MHD Shock Wave Structure in Supersonic Mag. Reconnection

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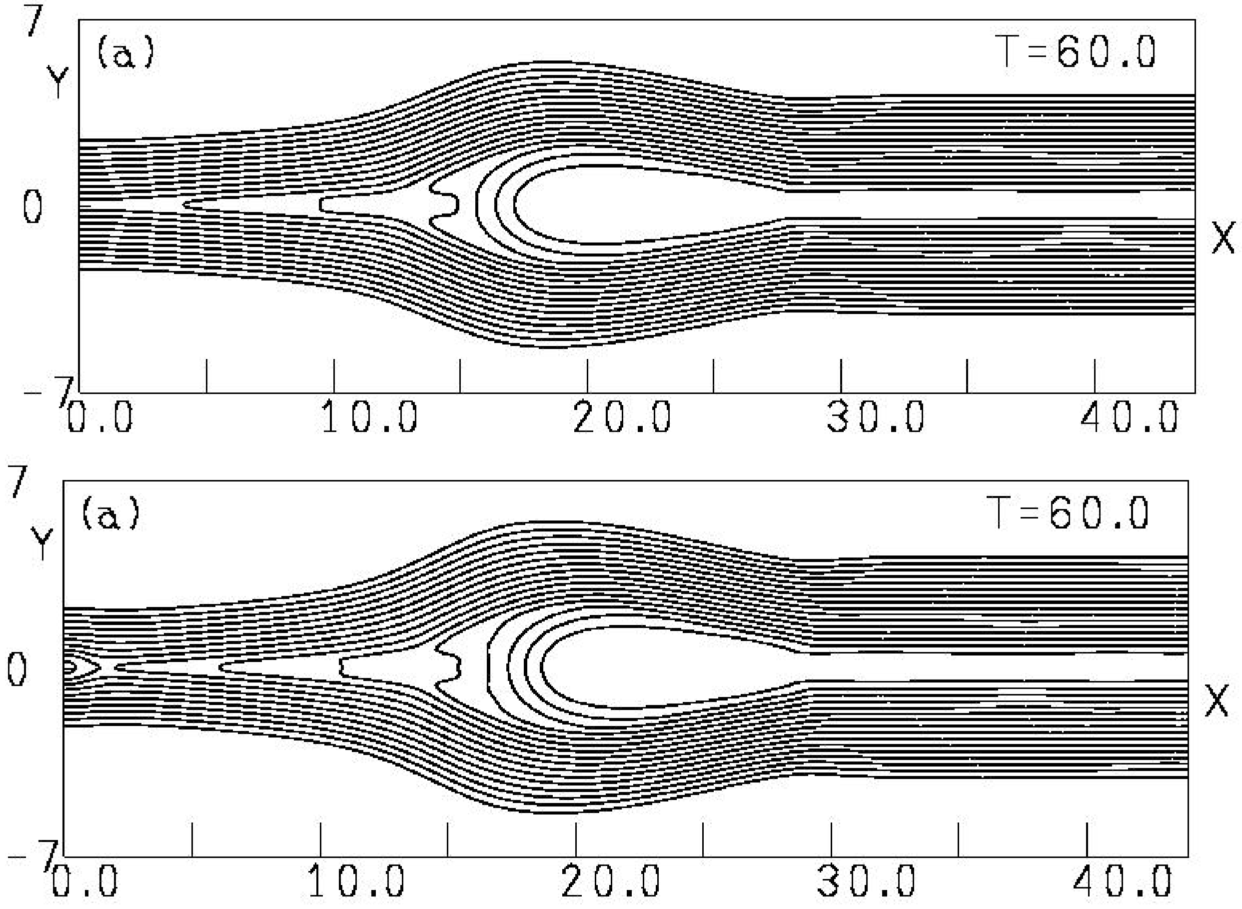
Contents

- **Application of the "Rankine Hugoniot" relation**
to MHD shocks in "superfast" magnetic reconnection.

- **Theoretical estimation of**
"Mach Number" of Rec. jet and
"Plasmoid Propagation Speed".
Then, comparison with MHD simulations.

- **Summary**

MHD simulations: β value =0.15 and 0.01 (upstream)



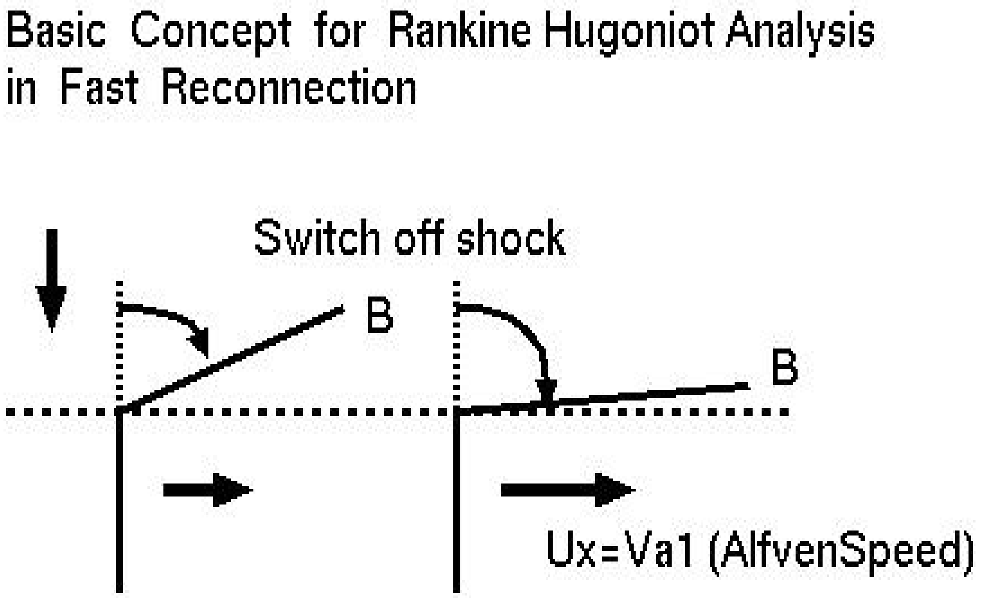
There is no significant difference. ➔ Why?

How is the plasmoid formed ?

How is the plasmoid propagation speed controlled ? …… etc.

<Petschek Reconnection Model>

Reconnection jet can reach the ”Alfven Speed” measured in the upstream region via the “switch off shock acceleration”.



90deg Angle limit ➔ (Convergence) ➔ “Jet speed”, Plasma Temperature and hence “Sound Mach number” can be predicted.

(But, note that the β value in the downstream goes to infinity.)

If the β value in the upstream is given, we can estimate the reconnection jet.

1: Sound (=~Fast wave) Mach number

$$Ms_2 = \sqrt{2/(2\beta + 1)}$$

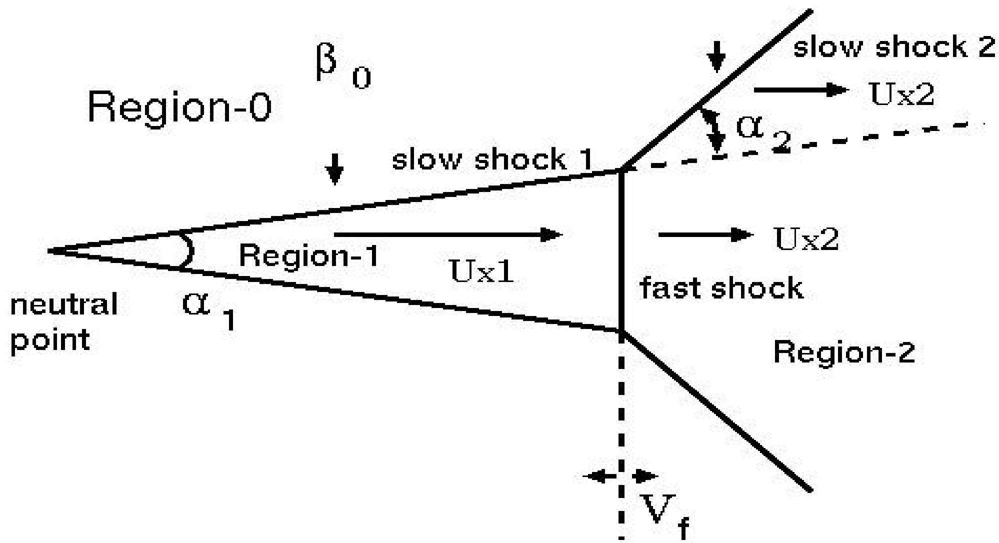
2: Plasma Temperature (ratio)

$$Cs_1 / Cs_2 = \sqrt{2\beta / (2\beta + 1)}$$

This story has been published in T.Shimizu, Phys. Plasmas 2003, including the asymmetric case study.

Plasmoid formation (and propagation) ➔ the slow shock is divided into two regions (i.e. the rec. jet region and plasmoid region).

T.Shimizu,Phys. Plasmas,2003

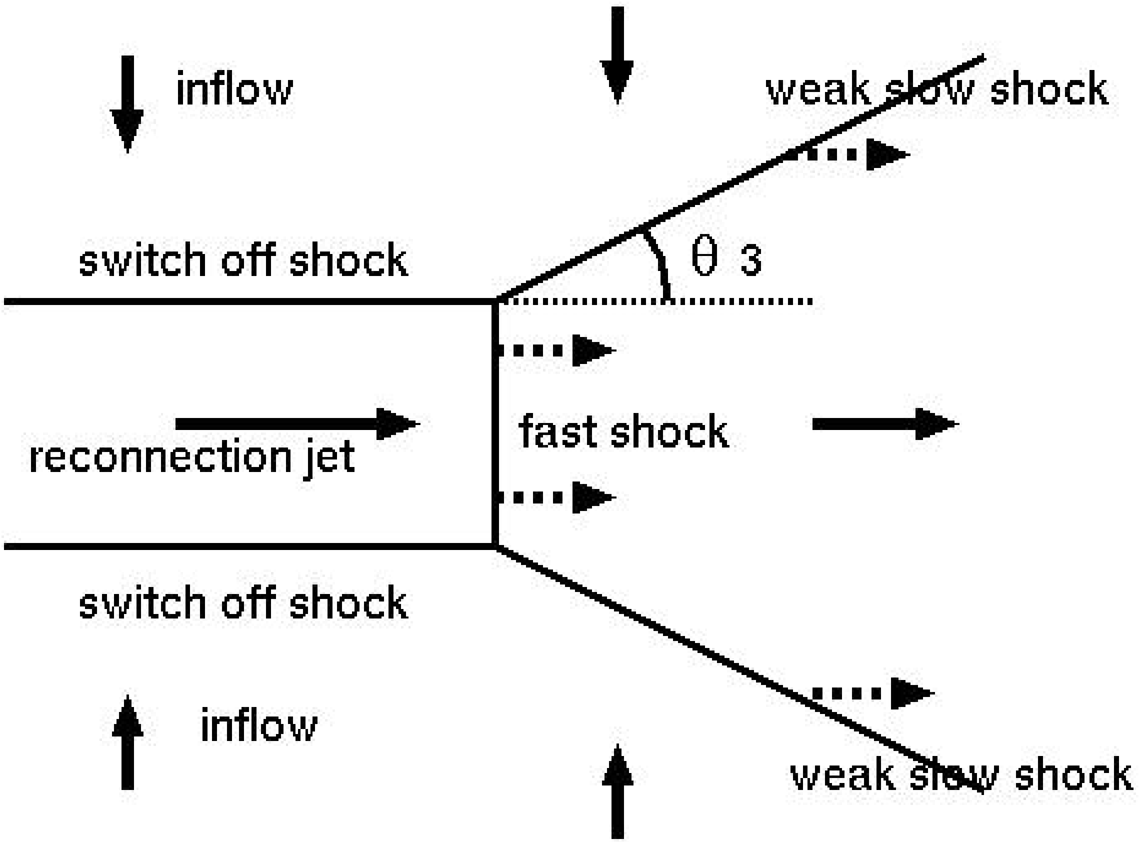


V_f : fast shock propagation speed

$\alpha_{1,2}$: separatrix (change) angle

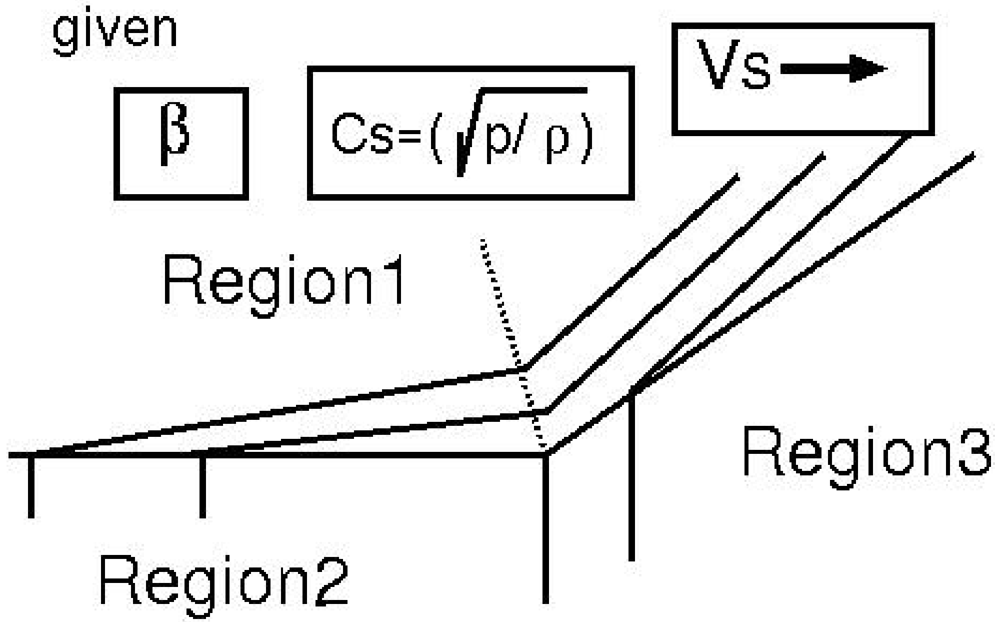
β_0 : beta value of upstream region

Simplification for Rankine Hugoniot Analysis



Let us introduce the plasmoid opening angle “theta3”.

Three upstream conditions to be given ➔ "θ_3".



< Some Assumptions >

γ =2

In Region1, β value and temperature is uniform and the inflow is almost vertical.

In Regions 2 and 3, the magnetic field line is vertical.

< MHD Shock Connection Problem >

After some manipulations with the Rankine Hugoniot relation, the next equations are derived.

Region 1➔2

$$Ms_2 = \sqrt{2/(2\beta + 1)} \quad \longleftarrow \quad \boxed{\beta,\ Cs_1}$$

$$Cs_1/Cs_2 = \sqrt{2\beta/(2\beta + 1)}$$

$$Ms_{2d} = Ms_2 - Vs/Cs_2 \quad \longleftarrow \quad \boxed{Vs}$$

Region 2➔3

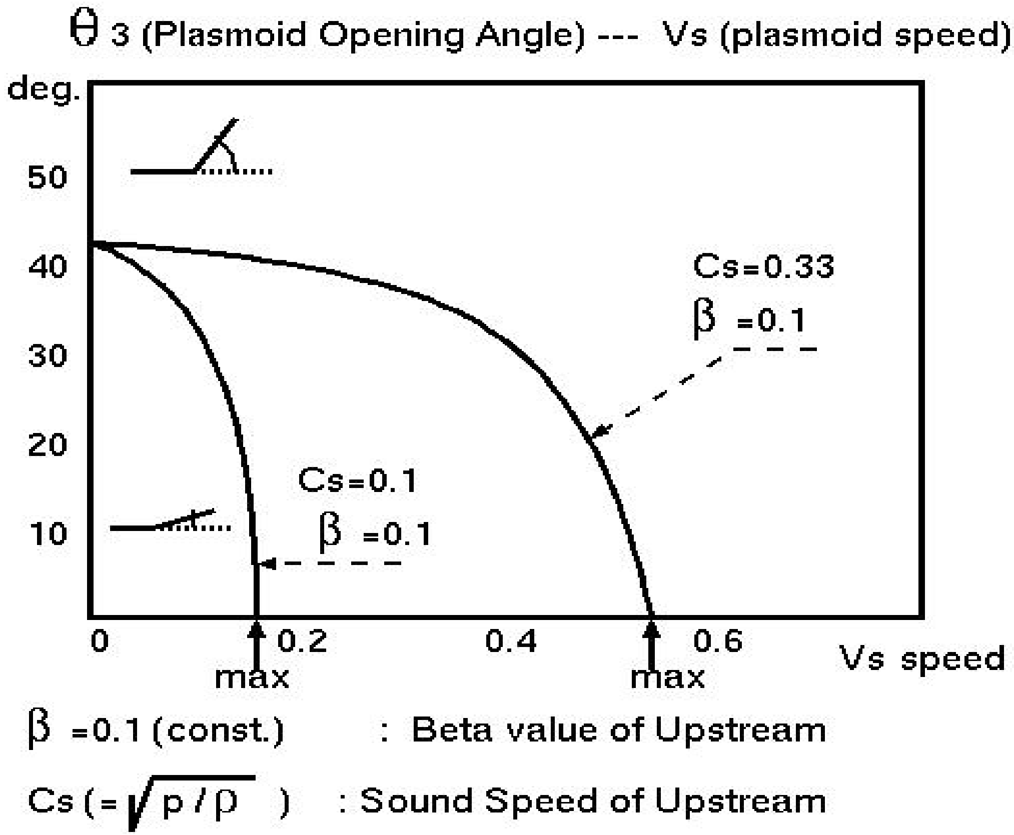
$$Ms_{3d} = \sqrt{(Ms_{2d}^2+2)/(4Ms_{2d}^2-1)}$$

$$Cs_3 = Cs_2\sqrt{(Ms_{2d}^2+2)(4Ms_{2d}^2-1)}/3/Ms_{2d}$$

Region 3➔1

$$\cos(\theta_3) = Ms_{3d}Cs_3\sqrt{\beta}/Cs_1 \quad \longrightarrow \quad \boxed{\theta 3}$$

Result 1



Constant β (=0.1)
Cs (=0.33 and 0.1)

Vs is normalized by the upstream Va in this case.

1: As the plasmoid opening angle θ 3 is narrower,

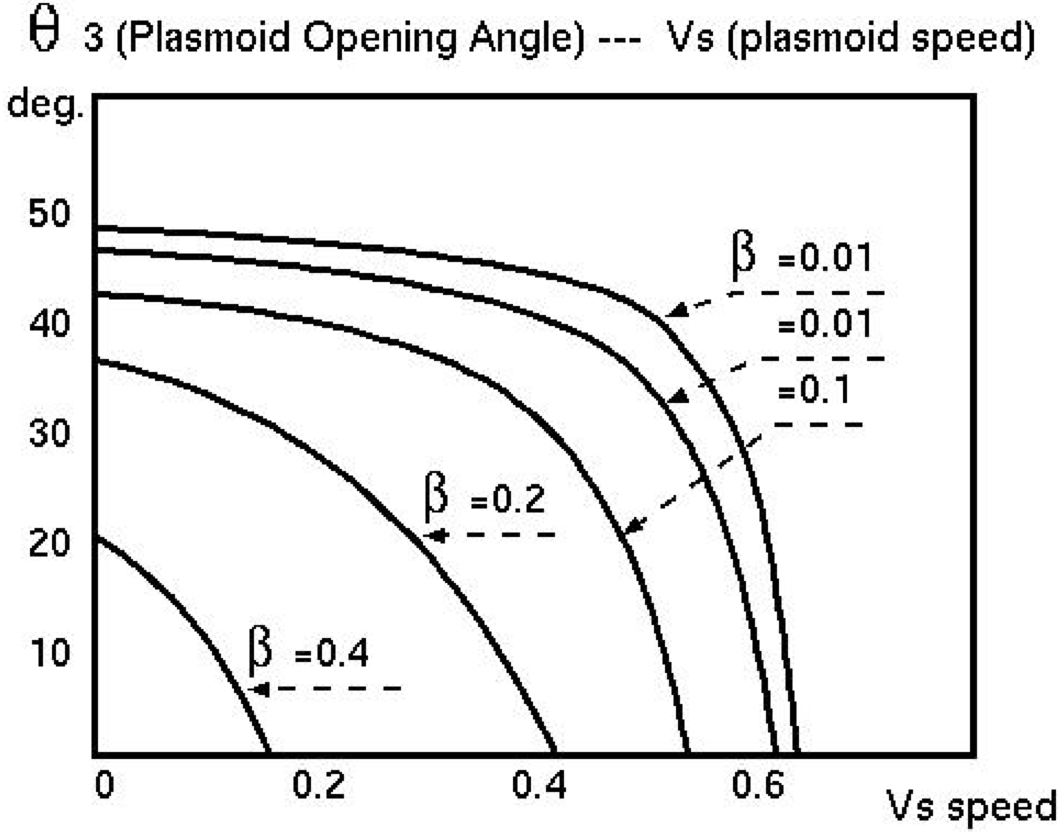
OR

2: As the temperature (Cs^2) in upstream is higher,

➔ the plasmoid speed "Vs" is faster.

3: There is a max speed for a set of β and Cs values.

Result 2



. β value (=0.001~0.4)

Vs is normalized by the upstream Va

β : Beta value of Upstream Field Region

Cs(= p / ρ) is assumed to be proportional to $\sqrt{\beta}$

As the β value (in upstream) goes to zero,
the plasmoid speed increases and also
the plasmoid opening angle tends to increase.

However, β =0.1 and 0.01 are not so different.

Conclusions

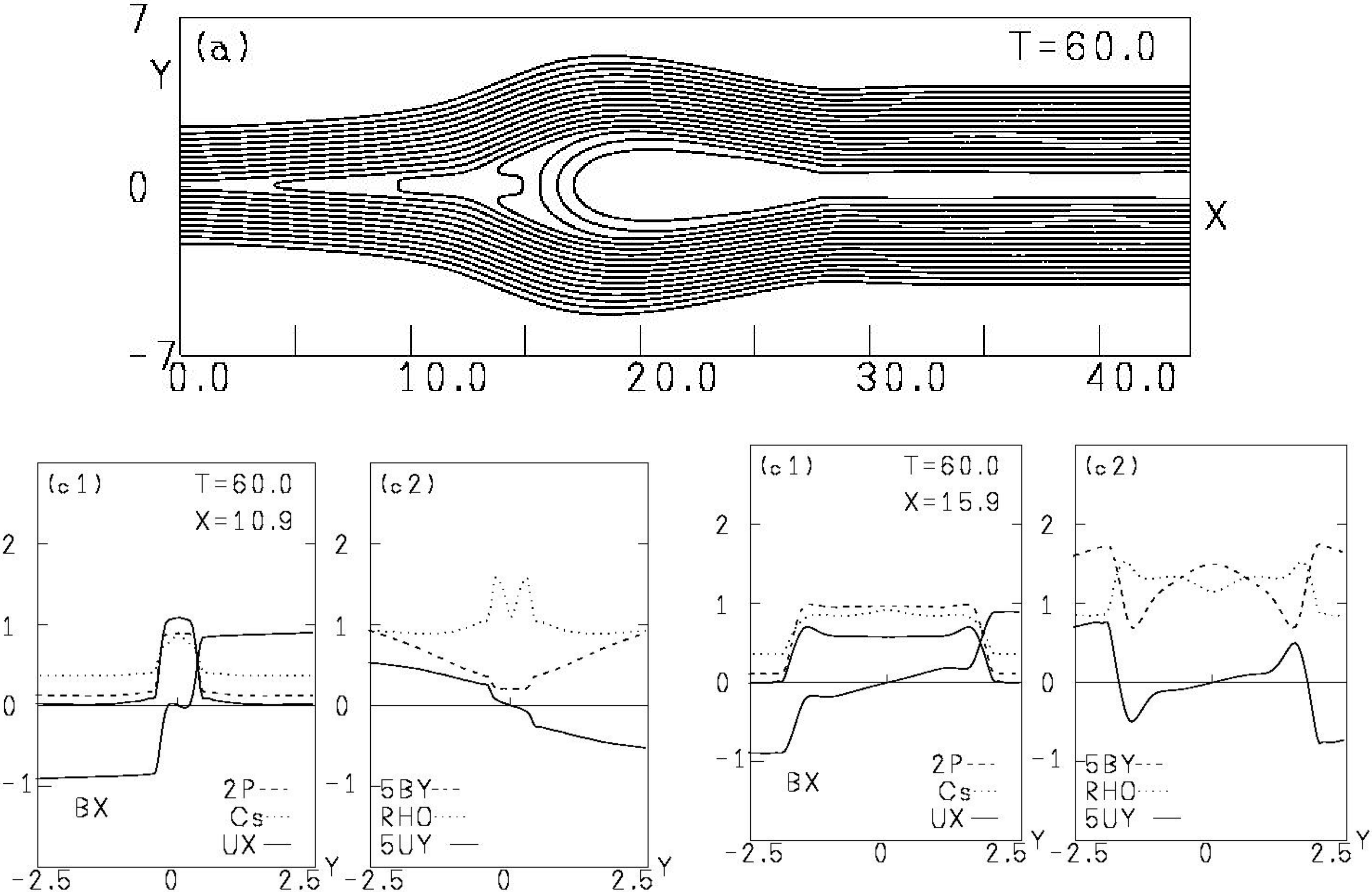
“Plasmoid propagation speed Vs”
is related to “plasmoid opening angle θ_3”

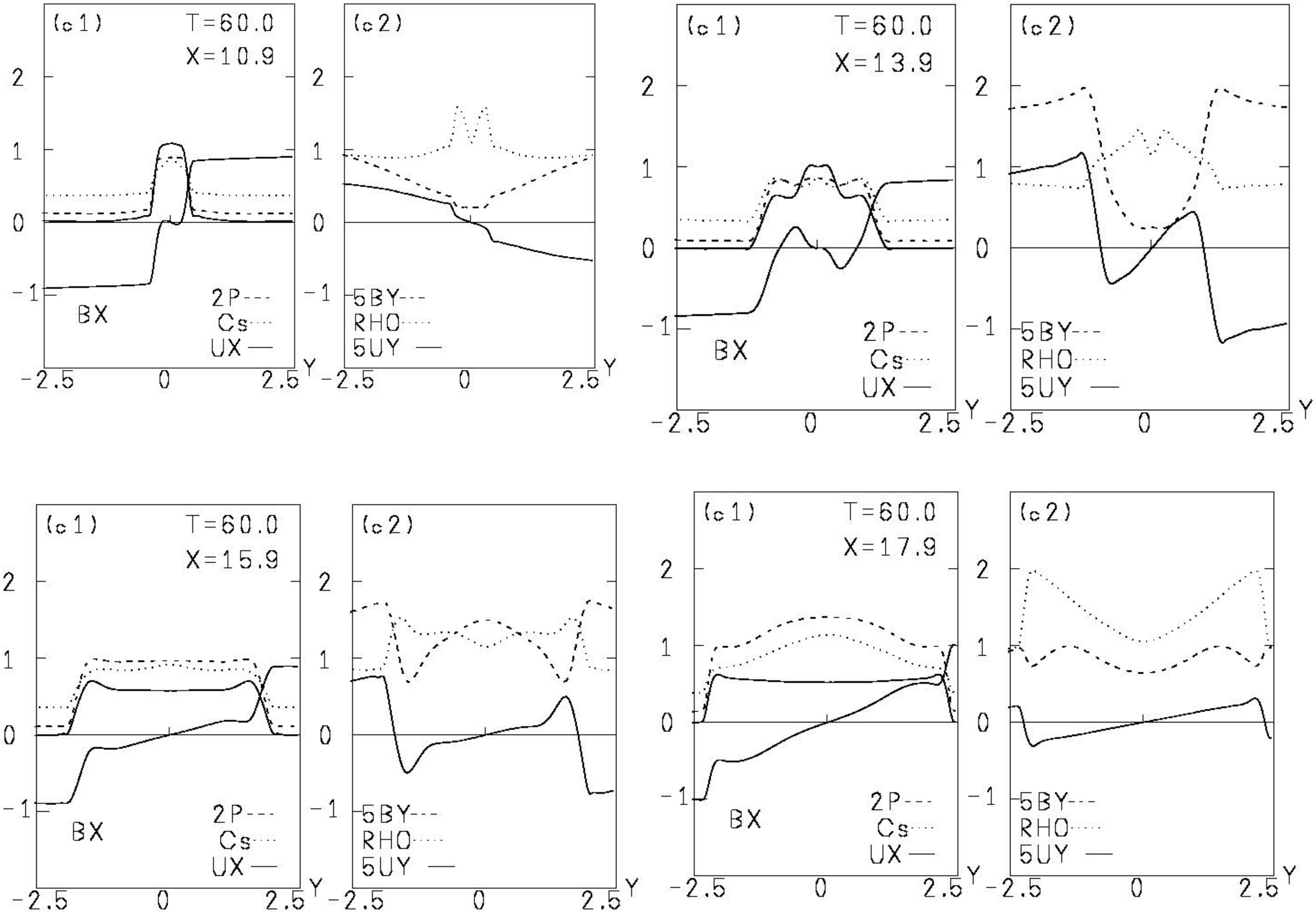
through the “ β value” and “temperature” in upstream region.

- **This result is consistent with MHD simulations, excepting around the super-subsonic transition regime.**

< Future works >

How is the “supersonic adiabatic expansion accel.” (T.Shimizu, Phys.Plasmas 2001) adapted in this model ?) In addition, we must consider the other theory for “subsonic” reconnection.


(a)
T=60.0
Y
X
7
0
-7
0.0
10.0
20.0
30.0
40.0
(c1)
T=60.0
X=10.9
2
1
0
-1
BX
2P
Cs
UX
-2.5
0
2.5
Y
(c2)
5BY
RHO
5UY
(c1)
T=60.0
X=15.9
BX
2P
Cs
UX
(c2)
5BY
RHO
5UY



(c1)
T=60.0
X=10.9
BX
2P---
Cs······
UX —
(c2)
5BY---
RHO······
5UY —
(c1)
T=60.0
X=13.9
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(c1)
T=60.0
X=15.9
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T=60.0
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