Flow Reversal in Spinning Detonation

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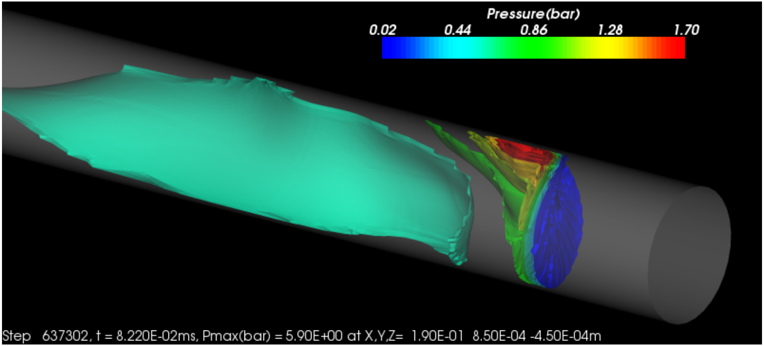
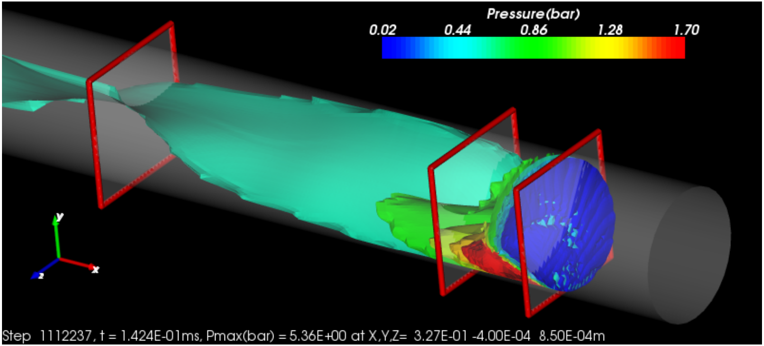
Outline

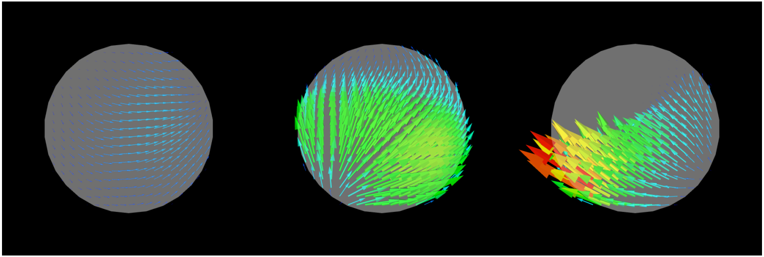
Flow Reversal in Spinning Detonation



The spinning sense of the detonation is not known a priori.
In these simulations, the triple point spins in clockwise direction.

Flow Reversal in Spinning Detonation





Outline

Main Assumptions

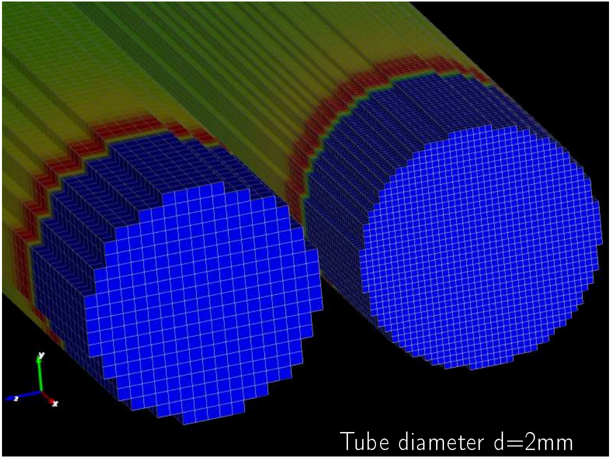
Euler Equations + Global Chemical Kinetic Law $A \longrightarrow B$

$$\begin{cases} \frac{\partial \rho}{\partial t} + div(\rho \overrightarrow{V}) = 0 \\ \frac{\partial \overrightarrow{V}}{\partial t} + \overrightarrow{V}.\overrightarrow{grad}\,\overrightarrow{V} = -\frac{1}{\rho}\overrightarrow{grad}\,p \\ \frac{\partial E}{\partial t} + div\left(E\overrightarrow{V} + p\overrightarrow{V}\right) = \rho Q \frac{\partial [A]}{\partial t}, \text{ with } E = \rho(e + V^2/2) \\ \frac{\partial [A]}{\partial t} + \overrightarrow{V} \cdot \overrightarrow{\nabla} A = Zp^n(1-[A])^n \exp\left(-\frac{Ea}{RT}\right) \end{cases}$$

In-house code EFAE

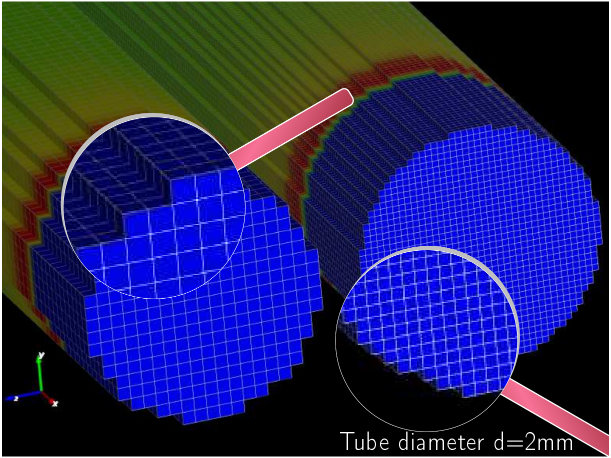
3D, Cartesian, FCT technique [Boris,Oran]

Grid and Resolution



	N_x	$N_y = N_z$	$\Delta x = \Delta y = \Delta z$
LR	1000	20	10^{-4} m
HR	2000	40	5.10^{-5} m

Grid and Resolution



	N_x	N_y=N_z	Δx=Δy=Δz
LR	1000	20	10^{-4} m
HR	2000	40	5.10^{-5} m

Flow and Simulation Properties

Gas Properties

p_0=20mbar, T_0=293K, W_M=30.3g.mol^{-1},γ=1.333

Kinetic Parameters

E_a=25kcal.mol^{-1}, n=1.1, Z=300s^{-1}.Pa^{-n}

Shock and Detonation Properties

u_{ZND}=2075.4m/s,	p_{ZND}=1.19bar,	T_{ZND}=1373K
D_{CJ}=2253.8m/s,	p_{CJ}=0.6bar,	T_{CJ}=4756K

Getting the Spinning Regime

1D simulation

Point Explosion (at x=0) → Propagation of the Detonation (up to x=0.1m)

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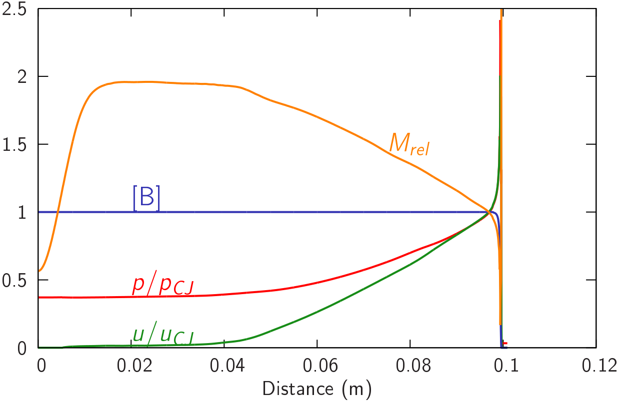
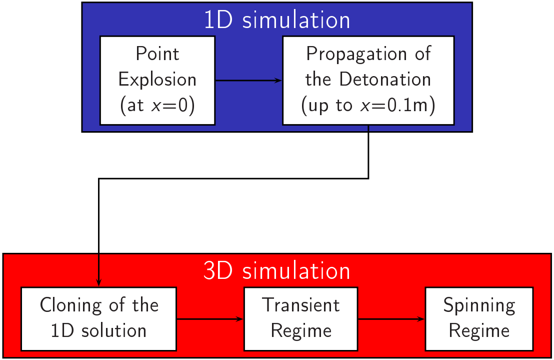
Point Explosion (at x=0) → Propagation of the Detonation (up to x=0.1m)

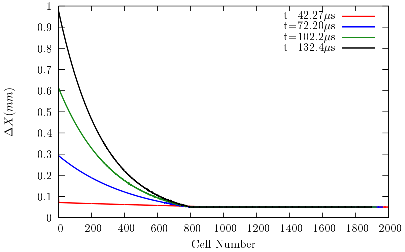


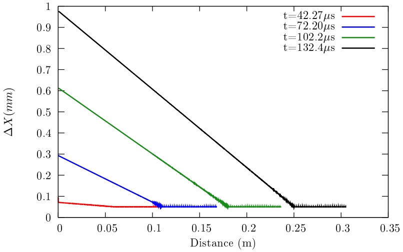
Getting the Spinning Regime



Adaptative Mesh

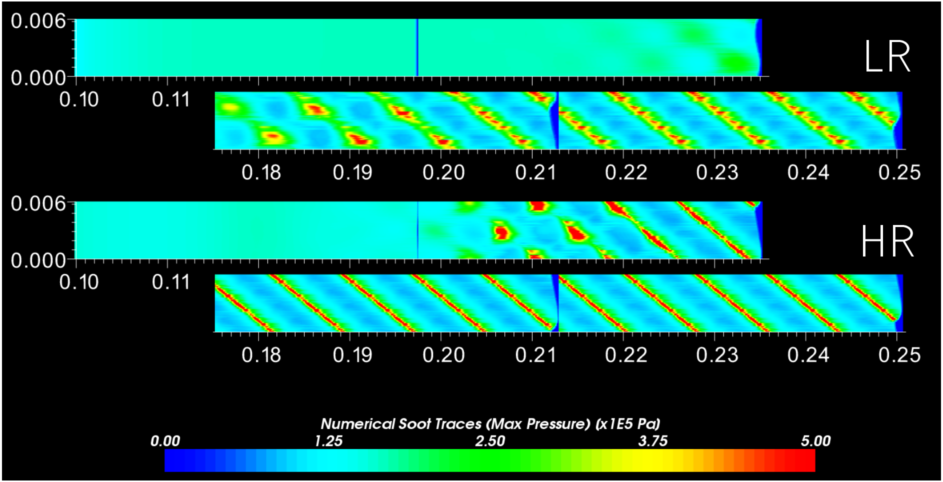
Unsupported detonation propagation : Adaptative mesh along x



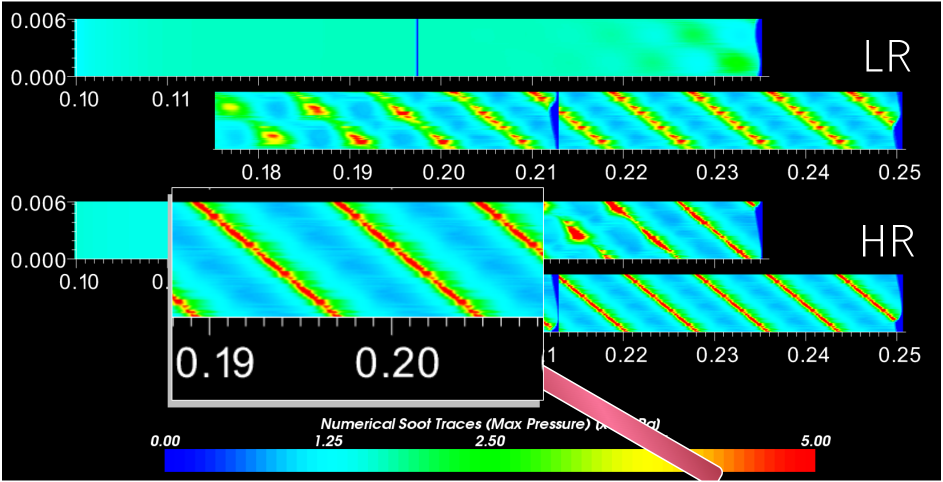


	N_x	$\Delta x = \Delta y = \Delta z$	Adapted cells	Fixed res. length
LR	1000	10^{-4} m	500	50mm
HR	2000	5.10^{-5} m	1000	50mm

Grid Sensitivity



Grid Sensitivity



Angle=46–48° , Pitch=8.75–7.8mm (LR–HR)

Outline

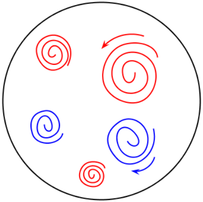
Local Spin

Vorticity ($\overrightarrow{\omega} = \overrightarrow{rot}\,\overrightarrow{V}$) is a mathematical concept used in fluid dynamics to characterize the amount of local rotation.

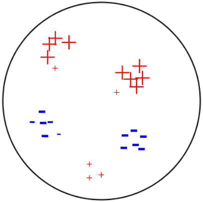
We will focus on longitudinal (x) component :

$$\omega_x = \overrightarrow{\omega} \cdot \overrightarrow{x} = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}$$

In a X-cross section ω_x describes local spin

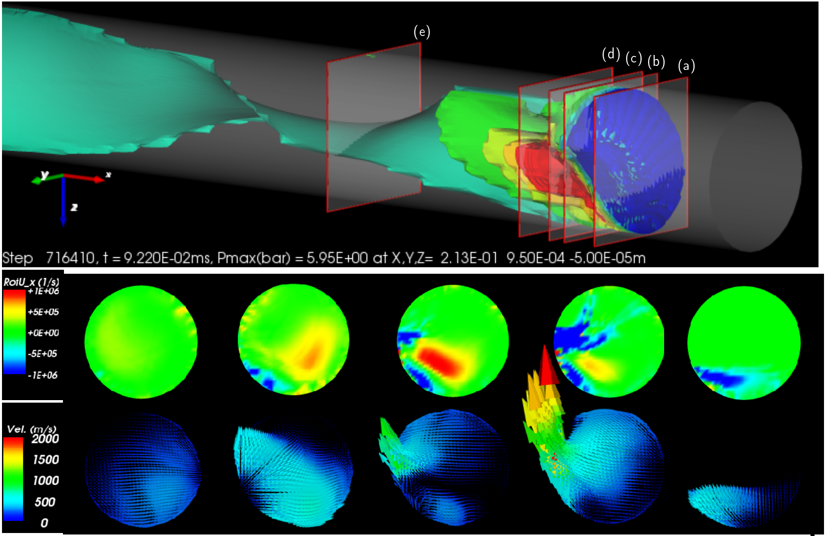


Velocity field



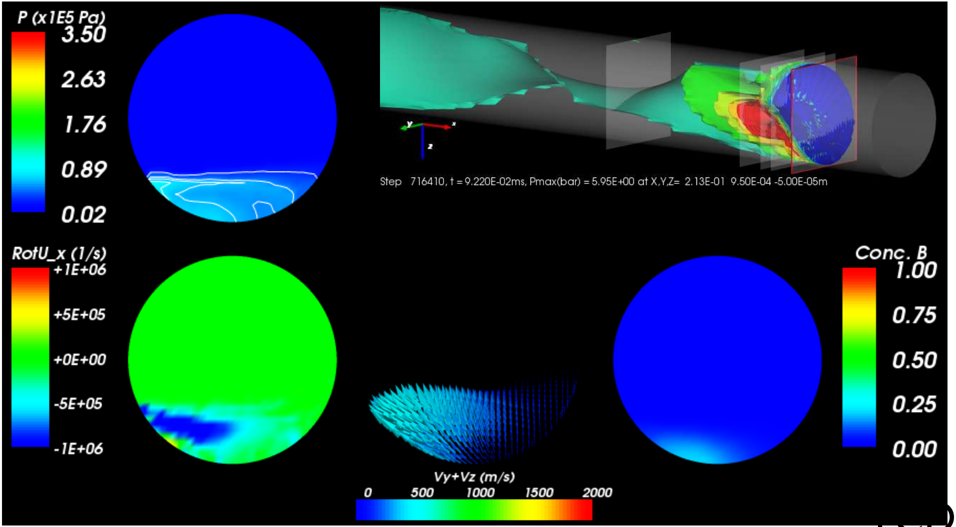
Vorticity field

Local Spin

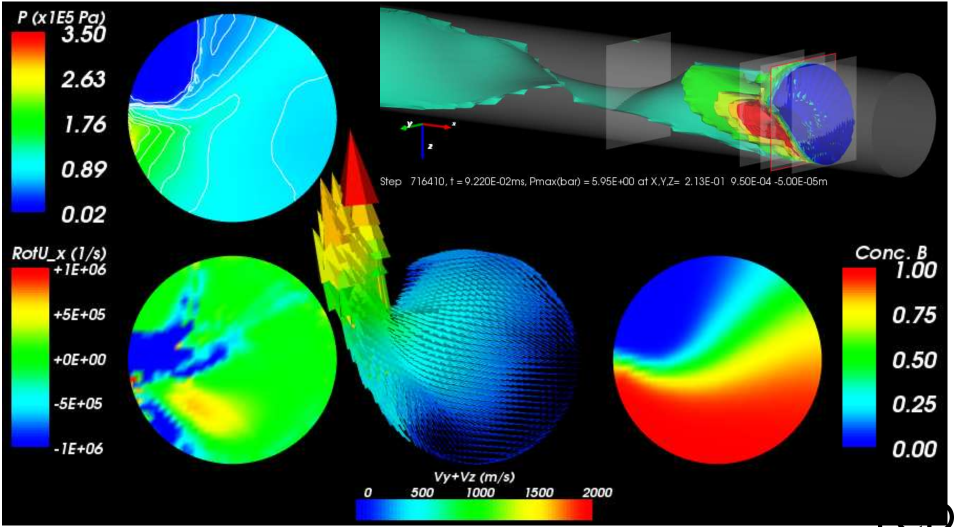


(e) x=208.924mm (d) x=212.126mm (c) x=212.626mm (b) x=212.876mm (a) x=213.377mm

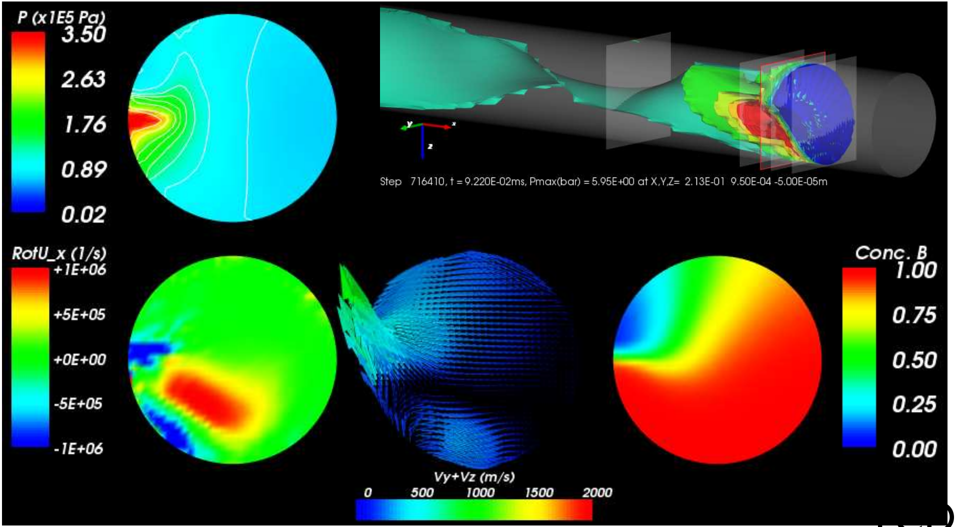
Local Spin - Details at x=213.377mm (a)



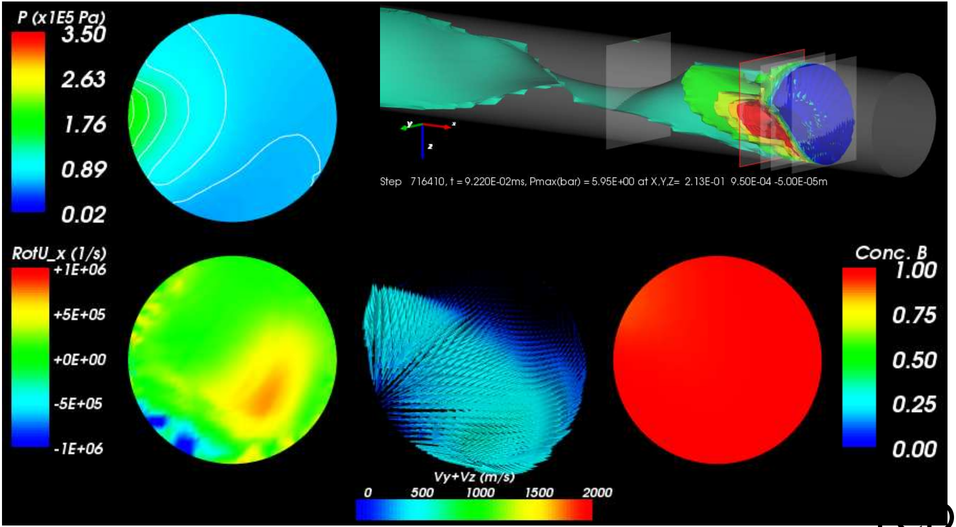
Local Spin - Details at x=212.876mm (b)



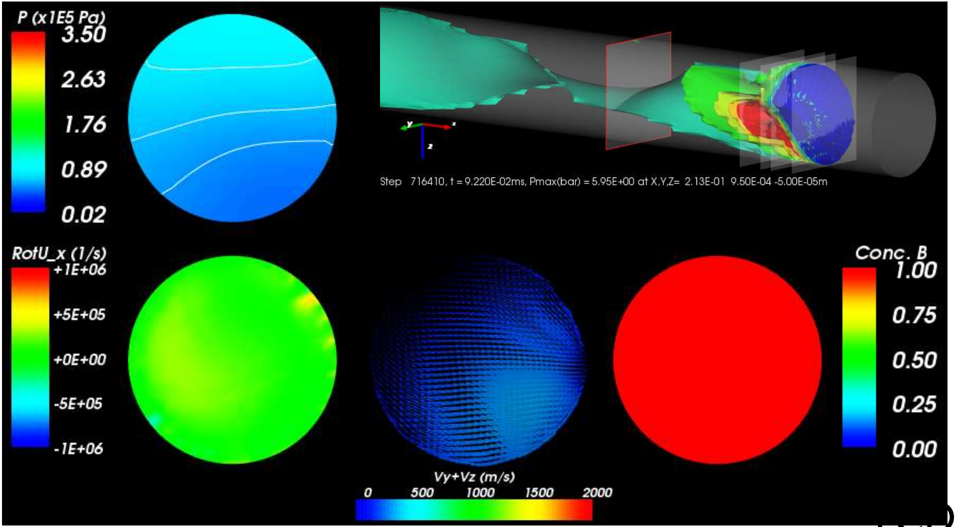
Local Spin - Details at x=212.626mm (c)



Local Spin - Details at x=213.126mm (d)

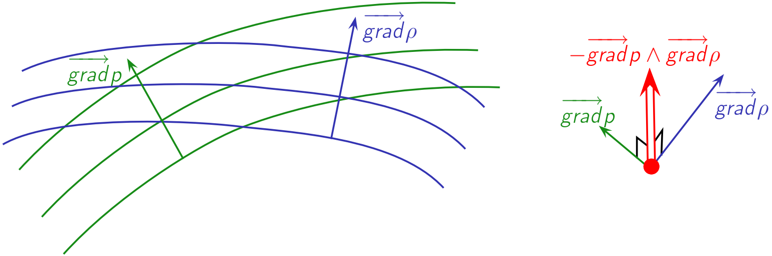


Local Spin - Details at x=208.924mm (e)



Source of Vorticity

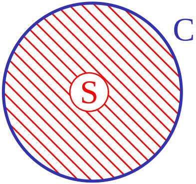
In inviscid flow, the only source of vorticity is
Baroclinic Torque $\overrightarrow{B} = -\frac{1}{\rho^2}\overrightarrow{grad}\,p \wedge \overrightarrow{grad}\,\rho$



- When the lines of iso-p and iso-ρ cross each other, baroclinic torque $B_x \neq 0$
- For isentropic flow, when the lines of iso-p and iso-ρ do not cross each other, baroclinic torque B_x=0

Global Spin on the surface S (X-Cross Section)

Circulation $\Gamma = \oiint_S \overrightarrow{rot}\,\overrightarrow{u} \cdot \overrightarrow{dS} = \oiint_S \omega_x dS = \oint_C \overrightarrow{V} \cdot \overrightarrow{dl}$ represents the overall spin in X-cross section.

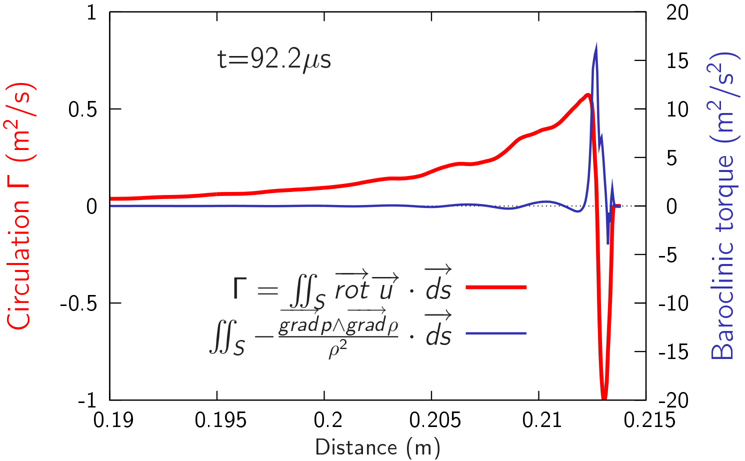


(Bjerkness theorem)

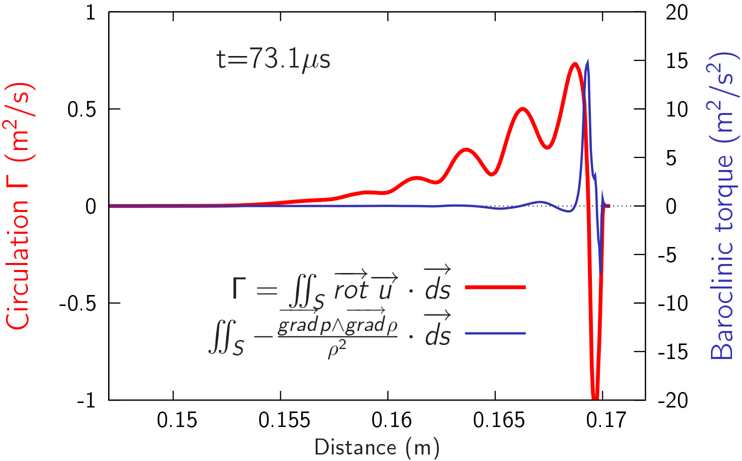
$$\frac{D\Gamma}{Dt} = -\oiint_S \frac{1}{\rho^2}\overrightarrow{grad}\,p \wedge \overrightarrow{grad}\,\rho\overrightarrow{dS} = -\oint_C \frac{1}{\rho}\overrightarrow{grad}\,p \cdot \overrightarrow{dl}$$

The rate of change of circulation is equal to the sum of all sources within the surface.

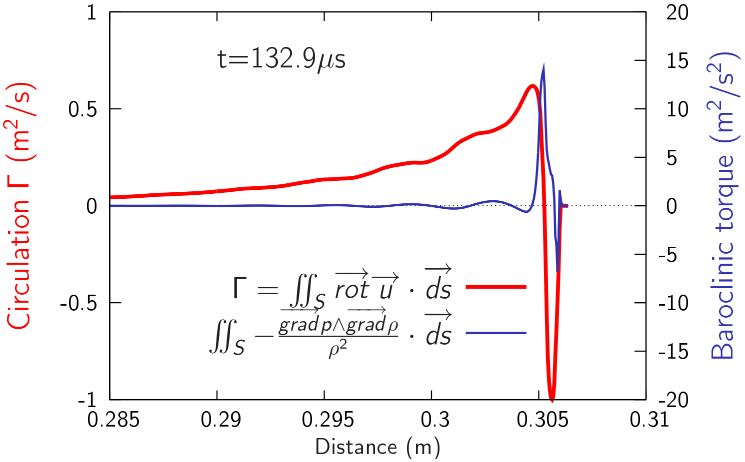
Global Spin on the surface S (X-Cross Section)



Global Spin on the surface S (X-Cross Section)



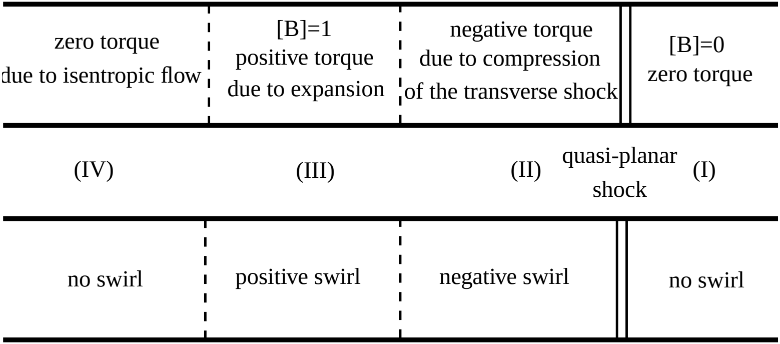
Global Spin on the surface S (X-Cross Section)



Outline

Conclusion

7^{th} ISHPMIE – Flow Reversal in Spinning Detonation



Signs are given for detonations spinning in clockwise direction.
If the detonation is spinning in counterclockwise direction, we have to take the opposite signs.

Conclusion

7^{th} ISHPMIE – Flow Reversal in Spinning Detonation

Thank you for your attention.

Conclusion

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Questions ?