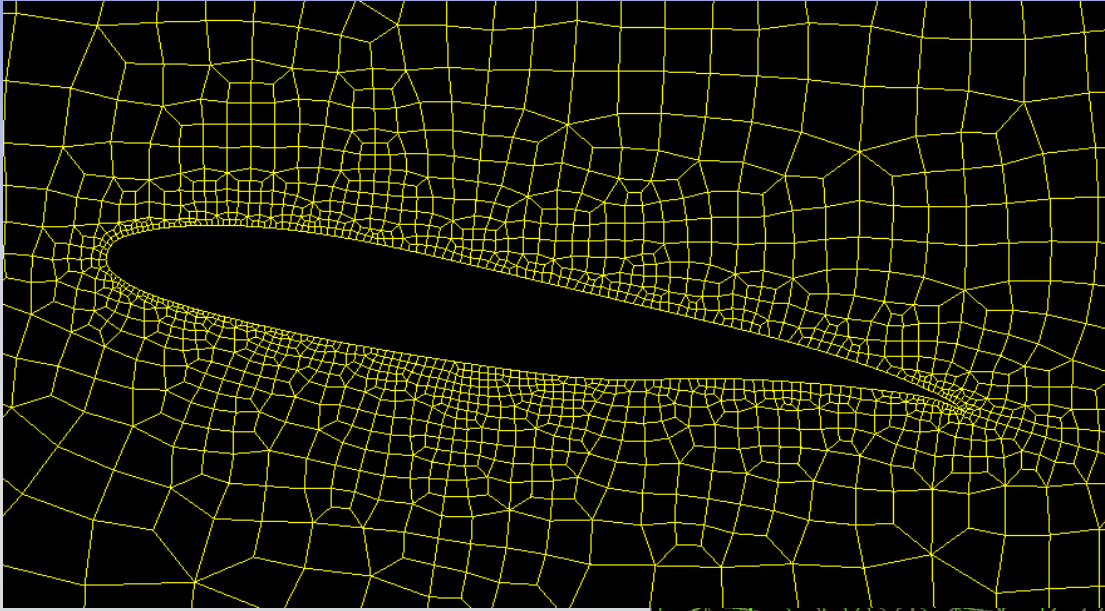
- Diferenças finitas;
- Volumes finitos;
- Elementos finitos;

A base de todos estes métodos está na substituição de derivadas por expressões algébricas. Exemplo:

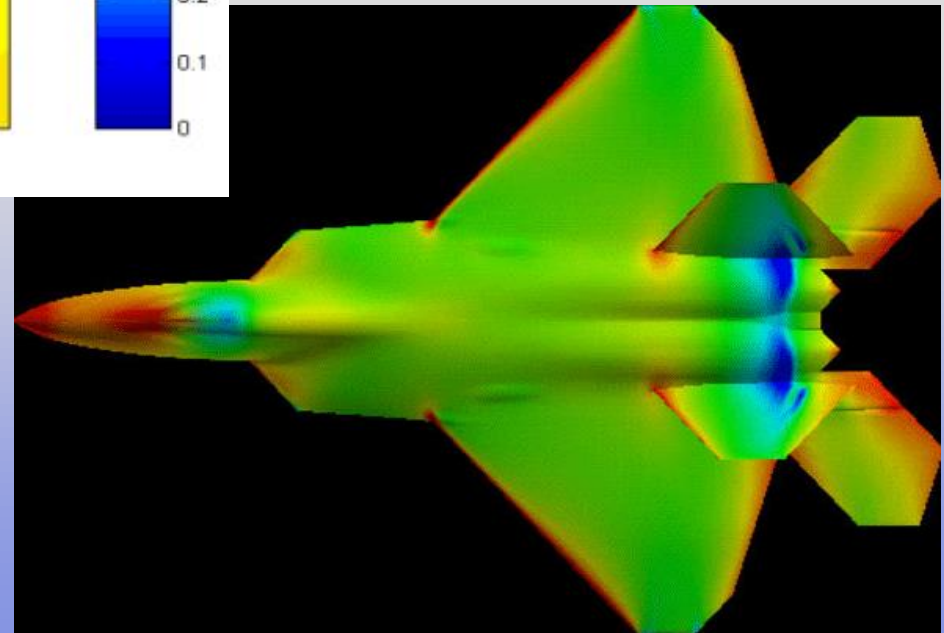
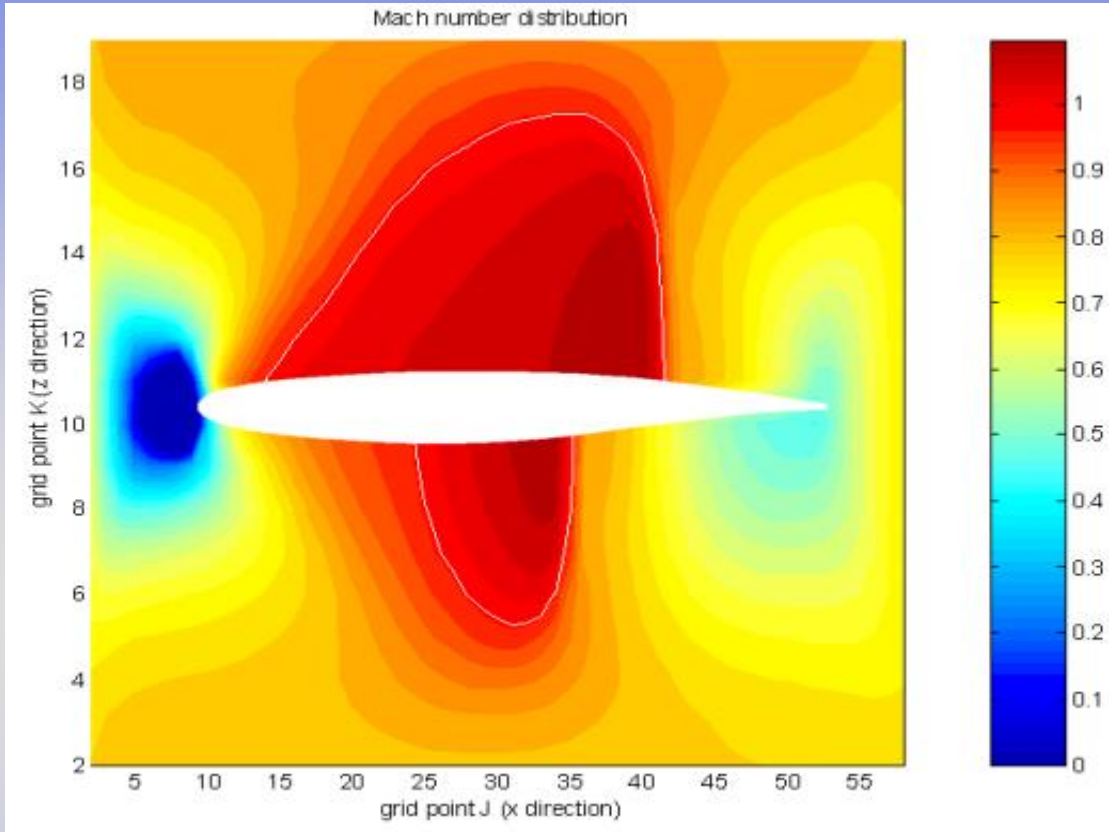
$$u_i^{t+\Delta t} = u_i^t + \left(\frac{\partial u}{\partial t}\right)_i^t \Delta t + \left(\frac{\partial^2 u}{\partial t^2}\right)_i^t \frac{(\Delta t)^2}{2} + \left(\frac{\partial^3 u}{\partial t^3}\right)_i^t \frac{(\Delta t)^3}{6} + \dots \Rightarrow$$

$$\Rightarrow \left(\frac{\partial u}{\partial t}\right)_i^t = \frac{u_i^{t+\Delta t} - u_i^t}{\Delta t} + O[\Delta t]$$

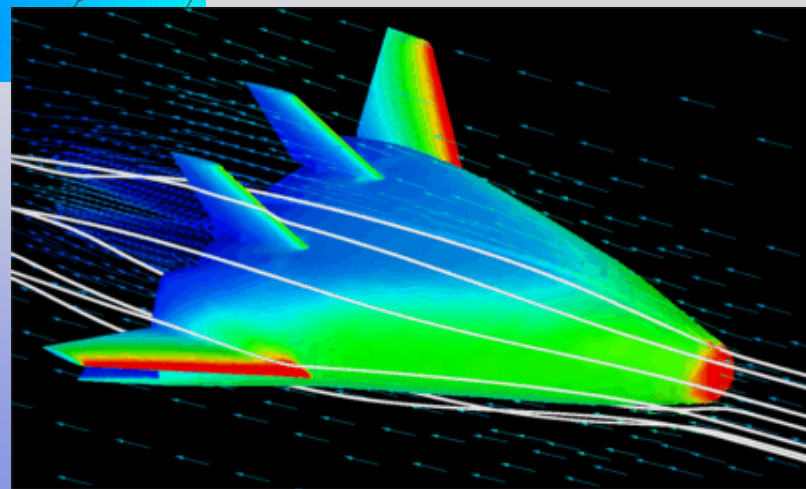
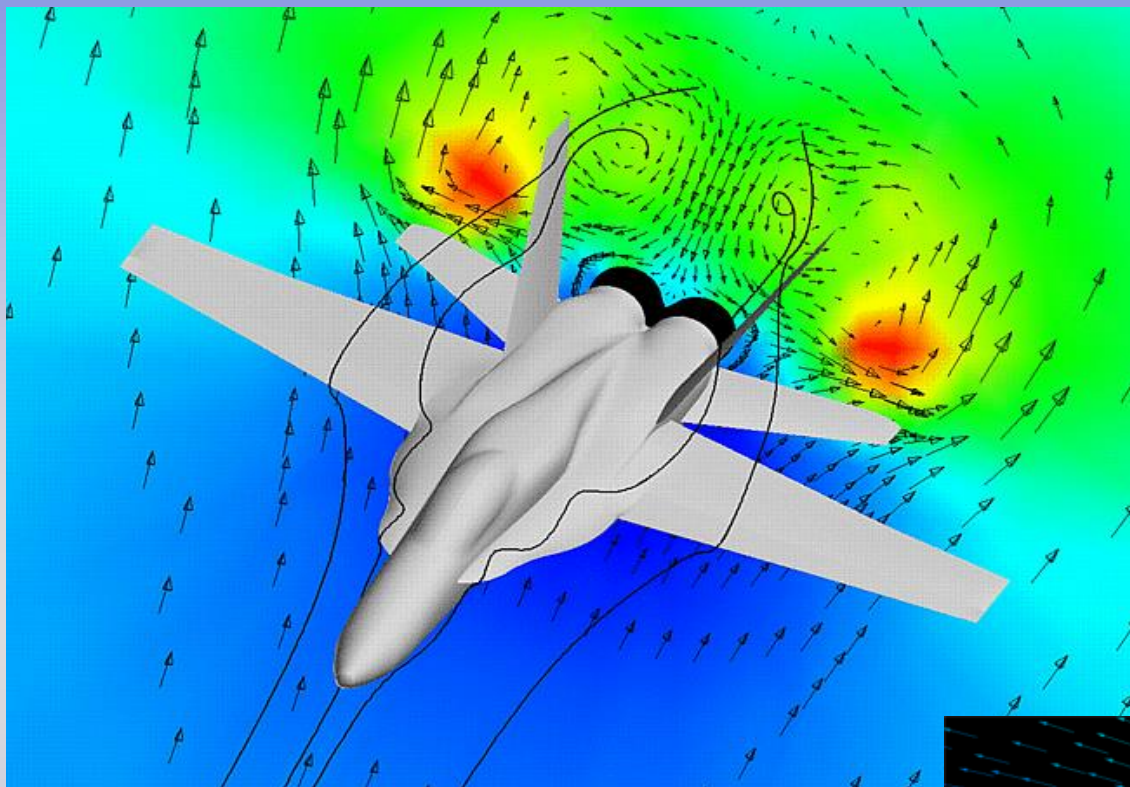
- Malhas não estruturadas:



Gráficos de contorno:



Gráficos vetoriais:



Exemplo de Aplicação

Fluxo em torno de uma seção de aerofólio NACA0012 em Mach 0.8 e ângulo de ataque de $1,25^\circ$:



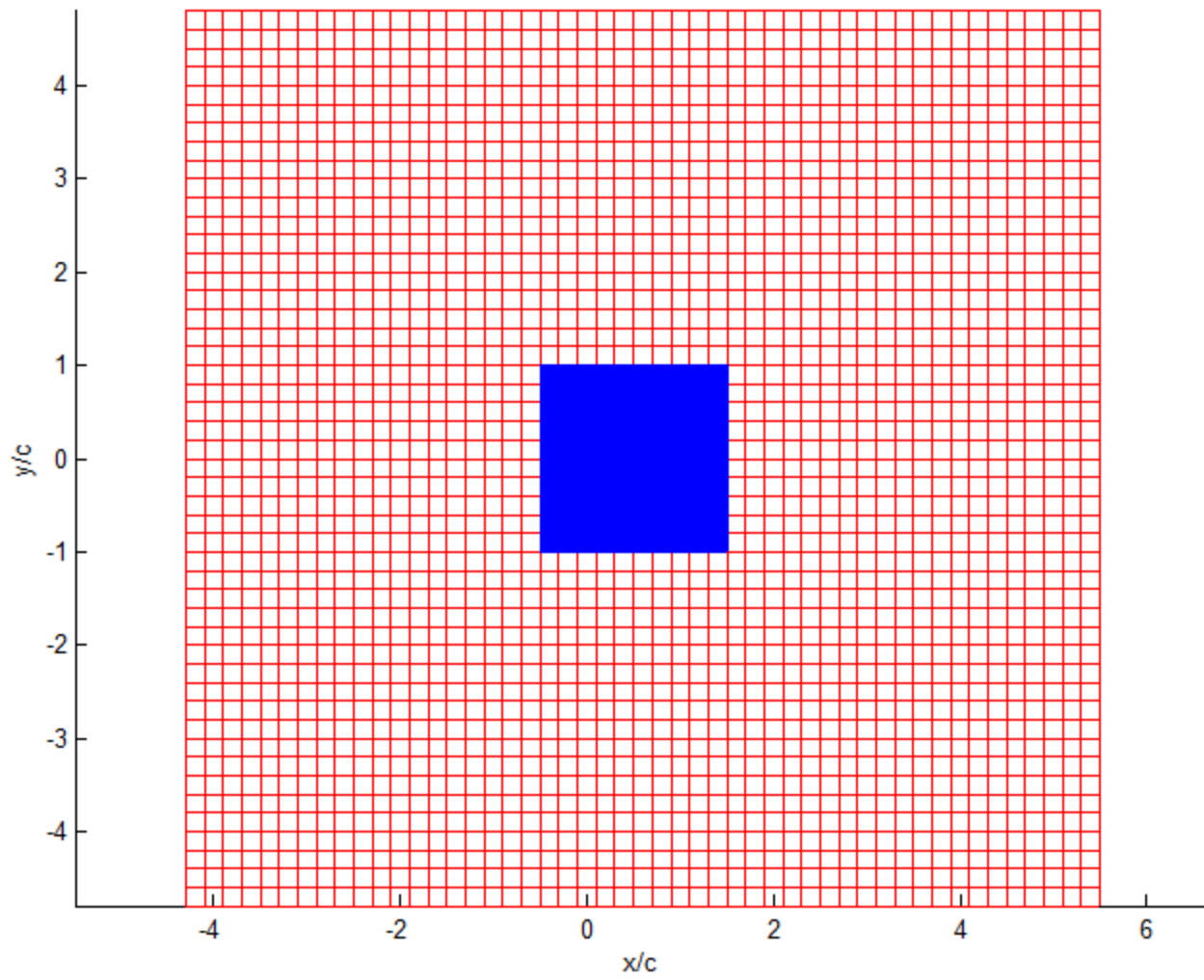
A seção de aerofólio NACA0012.

Solução da equação potencial de pequenas perturbações para regime transônico (TSD) bidimensional e estacionário:

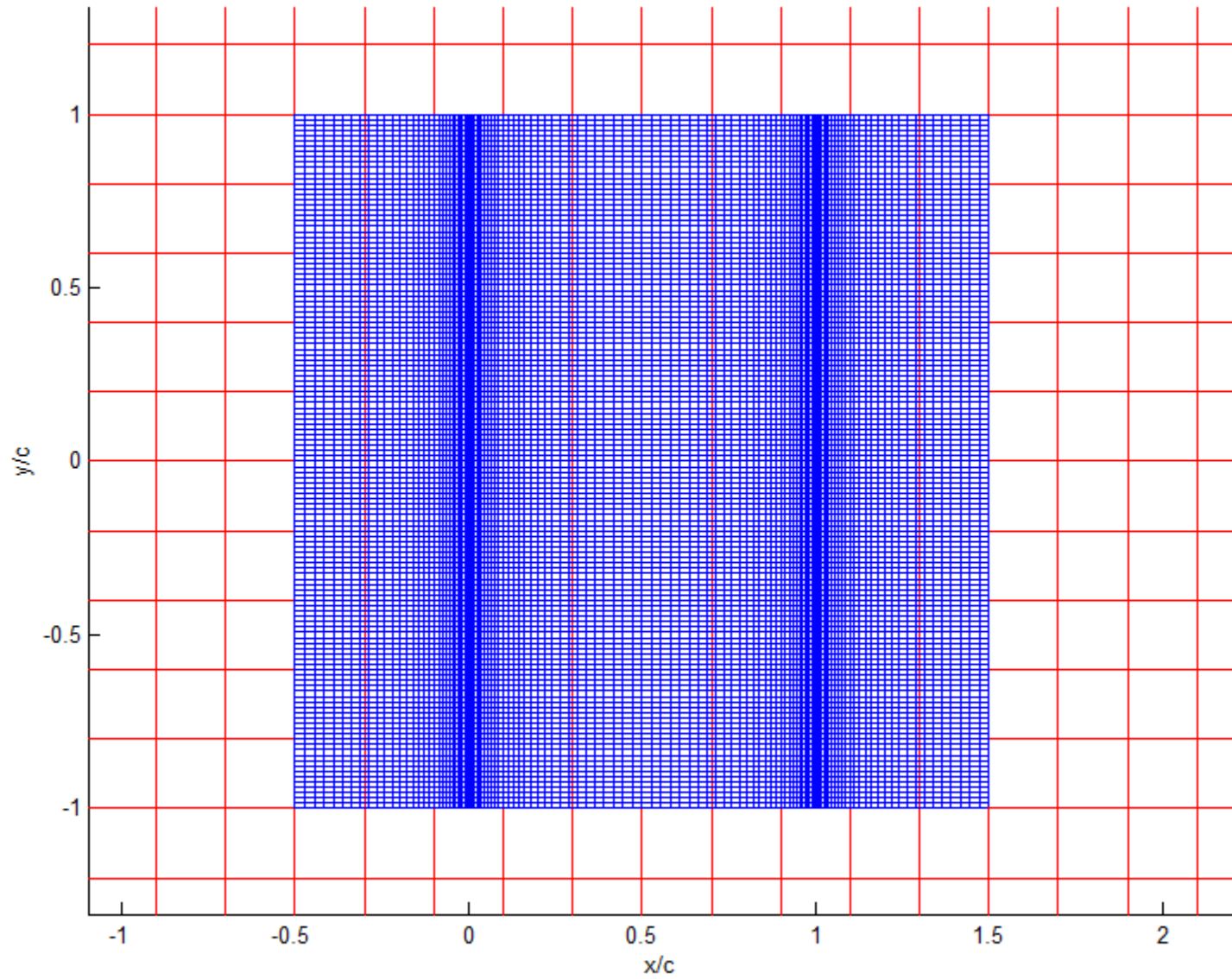
$$\frac{\partial}{\partial x} \left[\left(1 - M_{\infty}^2 \right) \phi_x - \frac{\gamma + 1}{2} M_{\infty}^2 \phi_x^2 \right] + \frac{\partial}{\partial y} \phi_y = 0$$

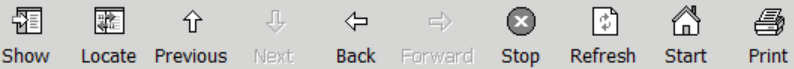
M_{∞} é o número de Mach do fluxo livre e γ é a razão de calores específicos.


Malha Computacional



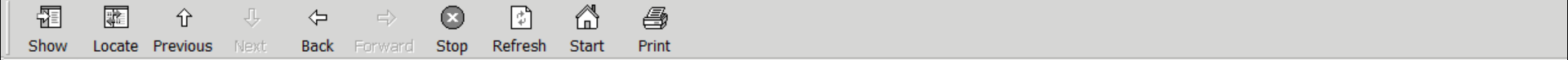
Malha Computacional



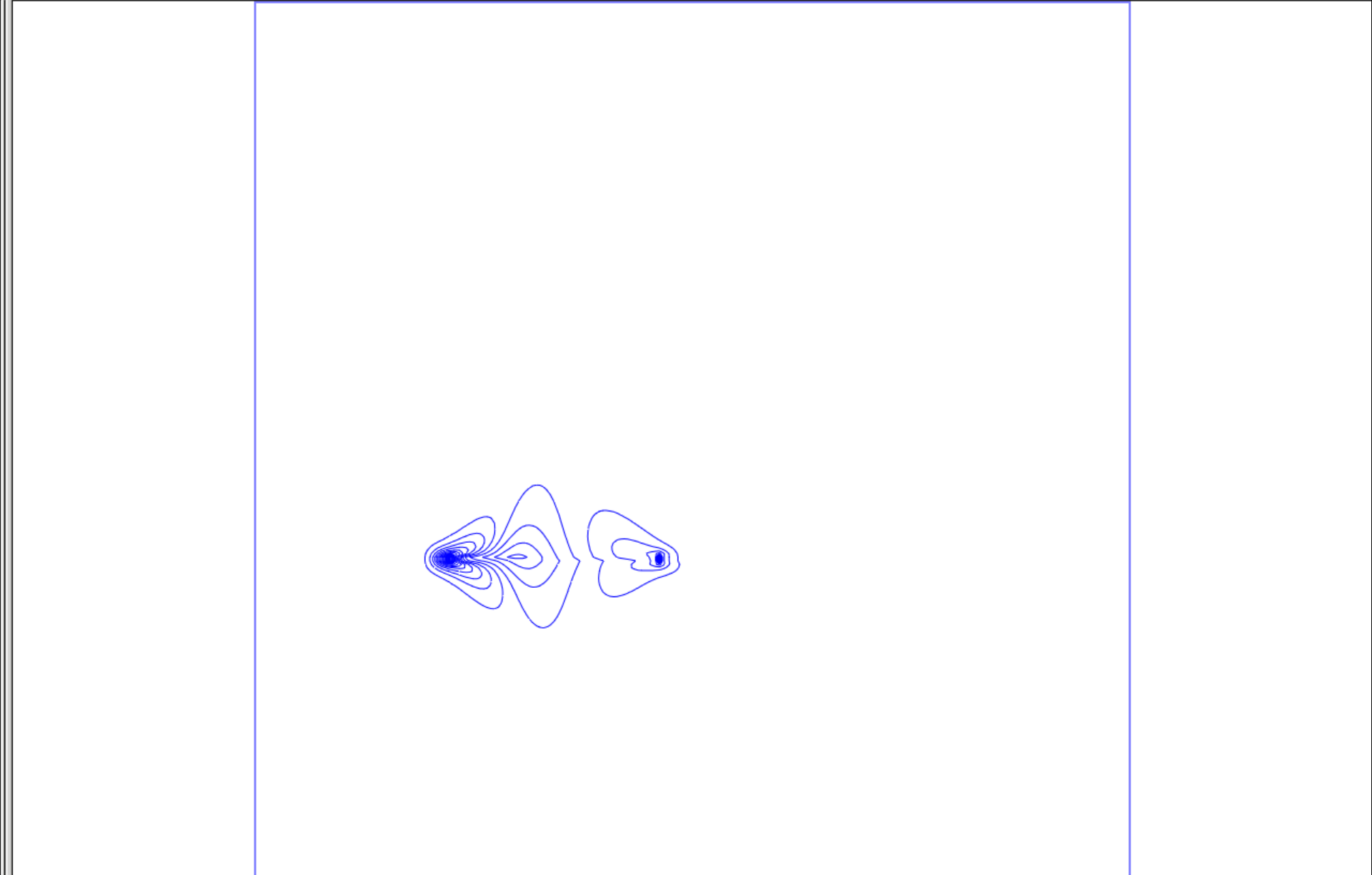


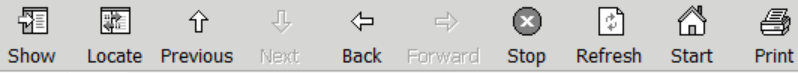
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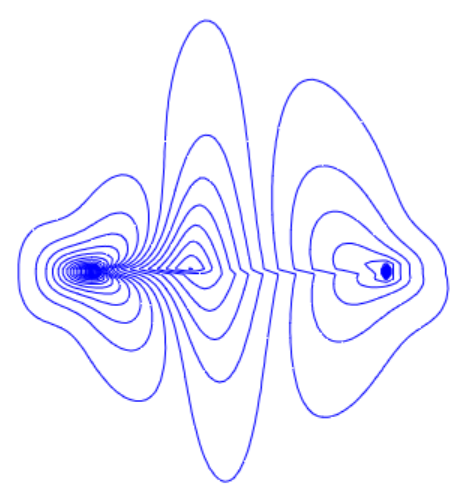


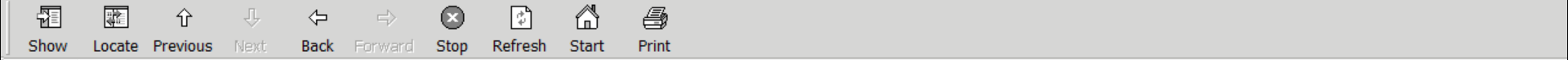
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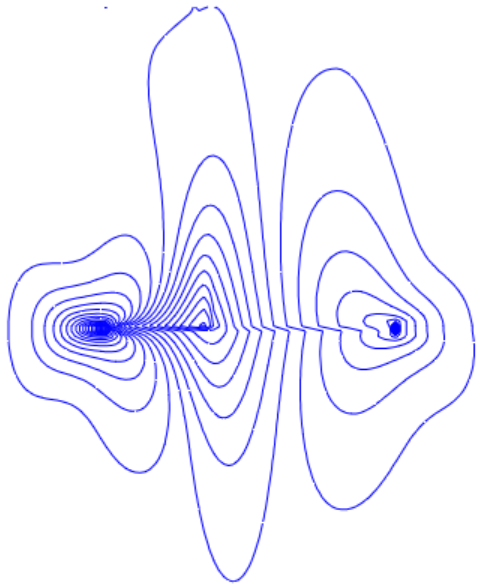


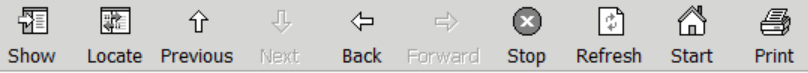
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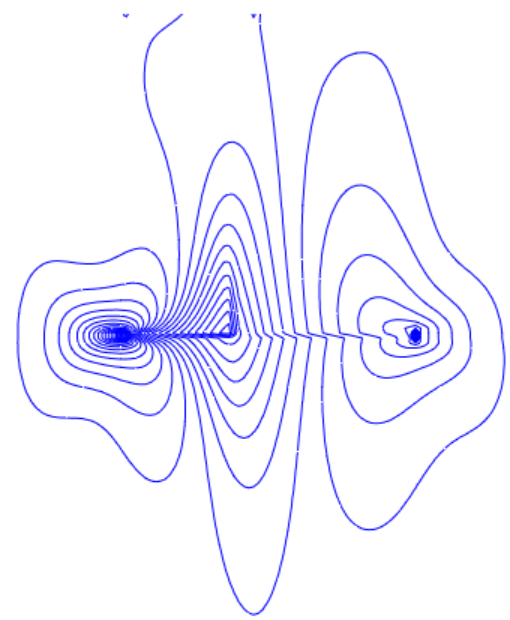


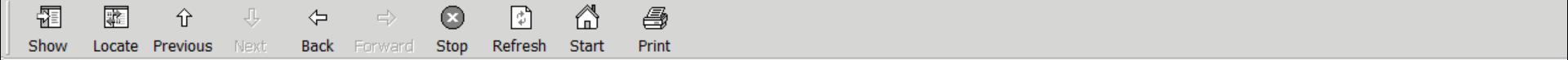
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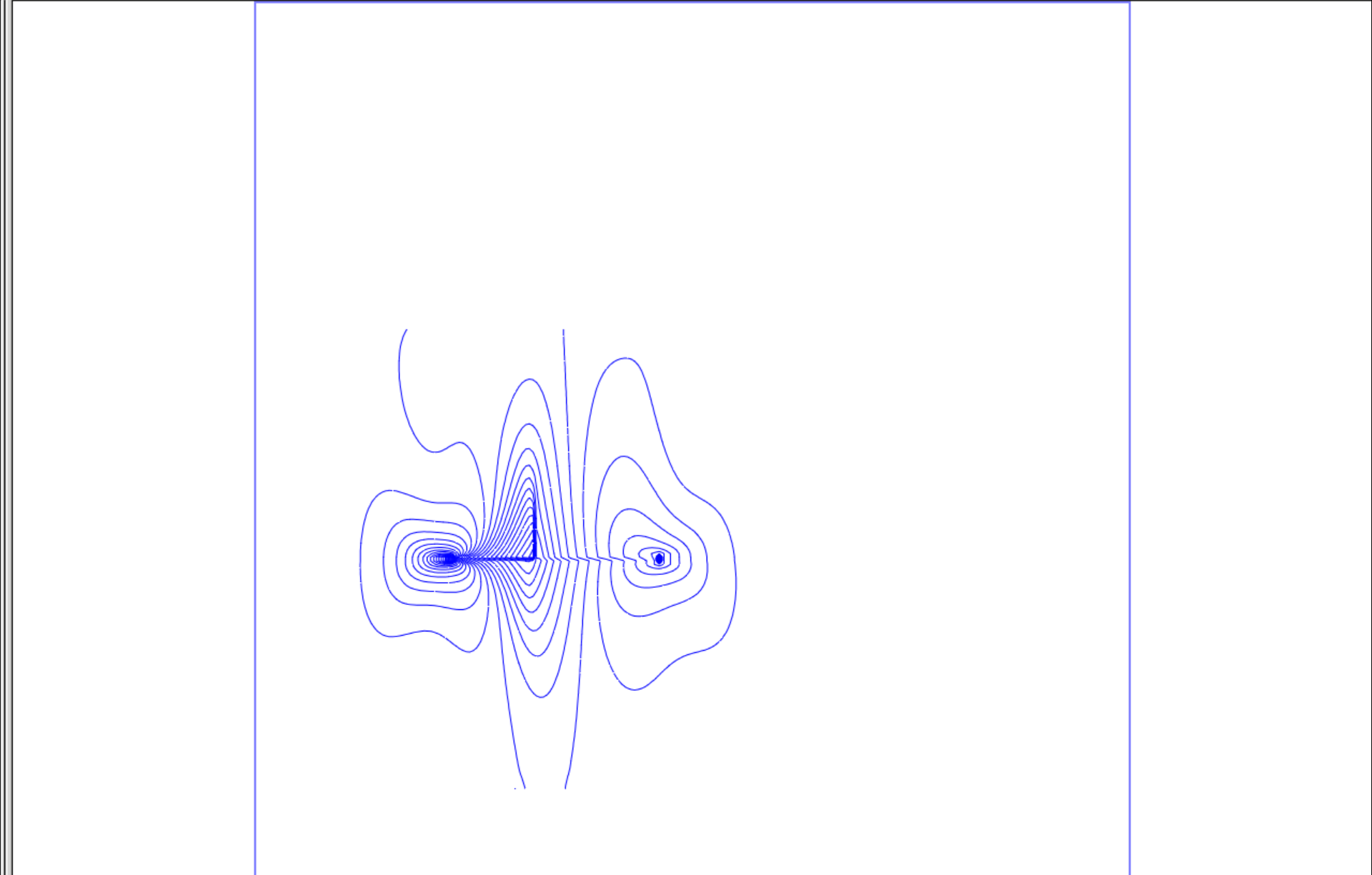


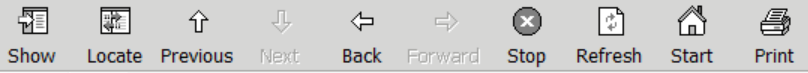
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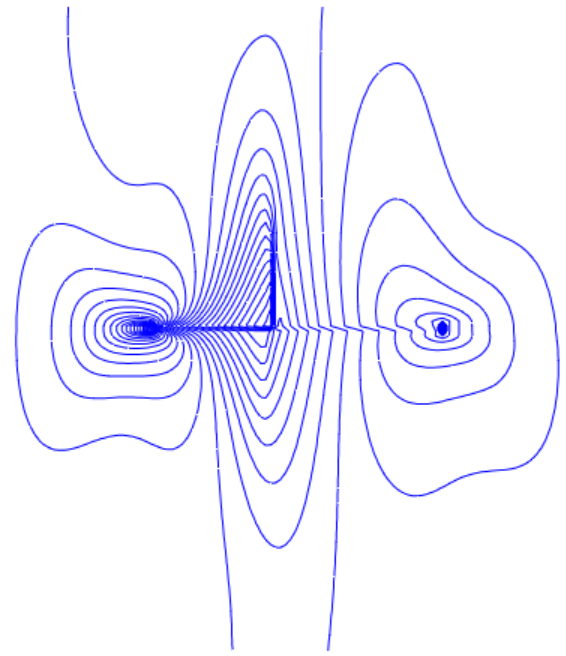


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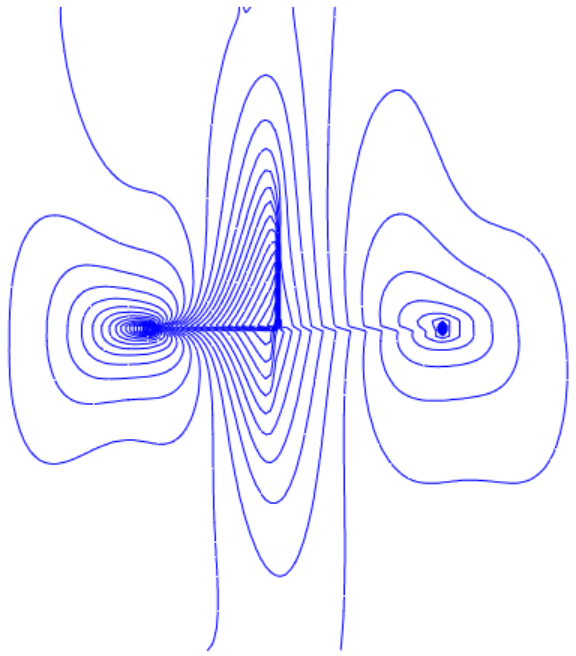


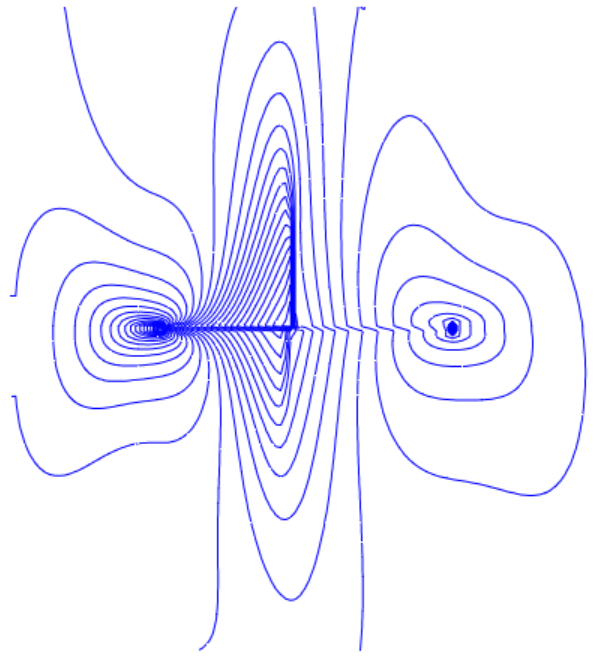
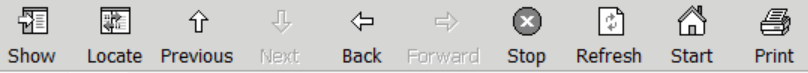
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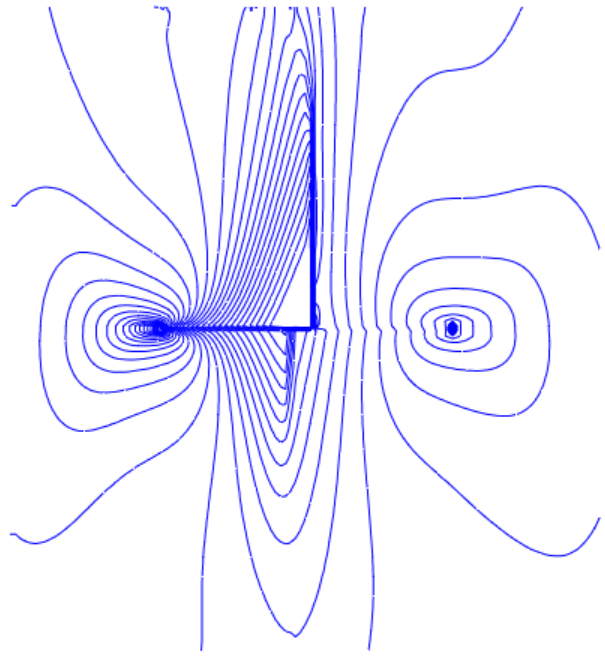
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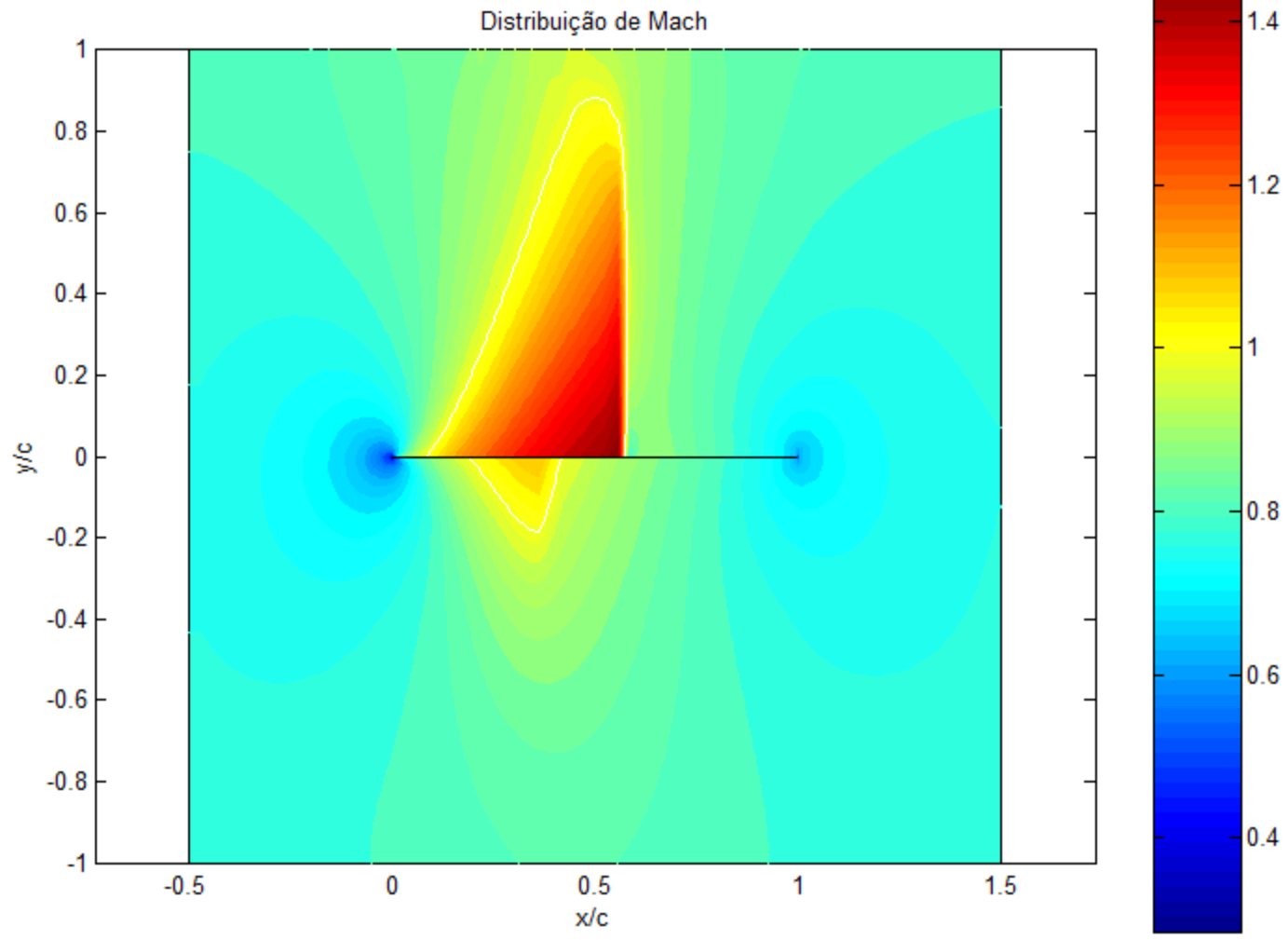




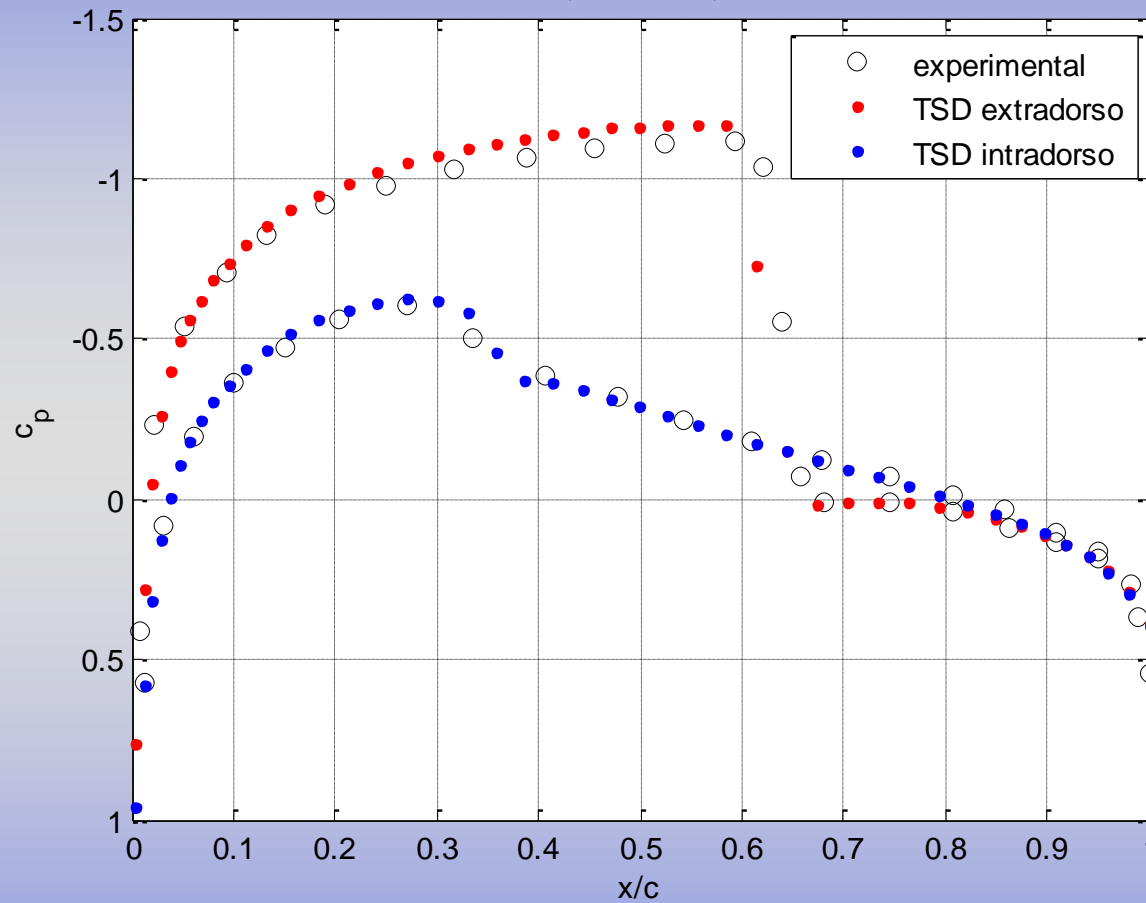
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NACA 0012, Mach 0.8, AoA 1.25°



Exemplos com pacotes comerciais existentes

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CFX - [CFX in Aerospace](#)

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