A Numerical Study of Shocked a Gas Cylinders

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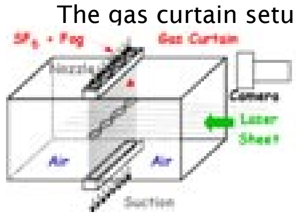
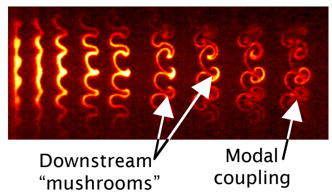
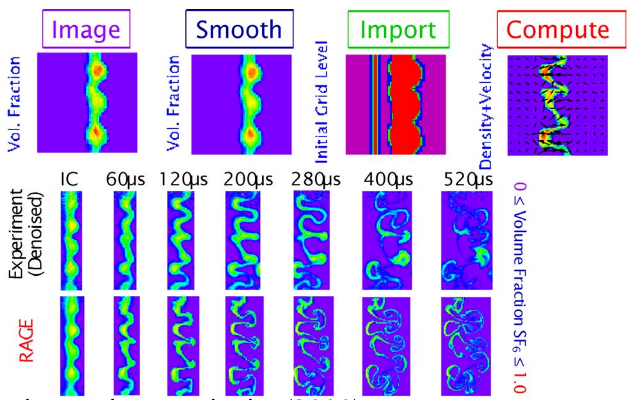
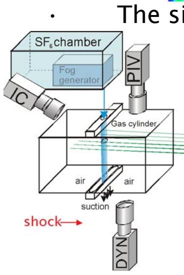
- The gas curtain setup (1997)

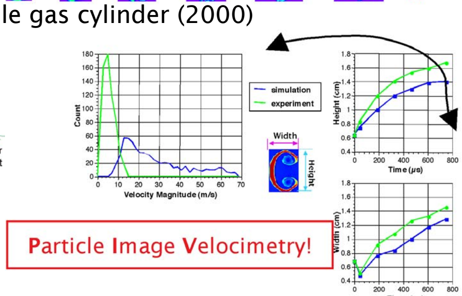






- The single gas cylinder (2000)

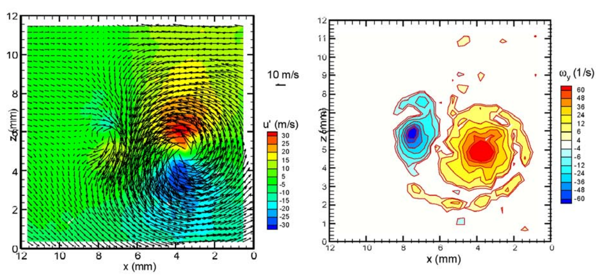




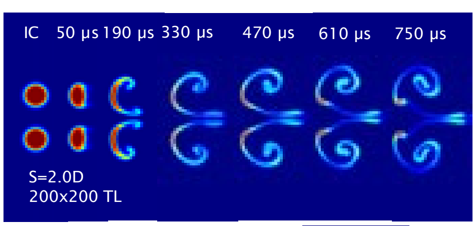
Initial PIV shows 5:1 difference in velocities between the experiment and calculation.

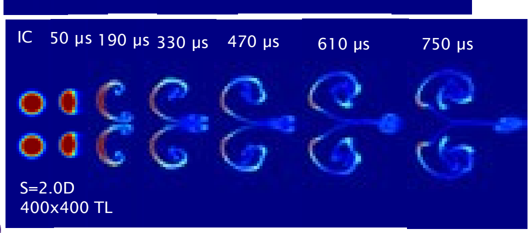
The integral scales also do not match!

- The double gas cylinder (2001)



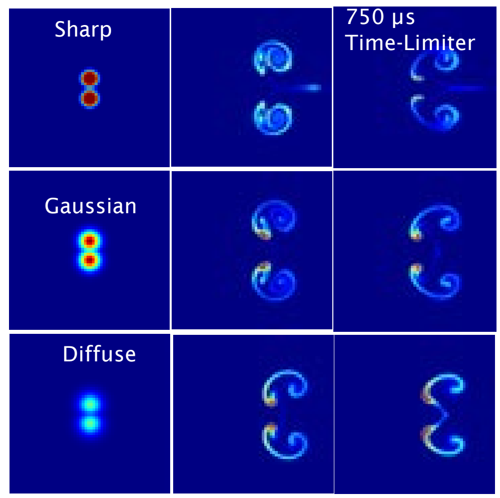
New PIV shows 5:3difference in velocities between the experiment and calculation. The air and SF6 have both been seeded giving the complete velocity field.





In general the results are not as variable with S as the experiments. This related to the strength of the inner vortices. The TL method does show less jetting and greater qualitative similarity than the standard MUSCL type scheme.

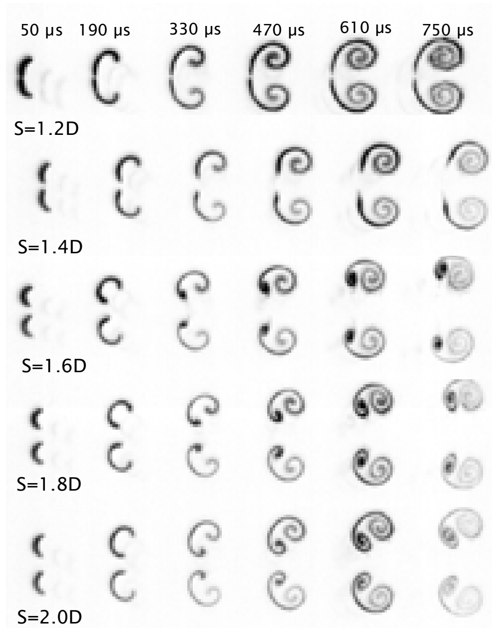
Double Cylinder Experiment ICs



The initial conditions have not been imaged for the double cylinder. Here, we test various initial conditions with two schemes, the standard method and a modified method. With a sharper IC and the modified scheme, the most consistent results are found.

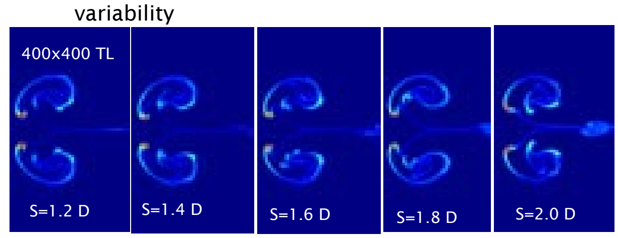
Double Cylinder Experiments

The behavior of the cylinders shows considerable variation with spacing with a spacing of 1.5 D being a critical value in the behavior.

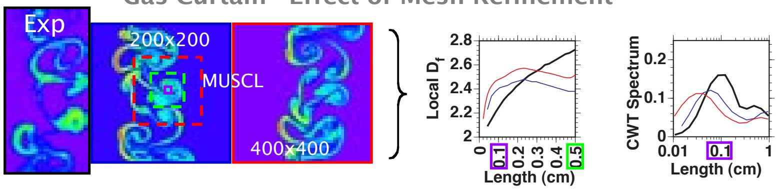


Double Cylinder Simulations

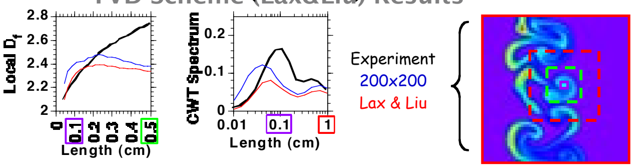
The simulations do not show the experimental variability



Gas Curtain - Effect of Mesh Refinement

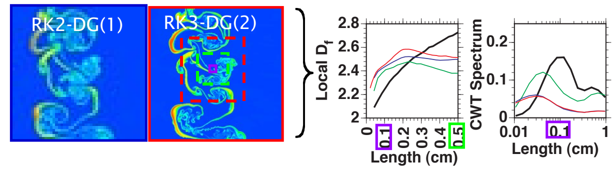


TVD Scheme (Lax&Liu) Results

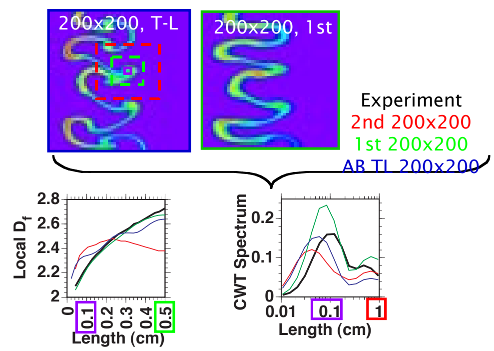


All standard modern schemes tested (MUSCL, WENO, PPM, TVD,…showed similar results. All results with these schemes were not consistent with the scaling exhibited by the experimental data. Mesh refinement does not provide improved results, but first-order methods show more consistent scaling (below). We also show a modified method (time-limiter) that has second-order accuracy while providing scaling consistent with the experimental data.

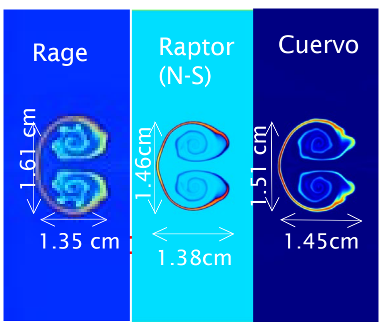
Discontinuous Galerkin Results

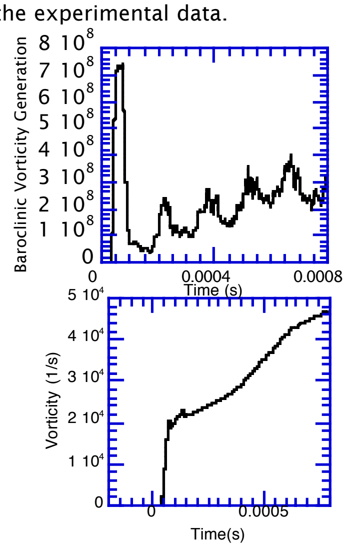


New Time Limiter Results



Ideal Gas Cylinder - 750 µs





Numerical Method

- Solves conservation equations

$$U_t + F(U)_x + G(U)_y = 0$$

for the variables $U = [\rho, \rho u, \rho v, \rho E]^T$
and flux $F(U) = [\rho u, \rho u^2, \rho uv, u(\rho E + p)]^T$
with $p = p(\rho, e)$, $E = e + (u^2 + v^2)/2$

- Eq'ns are cast in "primitive" form for parts of the numerics and analysis:

$$V_t + A V_x + B V_y = 0$$

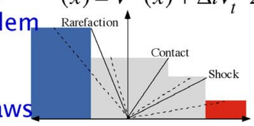
$$A \equiv \partial F/\partial V \quad B \equiv \partial G/\partial V \quad V \equiv [\rho, u, v, p, \rho e]^T$$

1 Compute "limited" spatial gradients

$$V^n(x) = \bar{V}^n + \nabla V^n (\bar{x} - x)$$

2 Advance data in time $V^{n+1/2}(x) = V^n(x) + \Delta t V_t/2$

3 Solve the Riemann problem



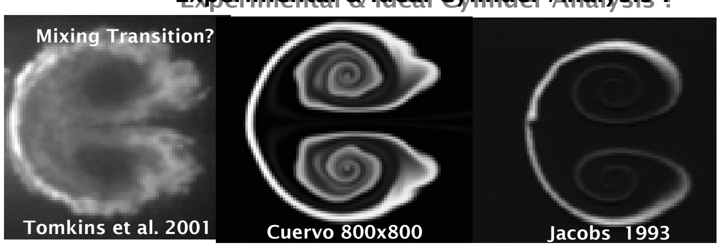
$$F(U) = R(U_-, U_+)$$

4 Advance conservation laws

$$\bar{U}_j^{n+1} = \bar{U}_j^n + \Delta t \left(F_{j+1/2}^{n+1/2} - F_{j-1/2}^{n+1/2}\right)/\Delta x$$

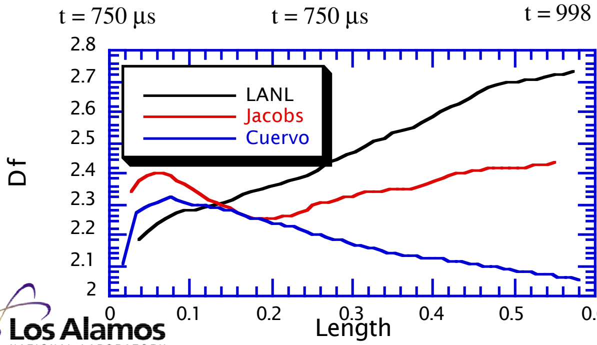
5 Update constitutive laws $p^{n+1} = p\left(\rho^{n+1}, e^{n+1}\right)$

Experimental & Ideal Cylinder Analysis ?



Tomkins et al. 2001	Cuervo 800x800	Jacobs 1993
$\tau = 9.4$, $Re \approx 24{,}000$	$\tau = 15$	$\tau = 6.3$, $Re \approx 12{,}000$
$U = 10^{-2}$ cm/µs	$U = 10^{-2}$ cm/µs	$U = 5\times10^{-3}$ cm/µs
D = 0.794 cm	D = 0.5 cm	D = 0.794 cm
t = 750 µs	t = 750 µs	t = 998 µs

$$\tau = \frac{tU}{D}$$



The results of the computations are most like Jacobs experiment, while the LANL exps. show scaling like that seen in the curtain and unlike that computed despite its long time scale.

New Time Limiter

- 2nd Order Adams-Bashforth

$$\frac{\partial V}{\partial t} = \frac{V^n - V^{n-1}}{\Delta t} \rightarrow V^{n+1/2} = V^n + \frac{\Delta t}{2}\frac{\partial V}{\partial t}$$

- Stiff ODE integrators control order dynamically $V + \Delta t V_t + C\Delta t^2 V_{tt}; C < 1$

- Use standard scheme to limit

$$\frac{\partial V}{\partial t} := \varphi \frac{\partial V}{\partial t} \text{ and } \nabla V := \varphi \nabla V, \text{ with}$$

$$\varphi = \max\left[0, \min\left(1, \frac{2\partial V/\partial t}{-A\nabla V}, \frac{-2A\nabla V}{\partial V/\partial t}\right)\right]$$