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.

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.

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

onde

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

Equações constitutivas:

Gás ideal: $p = \rho R T$

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

Gás caloricamente perfeito: $T = c_V e$

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

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

Métodos de discretização das equações:

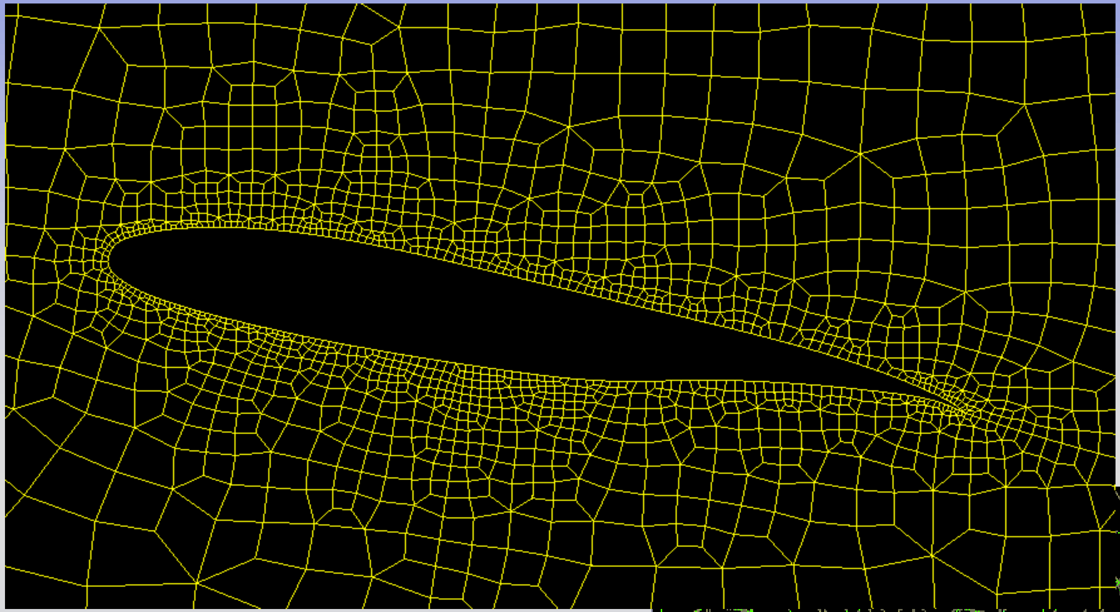
- Diferenças finitas;
- Volumes finitos;
- Elementos finitos;

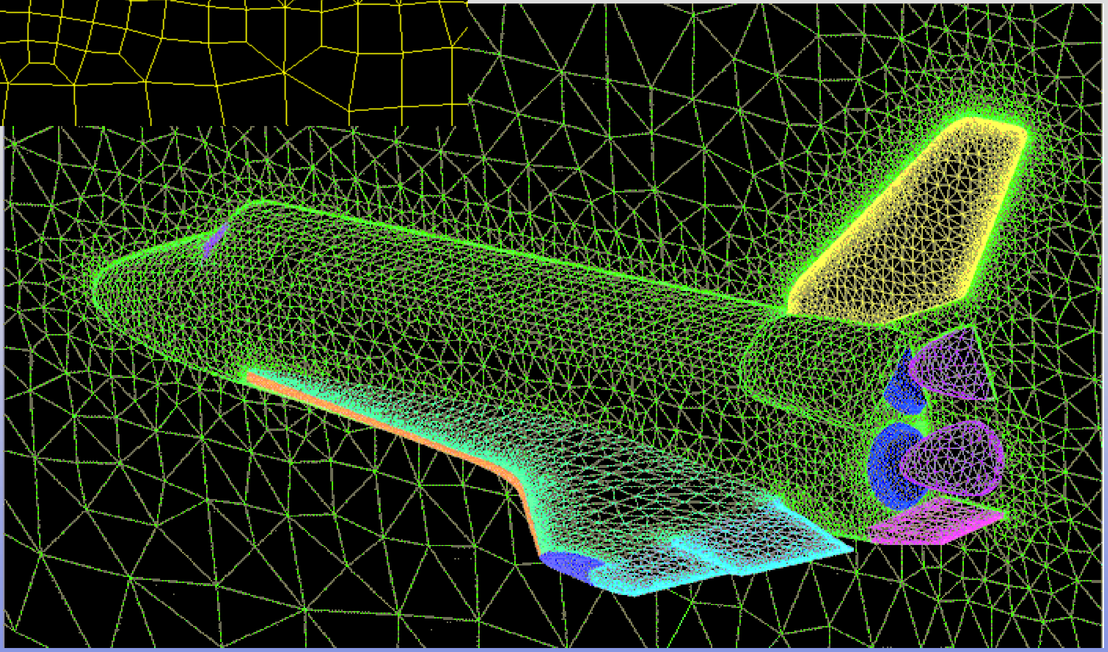
A base de todos estes métodos está na substituição de derivadas por expressões algébricas. Exemplo:

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

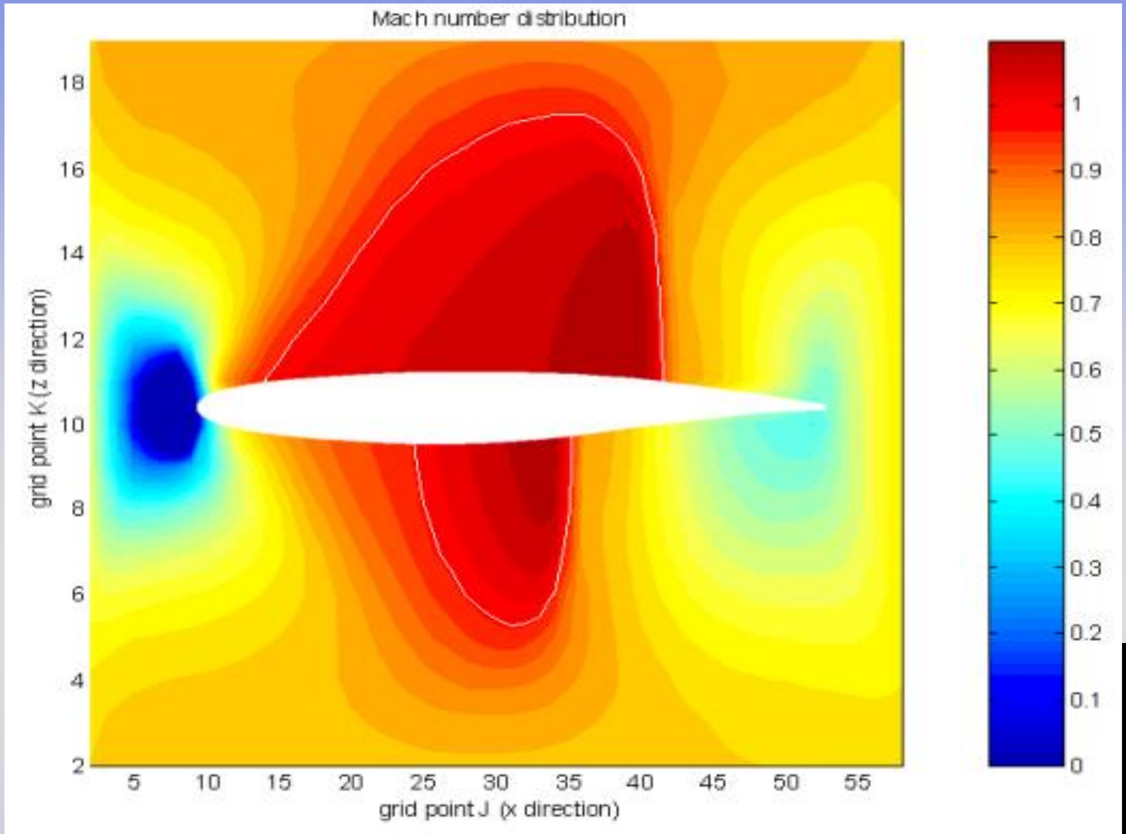
$$\Rightarrow \left(\frac{\partial u}{\partial t}\right)_i^t = \frac{u_i^{t+\Delta t} - u_i^t}{\Delta t} + O[\Delta t]$$

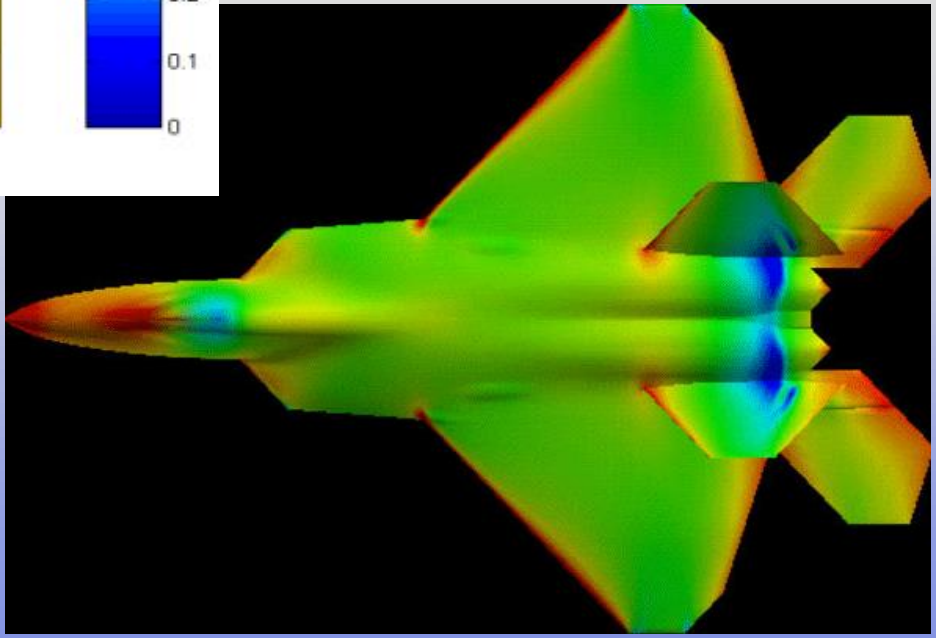
- Malhas não estruturadas:



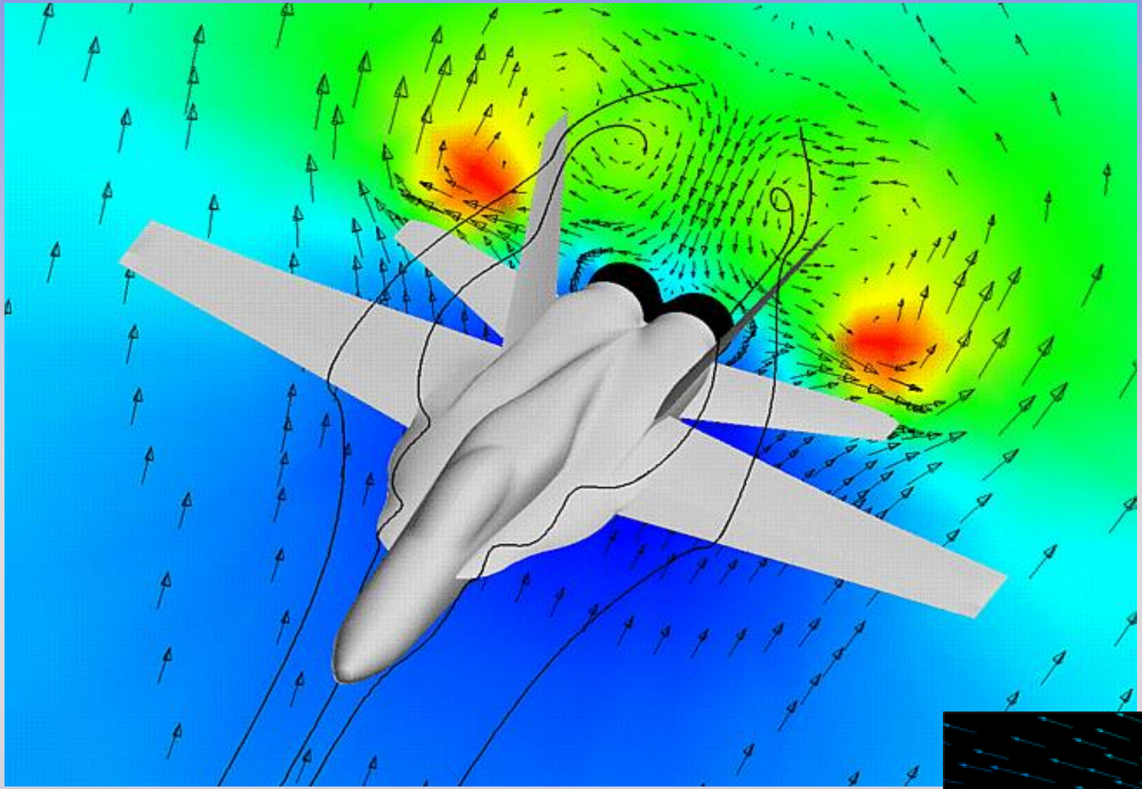


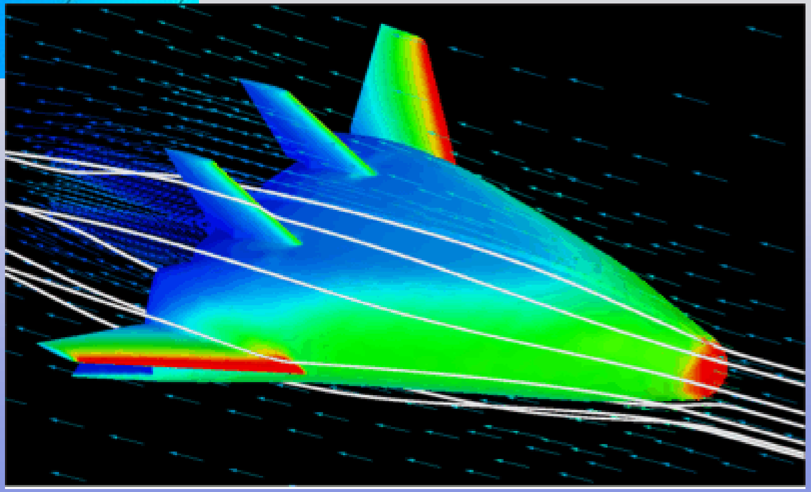
Gráficos de contorno:





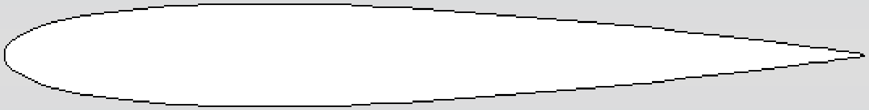
Gráficos vetoriais:





Exemplo de Aplicação

Fluxo em torno de uma seção de aerofólio NACA0012 em Mach 0.8 e ângulo de ataque de 1,25º:



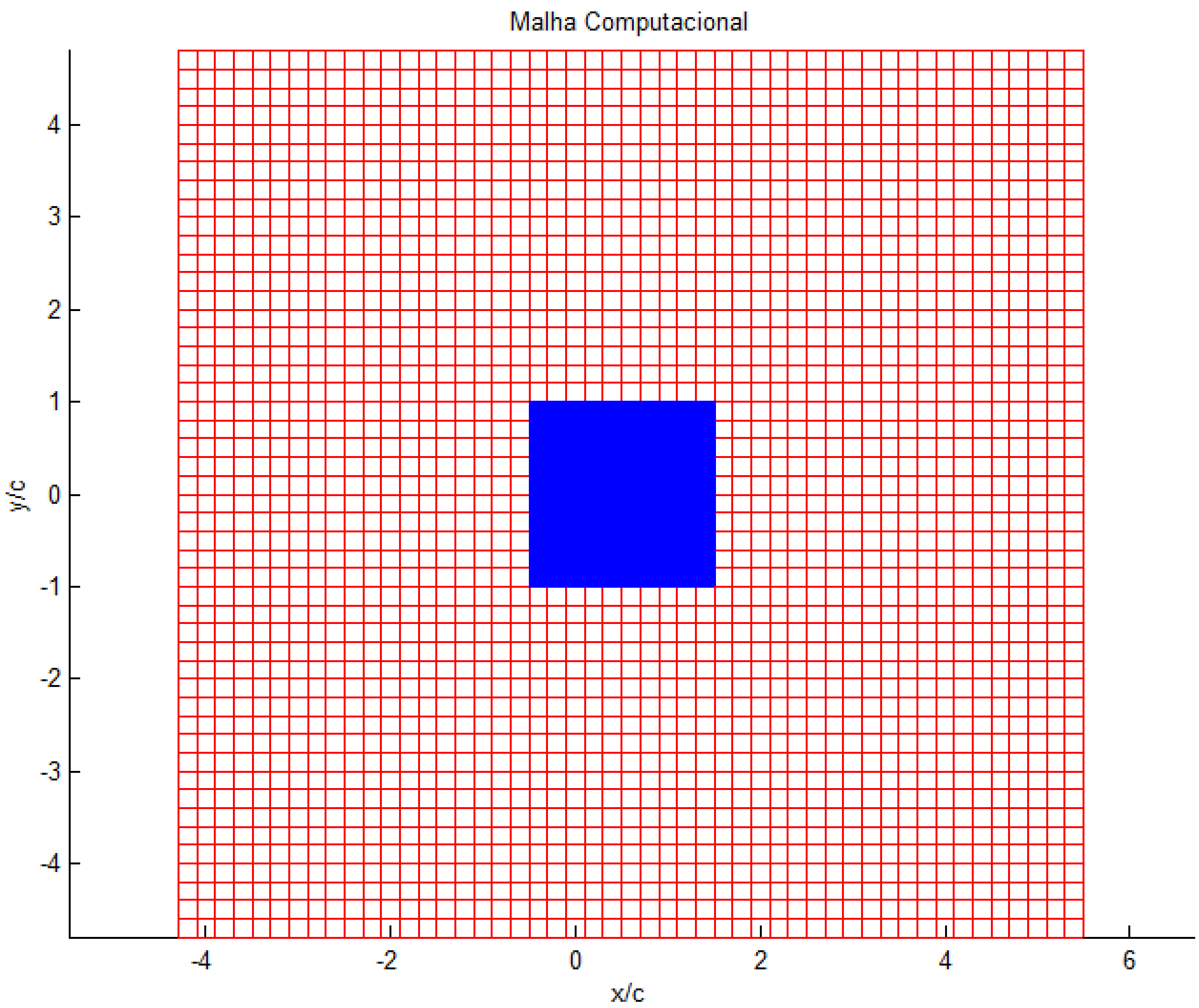
A seção de aerofólio NACA0012.

Programa TSD

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
y/c
x/c
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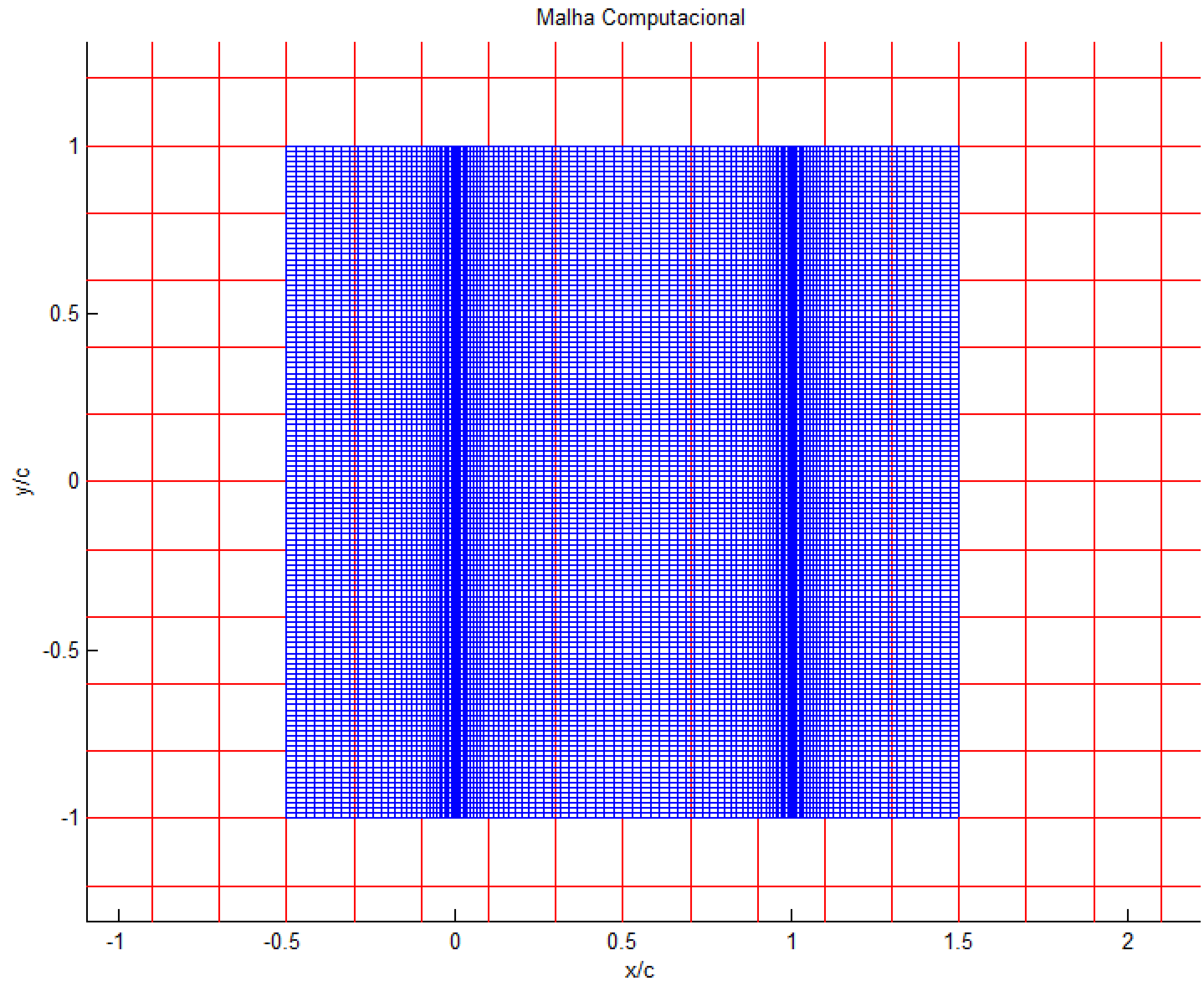
3
2
1
0
-1
-2
-3
-4
6



Malha Computacional
1
0.5
0
-0.5
-1
y/c
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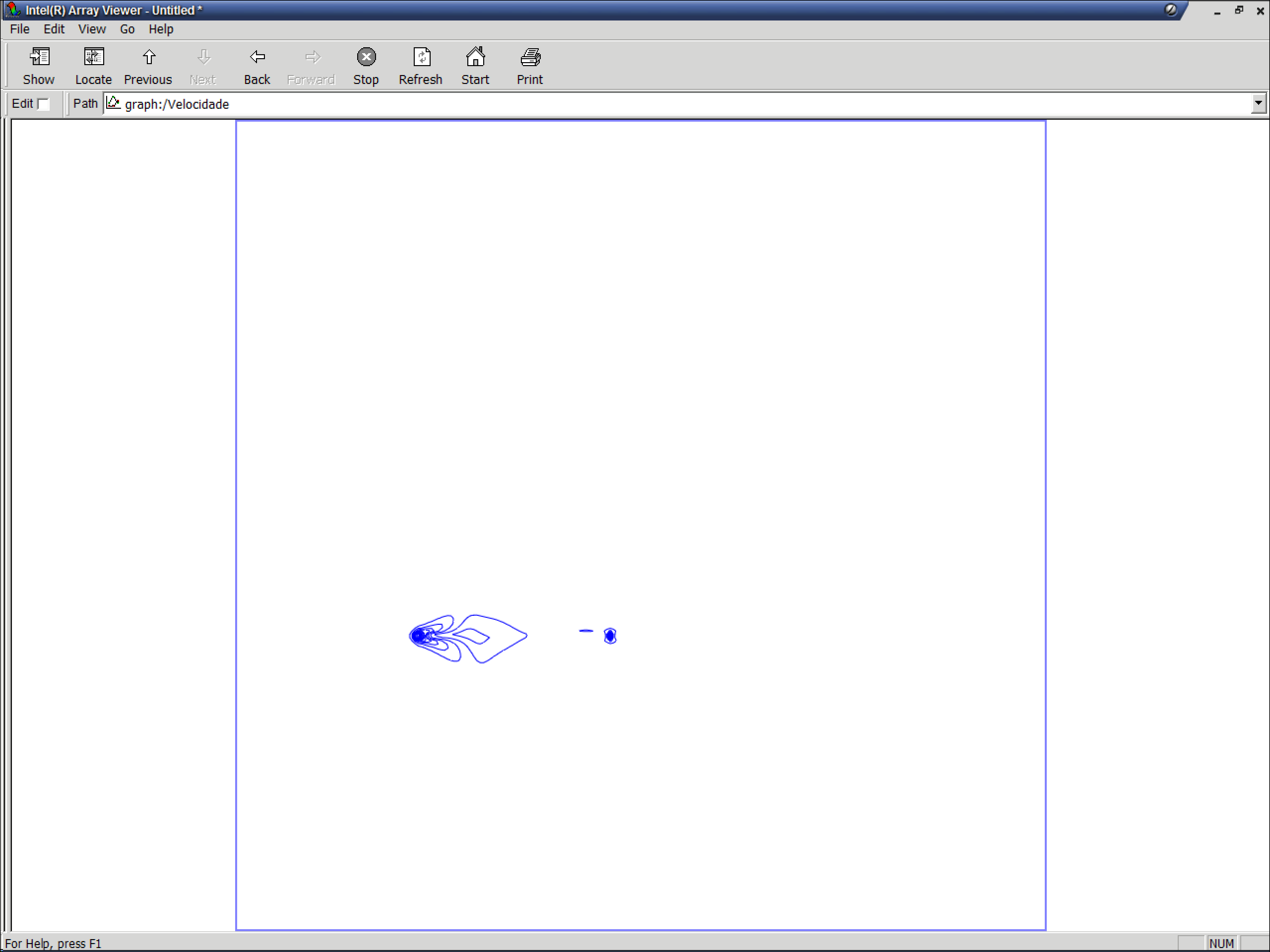
-0.5
0
0.5
1
1.5
2
x/c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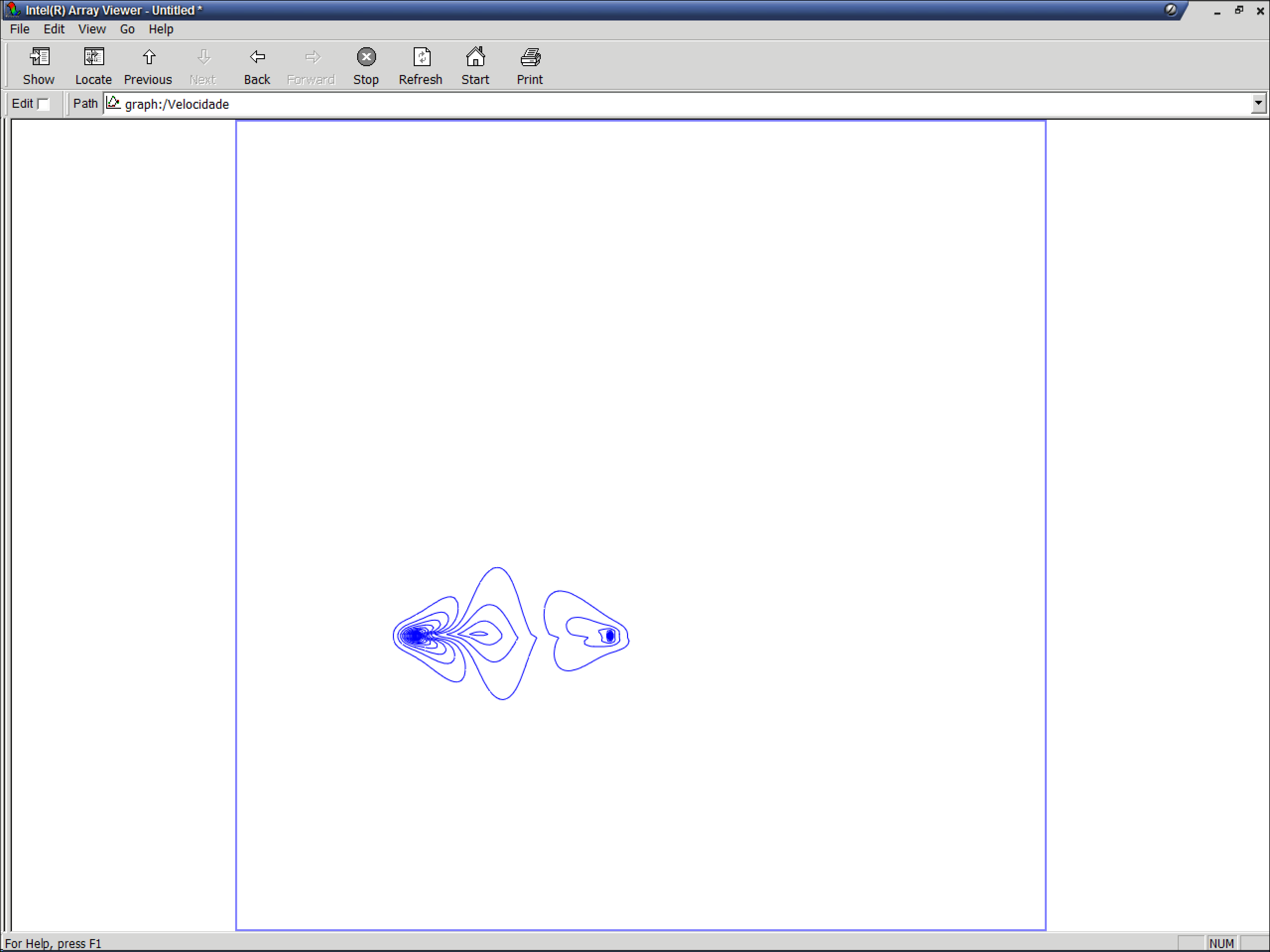
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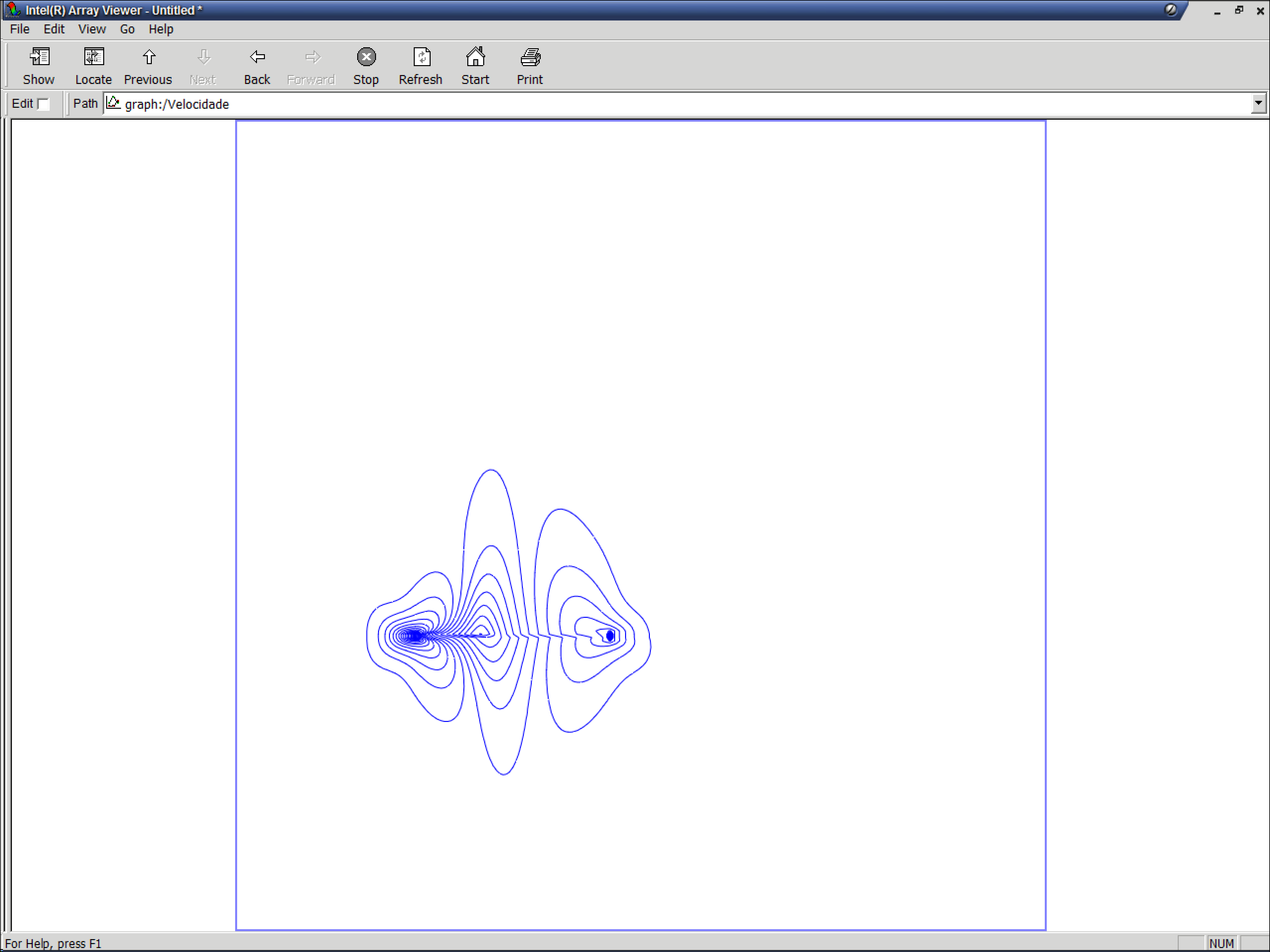
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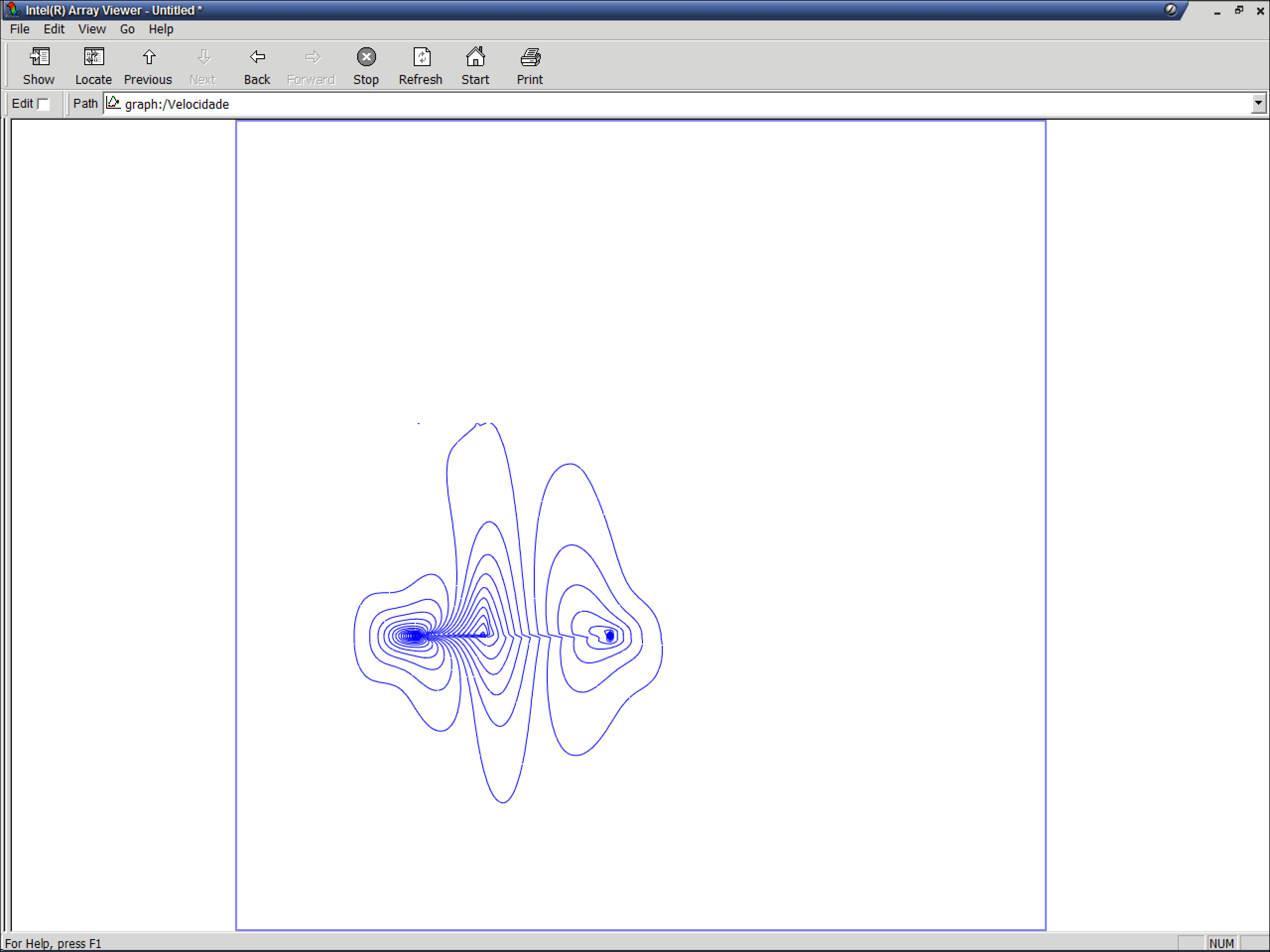
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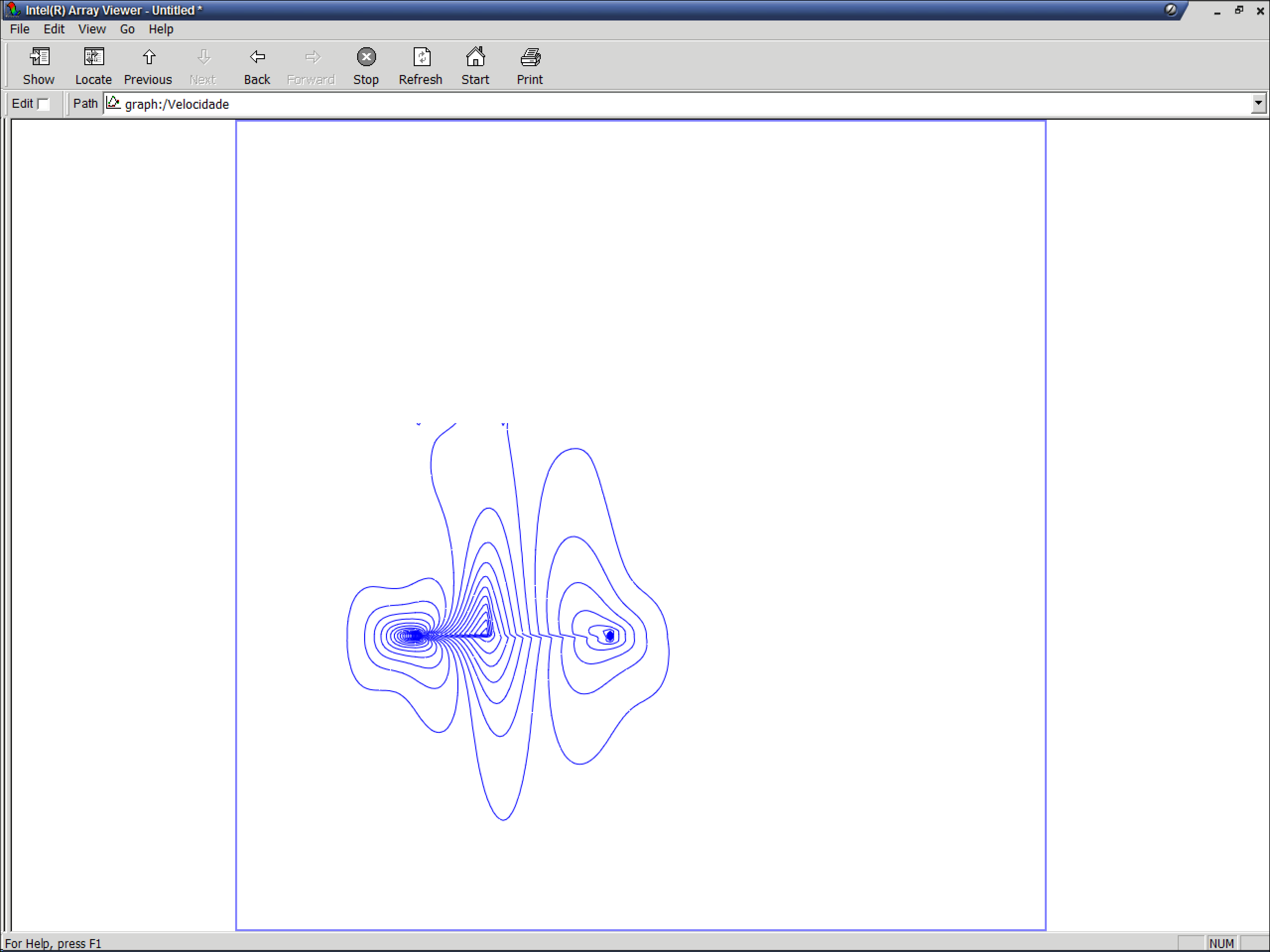
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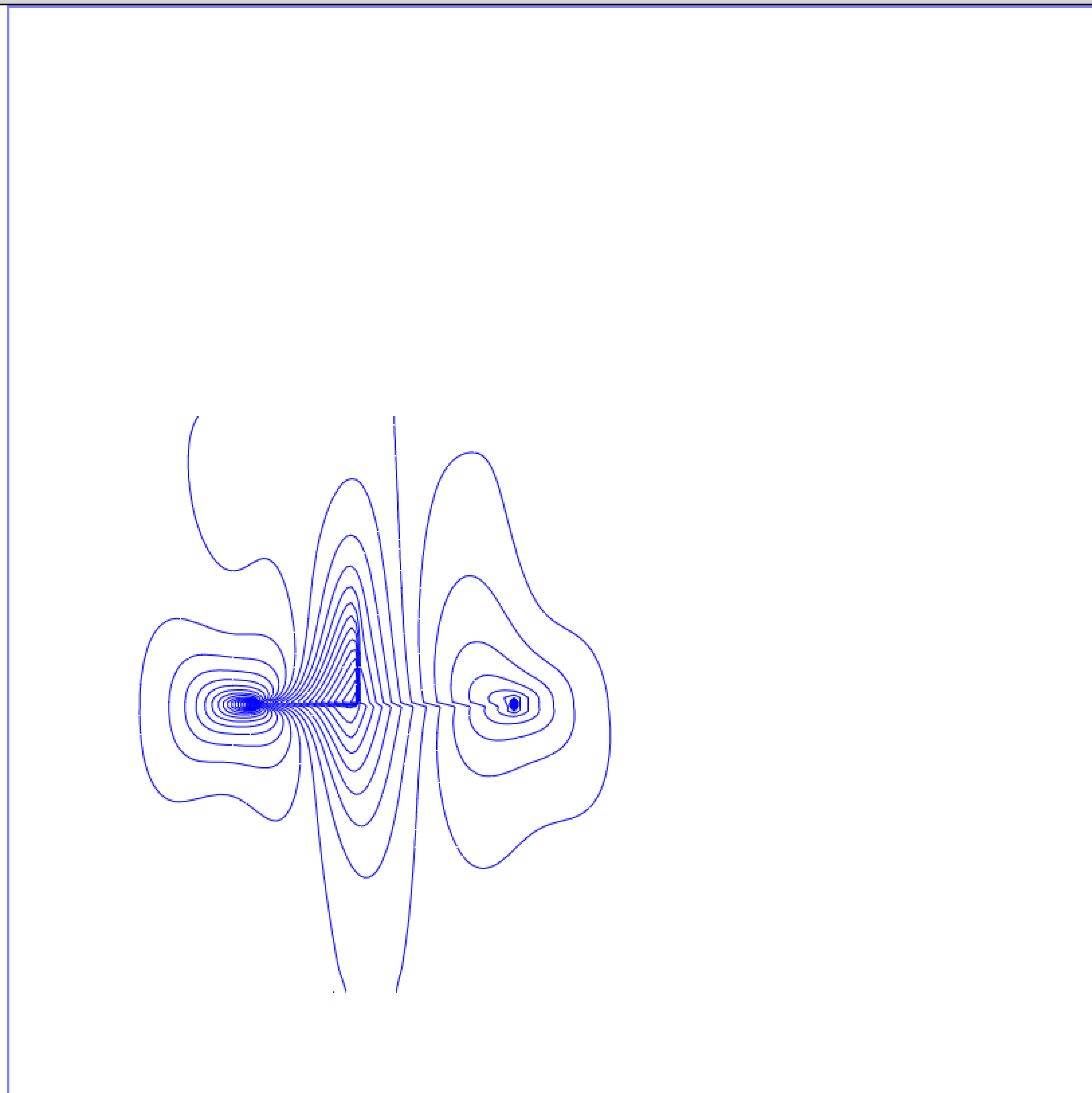

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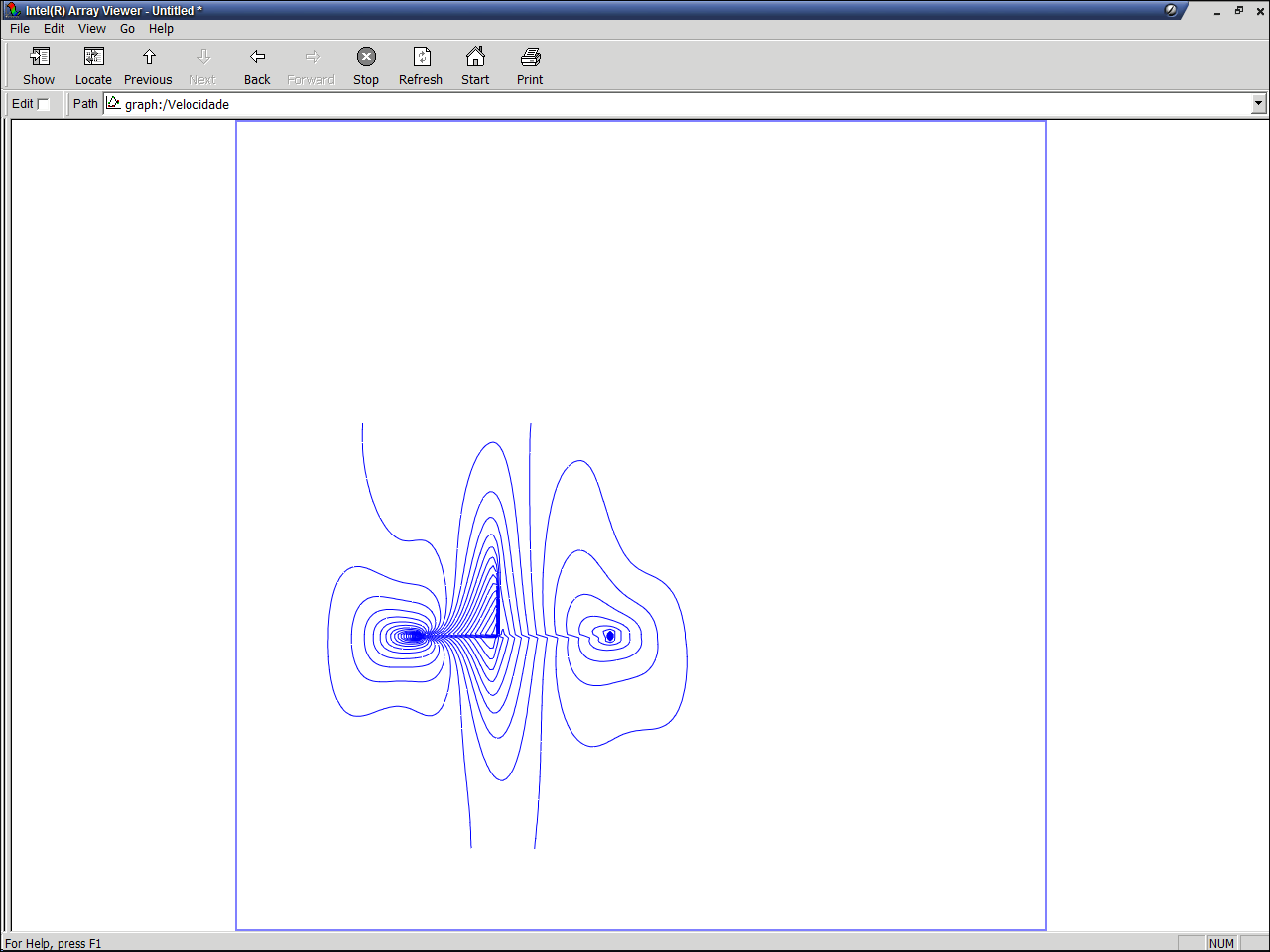
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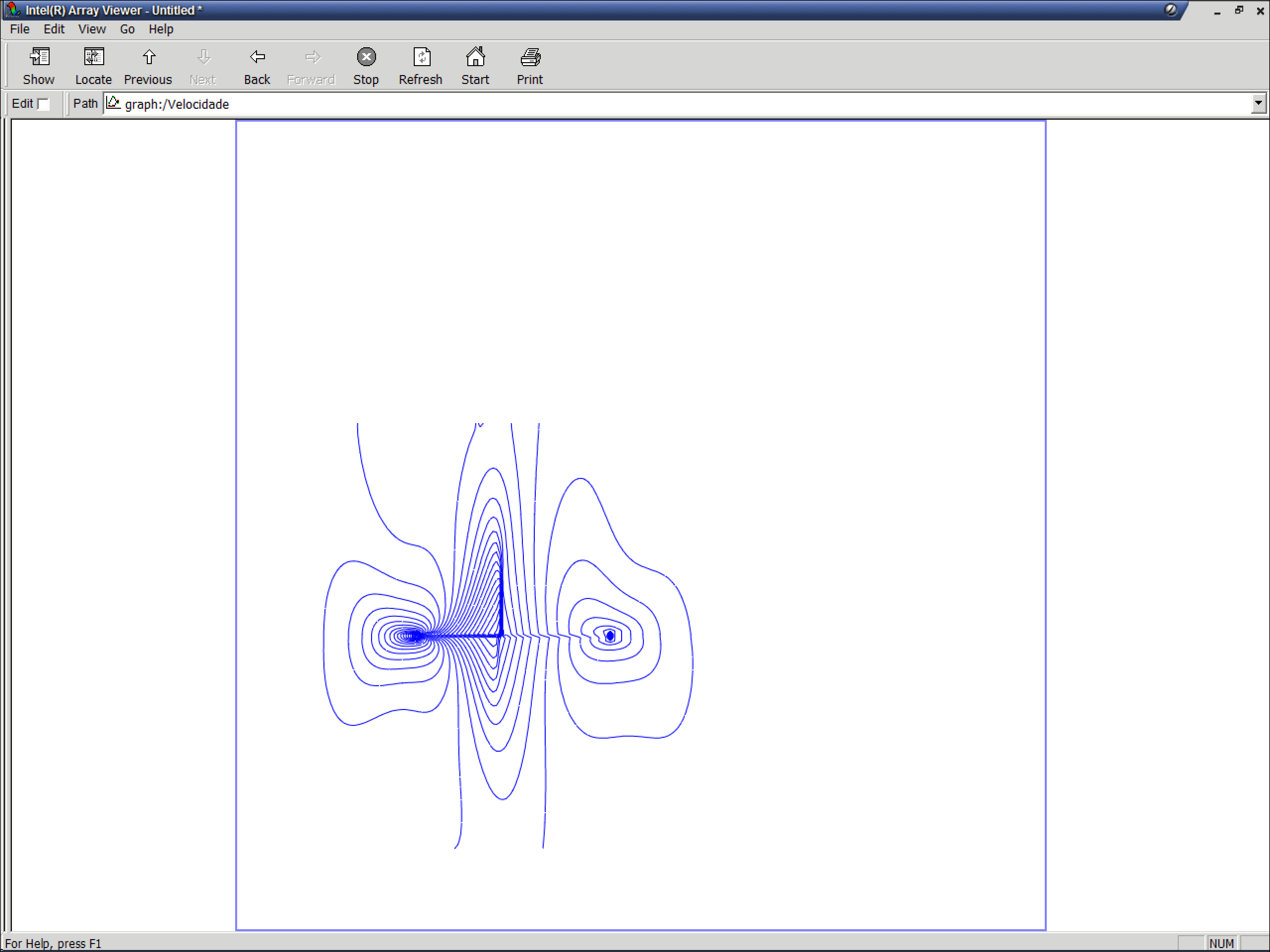
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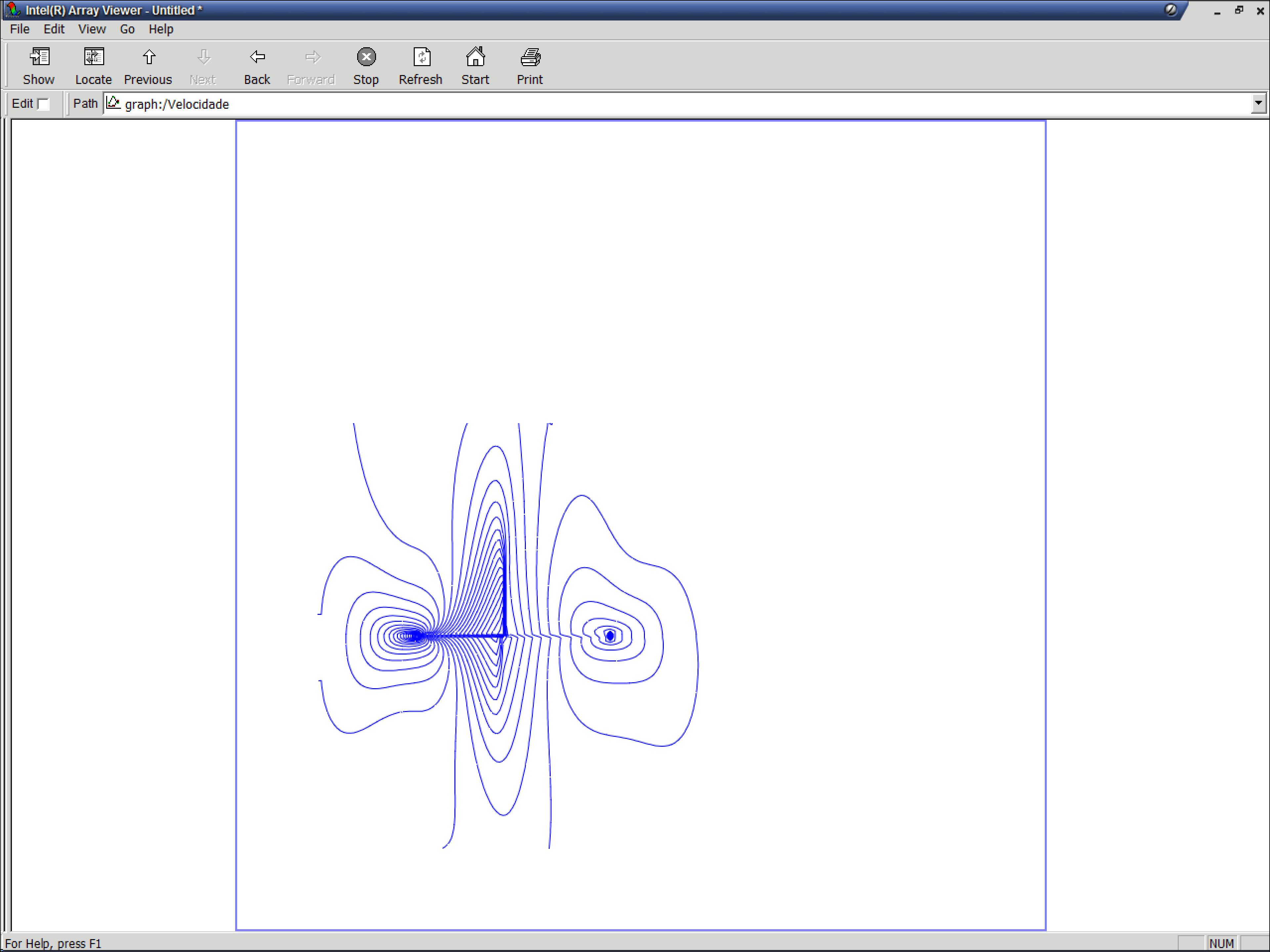
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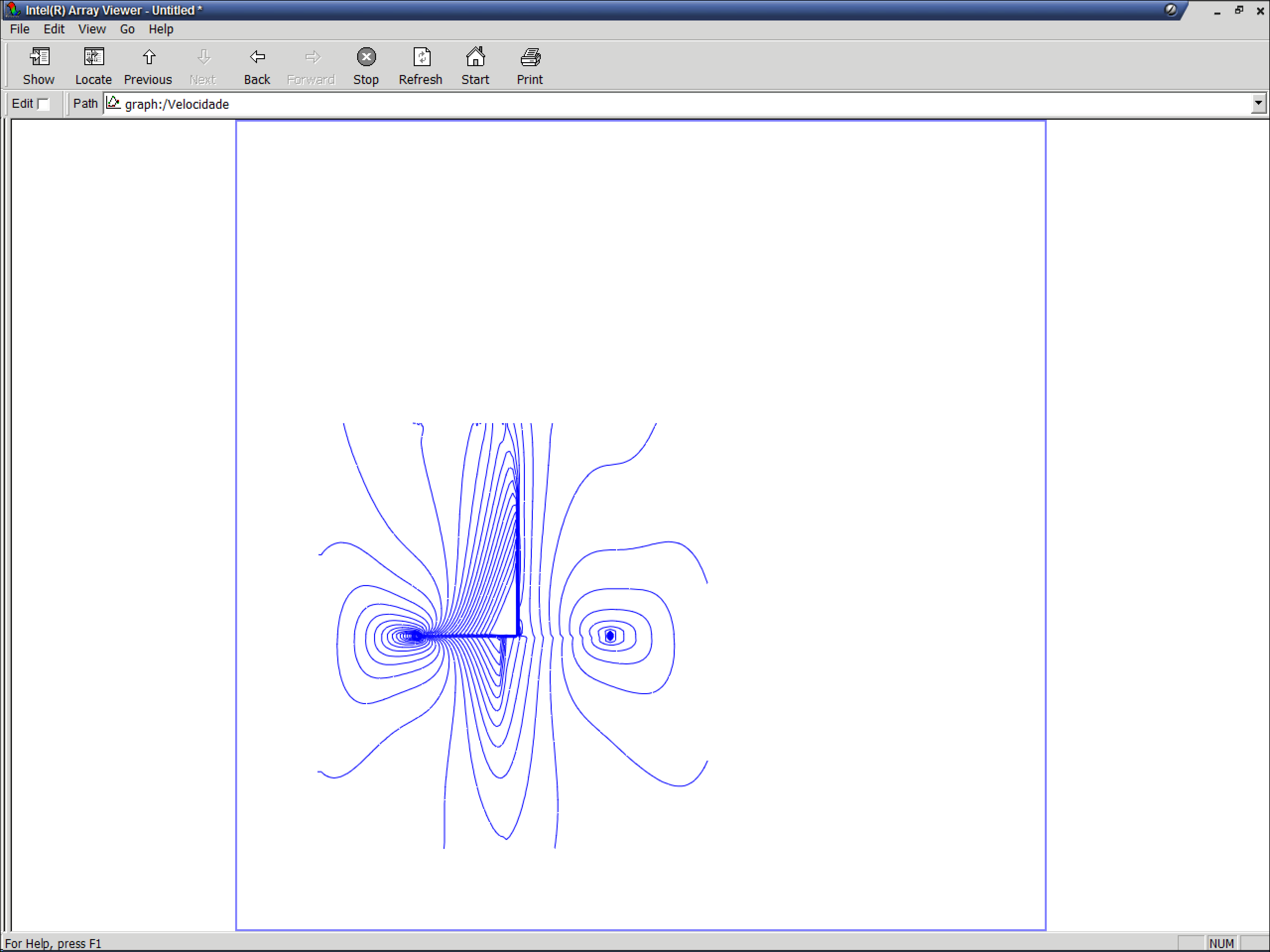
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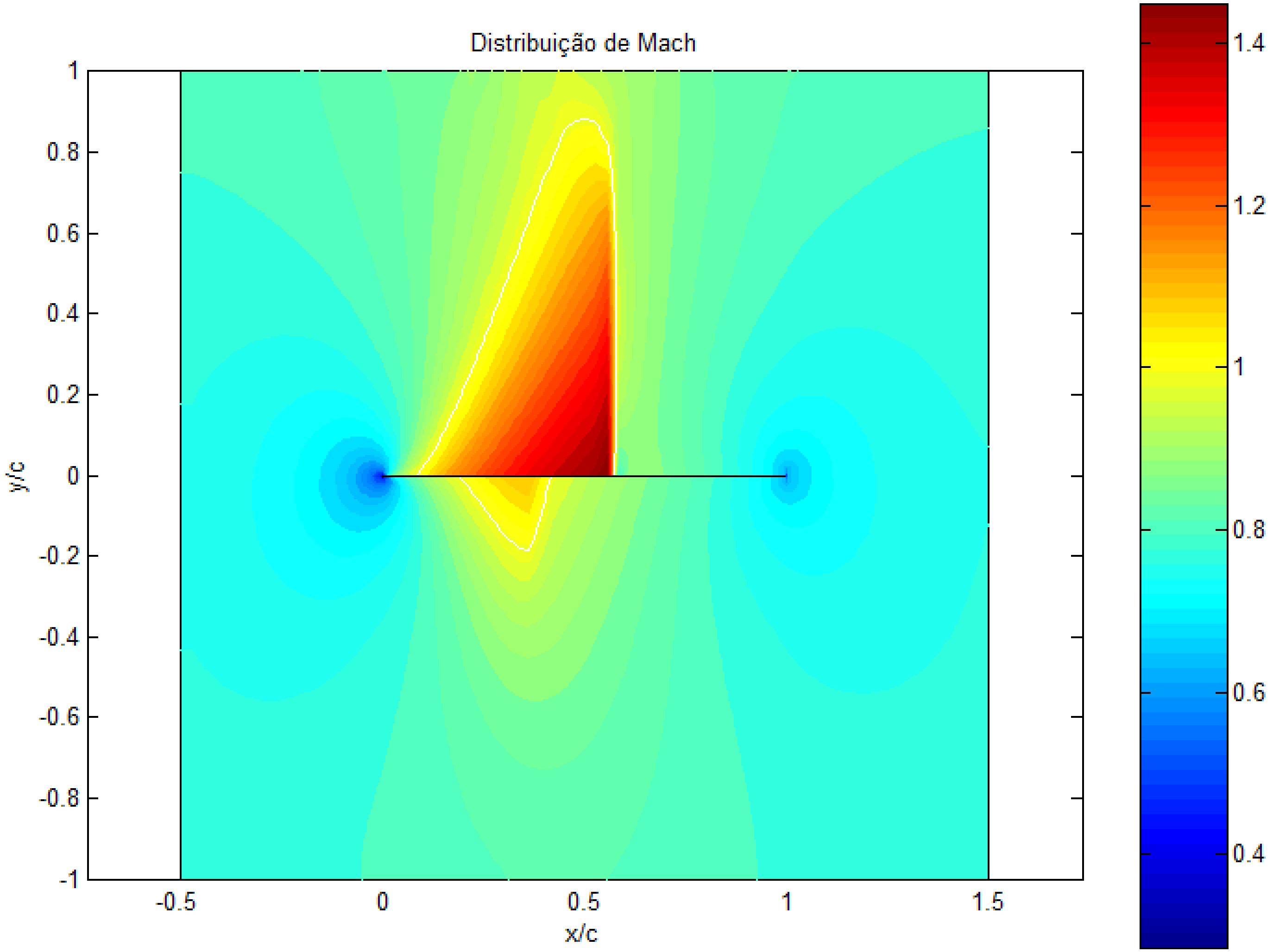
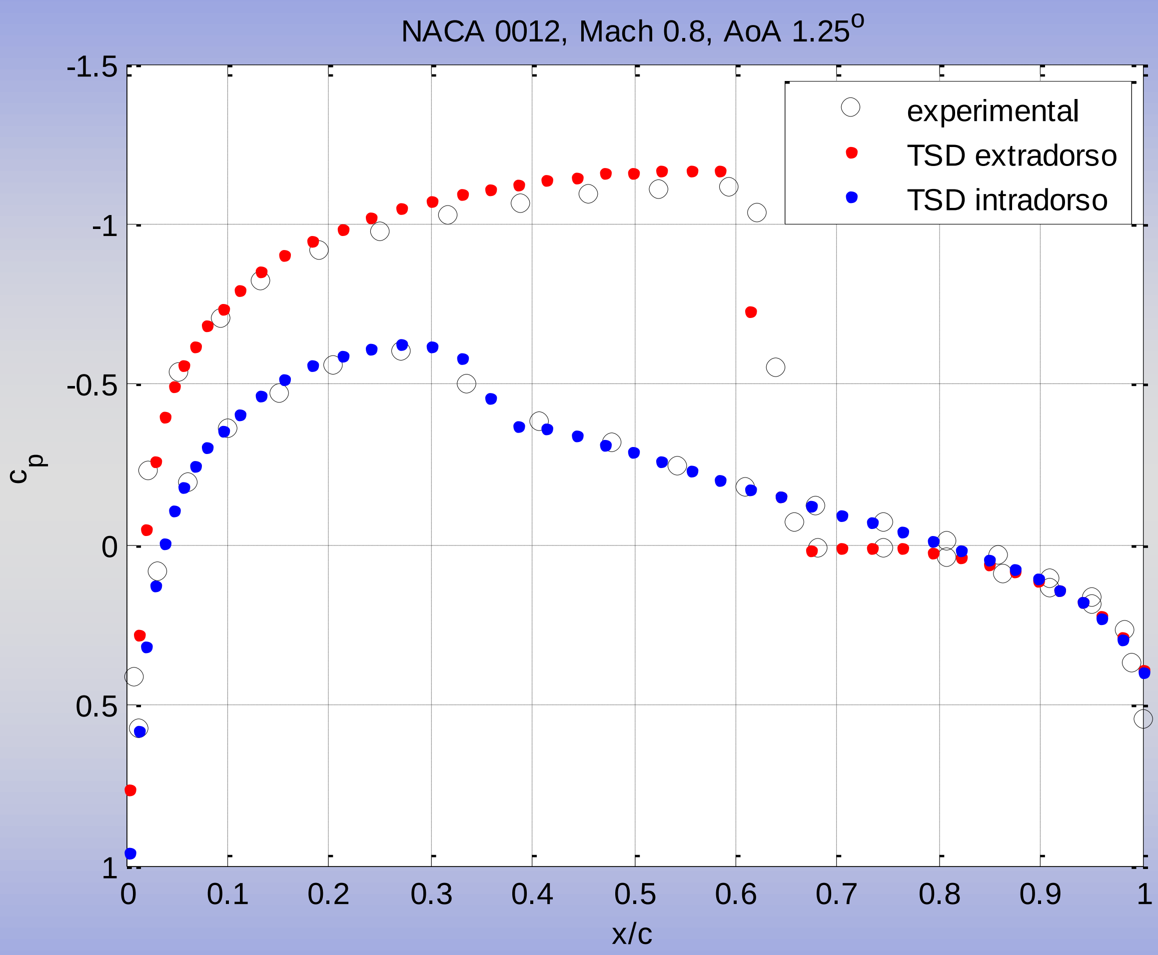

Distribuição de Mach
y/c
x/c
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.5
0
0.5
1
1.5
1.4
1.2
1
0.8
0.6
0.4



NACA 0012, Mach 0.8, AoA 1.25^o
experimental
TSD extradorso
TSD intradorso
c_p
x/c
-1.5
-1
-0.5
0
0.5
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Exemplos com pacotes comerciais existentes

Fluent - Transonic Flow over a NACA Airfoil

CFX - CFX in Aerospace

StarCD - Aircraft Aerodynamics

CFD++ - CFD++

CFD codes list - commercial products