CANS1D モジュール hdcip

流体エンジン CIP 法＋ MOC-CT

ver. 0.2

1　はじめに

このモジュールは、流体力学方程式・MHD 方程式を CIP ＋ MOCCT 法で解くためのものです。

2　基礎方程式

以下で $\gamma =$ 定数 は比熱比、他の記号は通常の意味。

2.1　サブルーチン cip_a；移流

$$\frac{\partial}{\partial t}(\rho) + V_x \frac{\partial}{\partial x}(\rho) = -\rho \frac{\partial}{\partial x}(V_x) \tag{1}$$

2.2　サブルーチン cip_h；流体

$$\frac{\partial}{\partial t}(\rho) + V_x \frac{\partial}{\partial x}(\rho) = -\rho \frac{\partial}{\partial x}(V_x) \tag{2}$$

$$\frac{\partial}{\partial t}(V_x) + V_x \frac{\partial}{\partial x}(V_x) = -\frac{1}{\rho} \frac{\partial}{\partial x}(p) \tag{3}$$

$$\frac{\partial}{\partial t}(T) + V_x \frac{\partial}{\partial x}(T) = -(\gamma - 1) T \frac{\partial}{\partial x}(V_x) \tag{4}$$

$$p = \frac{k_{\rm B}}{m} \rho T \tag{5}$$

2.3　サブルーチン cip_h_g；流体重力

$$\frac{\partial}{\partial t}(\rho) + V_x \frac{\partial}{\partial x}(\rho) = -\rho \frac{\partial}{\partial x}(V_x) \tag{6}$$

$$\frac{\partial}{\partial t}(V_x) + V_x \frac{\partial}{\partial x}(V_x) = -\frac{1}{\rho} \frac{\partial}{\partial x}(p) + g \tag{7}$$

$$\frac{\partial}{\partial t}(T) + V_x \frac{\partial}{\partial x}(T) = -(\gamma - 1) T \frac{\partial}{\partial x}(V_x) \tag{8}$$

$$p = \frac{k_{\rm B}}{m} \rho T \tag{9}$$

2.4 サブルーチン cip_h_c；流体非一様断面

$$\frac{\partial}{\partial t}(\rho) + V_x \frac{\partial}{\partial x}(\rho) = -\frac{\rho}{S}\frac{\partial}{\partial x}(V_x S) \tag{10}$$

$$\frac{\partial}{\partial t}(V_x) + V_x \frac{\partial}{\partial x}(V_x) = -\frac{1}{\rho}\frac{\partial}{\partial x}(p) \tag{11}$$

$$\frac{\partial}{\partial t}(T) + V_x \frac{\partial}{\partial x}(T) = -(\gamma - 1)\frac{T}{S}\frac{\partial}{\partial x}(V_x S) \tag{12}$$

$$p = \frac{k_{\mathrm{B}}}{m}\rho T \tag{13}$$

S は断面積、

2.5 サブルーチン cip_h_cg；流体非一様断面重力

$$\frac{\partial}{\partial t}(\rho) + V_x \frac{\partial}{\partial x}(\rho) = -\frac{\rho}{S}\frac{\partial}{\partial x}(V_x S) \tag{14}$$

$$\frac{\partial}{\partial t}(V_x) + V_x \frac{\partial}{\partial x}(V_x) = -\frac{1}{\rho}\frac{\partial}{\partial x}(p) + g \tag{15}$$

$$\frac{\partial}{\partial t}(T) + V_x \frac{\partial}{\partial x}(T) = -(\gamma - 1)\frac{T}{S}\frac{\partial}{\partial x}(V_x S) \tag{16}$$

$$p = \frac{k_{\mathrm{B}}}{m}\rho T \tag{17}$$

S は断面積、

2.6 サブルーチン cip_ht；等温流体

$$\frac{\partial}{\partial t}(\rho) + V_x \frac{\partial}{\partial x}(\rho) = -\rho\frac{\partial}{\partial x}(V_x) \tag{18}$$

$$\frac{\partial}{\partial t}(V_x) + V_x \frac{\partial}{\partial x}(V_x) = -\frac{1}{\rho}\frac{\partial}{\partial x}(p) \tag{19}$$

$$p = \frac{k_{\mathrm{B}}}{m}\rho T \tag{20}$$

2.7 サブルーチン cip_ht_g；等温流体重力

$$\frac{\partial}{\partial t}(\rho) + V_x \frac{\partial}{\partial x}(\rho) = -\rho\frac{\partial}{\partial x}(V_x) \tag{21}$$

$$\frac{\partial}{\partial t}(V_x) + V_x \frac{\partial}{\partial x}(V_x) = -\frac{1}{\rho}\frac{\partial}{\partial x}(p) + g \tag{22}$$

$$p = \frac{k_{\mathrm{B}}}{m}\rho T \tag{23}$$

2.8 サブルーチン cip_ht_c；等温流体非一様断面

$$\frac{\partial}{\partial t}(\rho) + V_x \frac{\partial}{\partial x}(\rho) = -\frac{\rho}{S}\frac{\partial}{\partial x}(V_x S) \tag{24}$$

$$\frac{\partial}{\partial t}(V_x) + V_x \frac{\partial}{\partial x}(V_x) = -\frac{1}{\rho}\frac{\partial}{\partial x}(p) \tag{25}$$

$$p = \frac{k_{\mathrm{B}}}{m}\rho T \tag{26}$$

S は断面積、

2.9 サブルーチン cip_ht_cg；等温流体非一様断面重力

$$\frac{\partial}{\partial t}(\rho) + V_x \frac{\partial}{\partial x}(\rho) = -\frac{\rho}{S}\frac{\partial}{\partial x}(V_x S) \tag{27}$$

$$\frac{\partial}{\partial t}(V_x) + V_x \frac{\partial}{\partial x}(V_x) = -\frac{1}{\rho}\frac{\partial}{\partial x}(p) + g \tag{28}$$

$$p = \frac{k_{\mathrm{B}}}{m}\rho T \tag{29}$$

S は断面積、温度 T は既知の定数。

2.10 サブルーチン cip_m；MHD

$$\frac{\partial \rho}{\partial t} + V_x \frac{\partial \rho}{\partial x} = -\rho \frac{\partial V_x}{\partial x} \tag{30}$$

$$\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - \frac{1}{4\pi\rho} B_y \frac{\partial B_y}{\partial x} \tag{31}$$

$$\frac{\partial V_y}{\partial t} + V_x \frac{\partial V_y}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_y}{\partial x} \tag{32}$$

$$\frac{\partial T}{\partial t} + V_x \frac{\partial T}{\partial x} = -(\gamma - 1) T \frac{\partial V_x}{\partial x} \tag{33}$$

$$\frac{\partial B_y}{\partial t} = \frac{\partial E_z}{\partial x} \tag{34}$$

$$E_z = -V_x B_y + V_y B_x \tag{35}$$

$$p = \frac{k_{\mathrm{B}}}{m}\rho T \tag{36}$$

磁場 B_x は既知の定数。

2.11 サブルーチン cip_m_g；MHD 重力

$$\frac{\partial \rho}{\partial t} + V_x \frac{\partial \rho}{\partial x} = -\rho \frac{\partial V_x}{\partial x} \tag{37}$$

$$\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - \frac{1}{4\pi\rho} B_y \frac{\partial B_y}{\partial x} + g_x \tag{38}$$

$$\frac{\partial V_y}{\partial t} + V_x \frac{\partial V_y}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_y}{\partial x} + g_y \tag{39}$$

$$\frac{\partial T}{\partial t} + V_x \frac{\partial T}{\partial x} = -(\gamma - 1) T \frac{\partial V_x}{\partial x} \tag{40}$$

$$\frac{\partial B_y}{\partial t} = \frac{\partial E_z}{\partial x} \tag{41}$$

$$E_z = -V_x B_y + V_y B_x \tag{42}$$

$$p = \frac{k_{\mathrm{B}}}{m} \rho T \tag{43}$$

磁場 B_x は既知の定数。

2.12 サブルーチン cip_m_c；MHD 非一様断面

$$\frac{\partial \rho}{\partial t} + V_x \frac{\partial \rho}{\partial x} = -\frac{\rho}{S} \frac{\partial (V_x S)}{\partial x} \tag{44}$$

$$\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - \frac{1}{4\pi\rho} B_y \frac{\partial B_y}{\partial x} \tag{45}$$

$$\frac{\partial V_y}{\partial t} + V_x \frac{\partial V_y}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_y}{\partial x} \tag{46}$$

$$\frac{\partial T}{\partial t} + V_x \frac{\partial T}{\partial x} = -(\gamma - 1) \frac{T}{S} \frac{\partial (V_x S)}{\partial x} \tag{47}$$

$$\frac{\partial (B_y S)}{\partial t} = \frac{\partial (E_z S)}{\partial x} \tag{48}$$

$$E_z = -V_x B_y + V_y B_x \tag{49}$$

$$p = \frac{k_{\mathrm{B}}}{m} \rho T \tag{50}$$

B_x は既知で $S \propto 1/B_x$ は断面積。

2.13 サブルーチン cip_m_cg；MHD 非一様断面重力

$$\frac{\partial \rho}{\partial t} + V_x \frac{\partial \rho}{\partial x} = -\frac{\rho}{S} \frac{\partial (V_x S)}{\partial x} \tag{51}$$

$$\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} = -\frac{1}{\rho} \frac{\partial p}{\partial x} - \frac{1}{4\pi\rho} B_y \frac{\partial B_y}{\partial x} + g_x \tag{52}$$

$$\frac{\partial V_y}{\partial t} + V_x \frac{\partial V_y}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_y}{\partial x} + g_y \tag{53}$$

$$\frac{\partial T}{\partial t} + V_x \frac{\partial T}{\partial x} = -(\gamma - 1) \frac{T}{S} \frac{\partial (V_x S)}{\partial x} \tag{54}$$

$$\frac{\partial (B_y S)}{\partial t} = \frac{\partial (E_z S)}{\partial x} \tag{55}$$

$$E_z = -V_x B_y + V_y B_x \tag{56}$$

$$p = \frac{k_{\mathrm{B}}}{m} \rho T \tag{57}$$

B_x は既知で $S \propto 1/B_x$ は断面積。

2.14 サブルーチン cip_m_cgr；MHD 非一様断面重力回転

$$\frac{\partial \rho}{\partial t} + V_x \frac{\partial \rho}{\partial x} = -\frac{\rho}{S} \frac{\partial (V_x S)}{\partial x} \tag{58}$$

$$\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} = -\frac{1}{\rho} \frac{\partial p}{\partial x} - \frac{1}{4\pi\rho} \frac{B_y}{R} \frac{\partial (B_y R)}{\partial x} + \frac{V_y^2}{R} \frac{\partial R}{\partial x} + g_x \tag{59}$$

$$\frac{\partial (V_y R)}{\partial t} + V_x \frac{\partial (V_y R)}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial (B_y R)}{\partial x} \tag{60}$$

$$\frac{\partial T}{\partial t} + V_x \frac{\partial T}{\partial x} = -(\gamma - 1) \frac{T}{S} \frac{\partial (V_x S)}{\partial x} \tag{61}$$

$$\frac{\partial}{\partial t} \left(\frac{B_y S}{R} \right) = \frac{\partial}{\partial x} \left(\frac{E_z S}{R} \right) \tag{62}$$

$$E_z = -V_x B_y + V_y B_x \tag{63}$$

$$p = \frac{k_{\mathrm{B}}}{m} \rho T \tag{64}$$

B_x は既知で $S \propto 1/B_x$ は断面積。

2.15　サブルーチン cip_m3；3 成分 MHD

$$\frac{\partial \rho}{\partial t} + V_x \frac{\partial \rho}{\partial x} = -\rho \frac{\partial V_x}{\partial x} \tag{65}$$

$$\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - \frac{1}{4\pi\rho}\left(B_y \frac{\partial B_y}{\partial x} + B_z \frac{\partial B_z}{\partial x}\right) \tag{66}$$

$$\frac{\partial V_y}{\partial t} + V_x \frac{\partial V_y}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_y}{\partial x} \tag{67}$$

$$\frac{\partial V_z}{\partial t} + V_x \frac{\partial V_z}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_z}{\partial x} \tag{68}$$

$$\frac{\partial T}{\partial t} + V_x \frac{\partial T}{\partial x} = -(\gamma - 1) T \frac{\partial V_x}{\partial x} \tag{69}$$

$$\frac{\partial B_y}{\partial t} = \frac{\partial E_z}{\partial x} \tag{70}$$

$$\frac{\partial B_z}{\partial t} = -\frac{\partial E_y}{\partial x} \tag{71}$$

$$E_y = -V_z B_x + V_x B_z, \quad E_z = -V_x B_y + V_y B_x \tag{72}$$

$$p = \frac{k_{\mathrm{B}}}{m} \rho T \tag{73}$$

磁場 B_x は既知の定数。

2.16　サブルーチン cip_m3_g；3 成分 MHD 重力

$$\frac{\partial \rho}{\partial t} + V_x \frac{\partial \rho}{\partial x} = -\rho \frac{\partial V_x}{\partial x} \tag{74}$$

$$\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - \frac{1}{4\pi\rho}\left(B_y \frac{\partial B_y}{\partial x} + B_z \frac{\partial B_z}{\partial x}\right) + g_x \tag{75}$$

$$\frac{\partial V_y}{\partial t} + V_x \frac{\partial V_y}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_y}{\partial x} + g_y \tag{76}$$

$$\frac{\partial V_z}{\partial t} + V_x \frac{\partial V_z}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_z}{\partial x} + g_z \tag{77}$$

$$\frac{\partial T}{\partial t} + V_x \frac{\partial T}{\partial x} = -(\gamma - 1) T \frac{\partial V_x}{\partial x} \tag{78}$$

$$\frac{\partial B_y}{\partial t} = \frac{\partial E_z}{\partial x} \tag{79}$$

$$\frac{\partial B_z}{\partial t} = -\frac{\partial E_y}{\partial x} \tag{80}$$

$$E_y = -V_z B_x + V_x B_z, \quad E_z = -V_x B_y + V_y B_x \tag{81}$$

$$p = \frac{k_{\mathrm{B}}}{m} \rho T \tag{82}$$

磁場 B_x は既知の定数。

2.17 サブルーチン cip_m3_c；3 成分 MHD 非一様断面

$$\frac{\partial \rho}{\partial t} + V_x \frac{\partial \rho}{\partial x} = -\frac{\rho}{S}\frac{\partial (V_x S)}{\partial x} \tag{83}$$

$$\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - \frac{1}{4\pi\rho}\left(B_y \frac{\partial B_y}{\partial x} + B_z \frac{\partial B_z}{\partial x}\right) \tag{84}$$

$$\frac{\partial V_y}{\partial t} + V_x \frac{\partial V_y}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_y}{\partial x} \tag{85}$$

$$\frac{\partial V_z}{\partial t} + V_x \frac{\partial V_z}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_z}{\partial x} \tag{86}$$

$$\frac{\partial T}{\partial t} + V_x \frac{\partial T}{\partial x} = -(\gamma - 1)\frac{T}{S}\frac{\partial (V_x S)}{\partial x} \tag{87}$$

$$\frac{\partial (B_y S)}{\partial t} = \frac{\partial (E_z S)}{\partial x} \tag{88}$$

$$\frac{\partial (B_z S)}{\partial t} = -\frac{\partial (E_y S)}{\partial x} \tag{89}$$

$$E_y = -V_z B_x + V_x B_z, \quad E_z = -V_x B_y + V_y B_x \tag{90}$$

$$p = \frac{k_{\mathrm{B}}}{m}\rho T \tag{91}$$

磁場 B_x は既知の定数。

2.18 サブルーチン cip_m_cg；3 成分 MHD 非一様断面重力

$$\frac{\partial \rho}{\partial t} + V_x \frac{\partial \rho}{\partial x} = -\frac{\rho}{S}\frac{\partial (V_x S)}{\partial x} \tag{92}$$

$$\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - \frac{1}{4\pi\rho}\left(B_y \frac{\partial B_y}{\partial x} + B_z \frac{\partial B_z}{\partial x}\right) + g_x \tag{93}$$

$$\frac{\partial V_y}{\partial t} + V_x \frac{\partial V_y}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_y}{\partial x} + g_y \tag{94}$$

$$\frac{\partial V_z}{\partial t} + V_x \frac{\partial V_z}{\partial x} = \frac{1}{4\pi\rho} B_x \frac{\partial B_z}{\partial x} + g_z \tag{95}$$

$$\frac{\partial T}{\partial t} + V_x \frac{\partial T}{\partial x} = -(\gamma - 1)\frac{T}{S}\frac{\partial (V_x S)}{\partial x} \tag{96}$$

$$\frac{\partial (B_y S)}{\partial t} = \frac{\partial (E_z S)}{\partial x} \tag{97}$$

$$\frac{\partial (B_z S)}{\partial t} = -\frac{\partial (E_y S)}{\partial x} \tag{98}$$

$$E_y = -V_z B_x + V_x B_z, \quad E_z = -V_x B_y + V_y B_x \tag{99}$$

$$p = \frac{k_{\mathrm{B}}}{m}\rho T \tag{100}$$

磁場 B_x は既知の定数。