Experiments and simulations of instabilities in shock-accelerated gas cylinders

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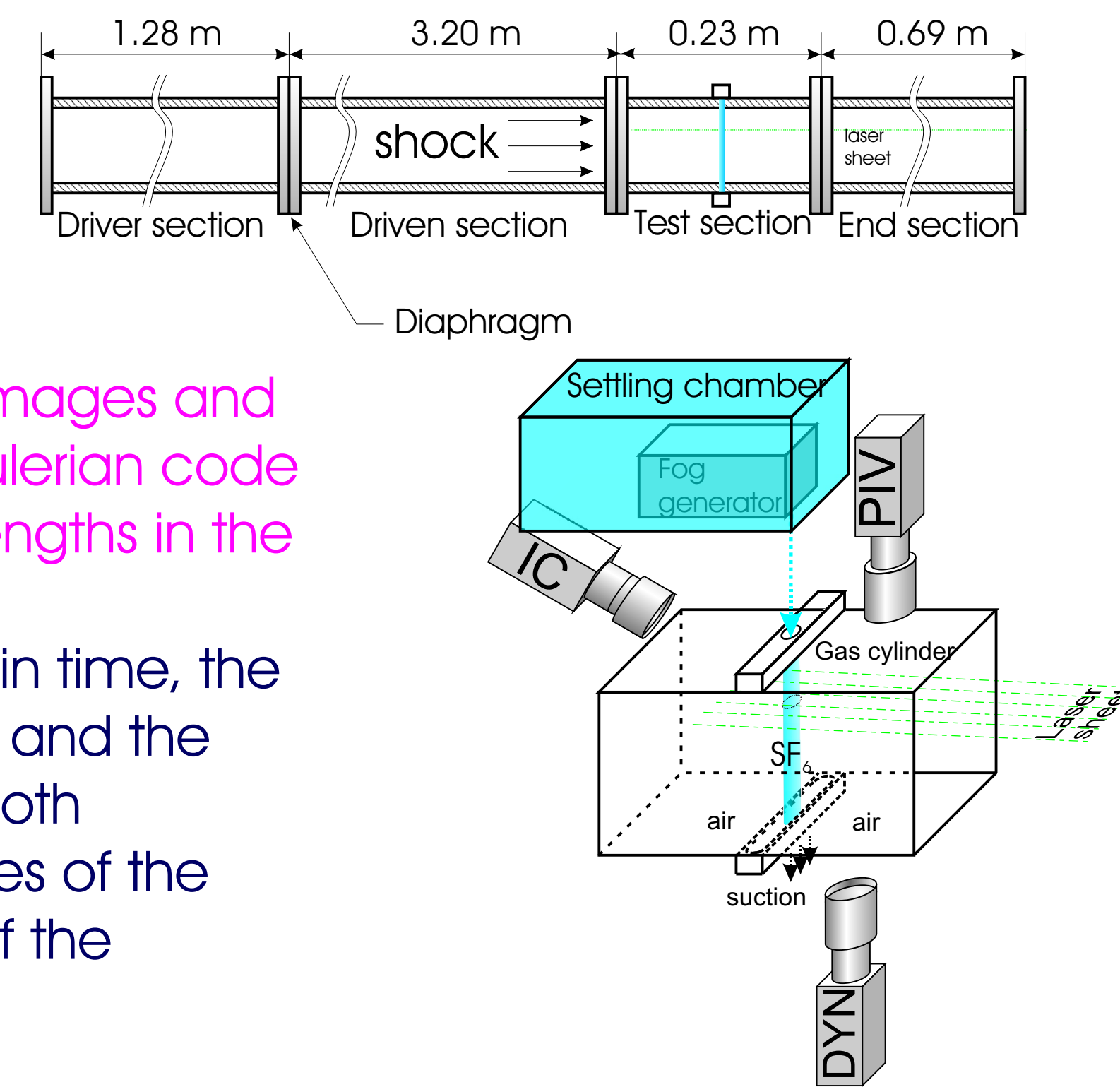
1 Los Alamos National Laboratory
2 SUNY Stony Brook
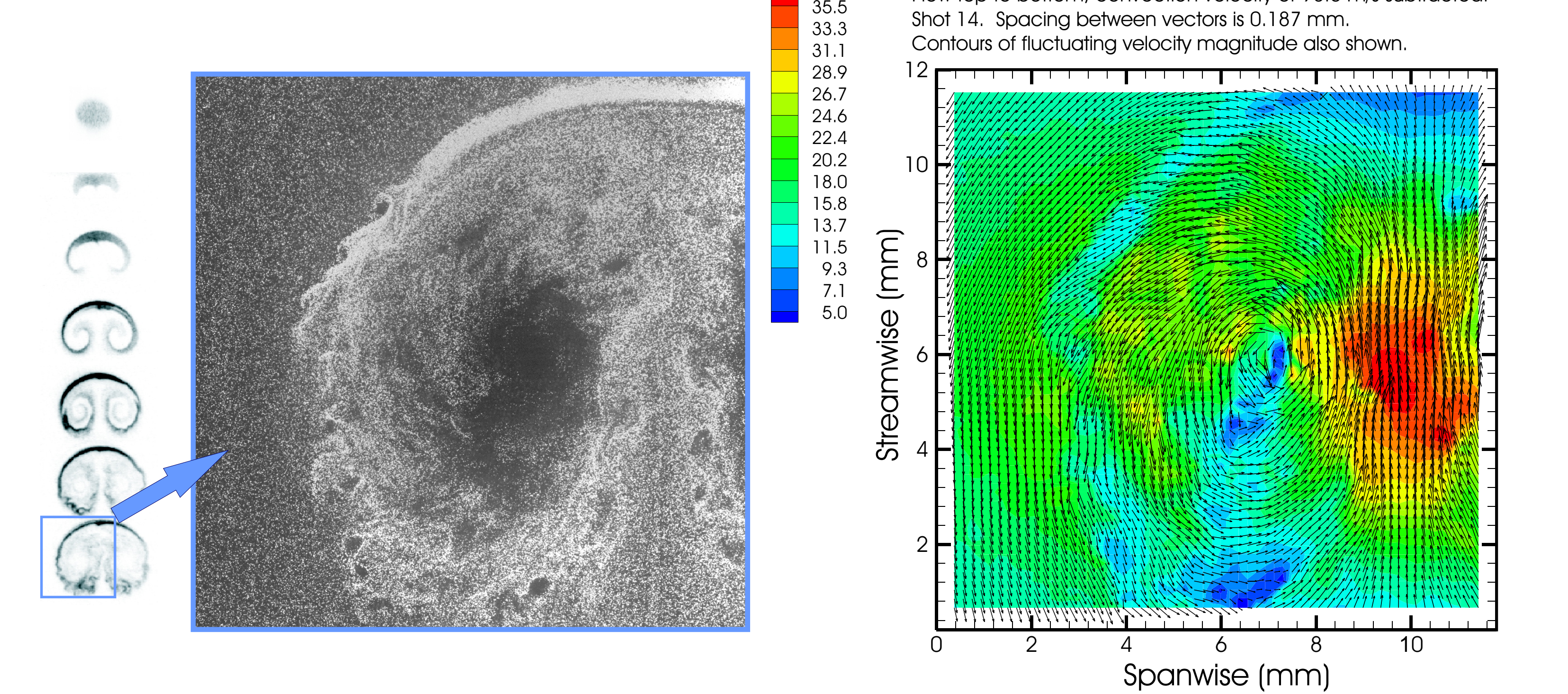3 University of New Mexico

Shock-accelerated gas cylinder

- Comparison between experimental density-field images and density-field images from a 2-D adaptive-mesh Eulerian code simulation reveal that the simulation has smaller lengths in the spanwise and streamwise directions.
- When velocity fields are compared at one instant in time, the higher magnitudes appear in the backflow region and the lower magnitudes appear in the vortex cores for both experiment and simulation. The overall magnitudes of the velocities in the simulation are higher than those of the experiment.
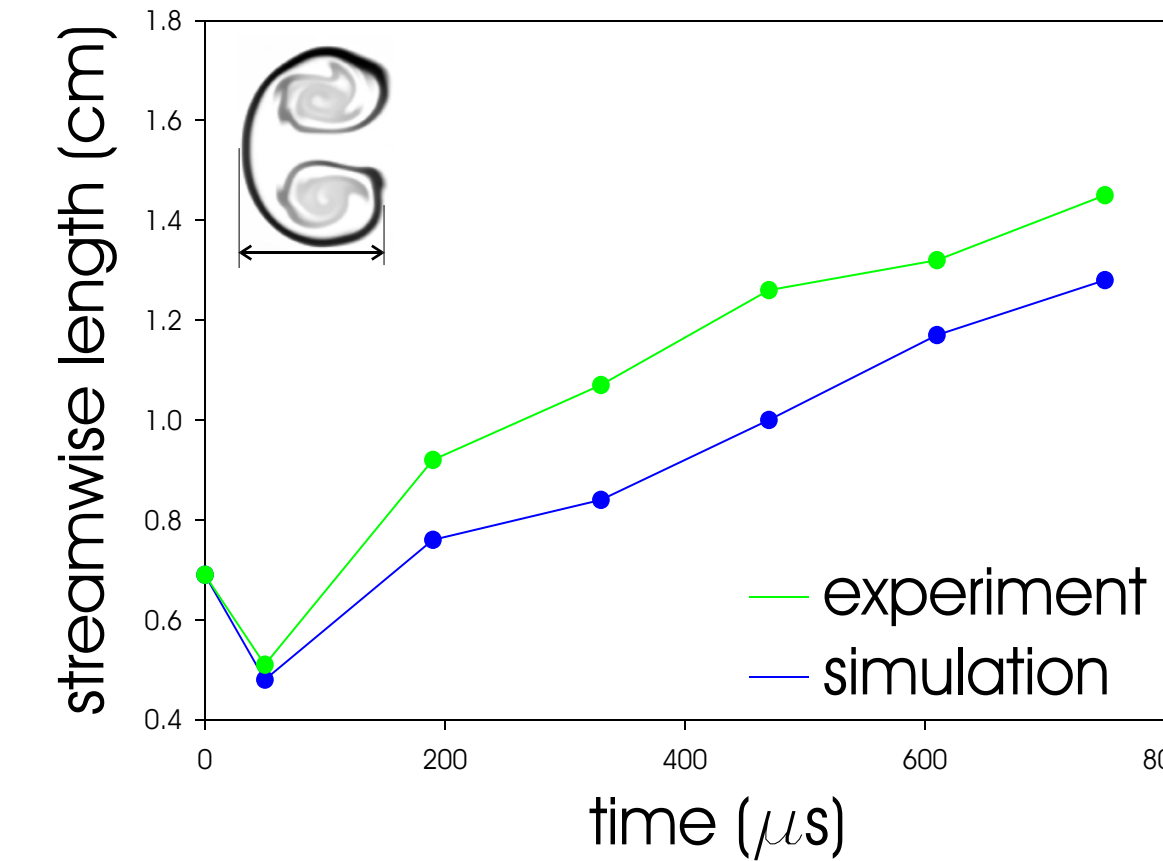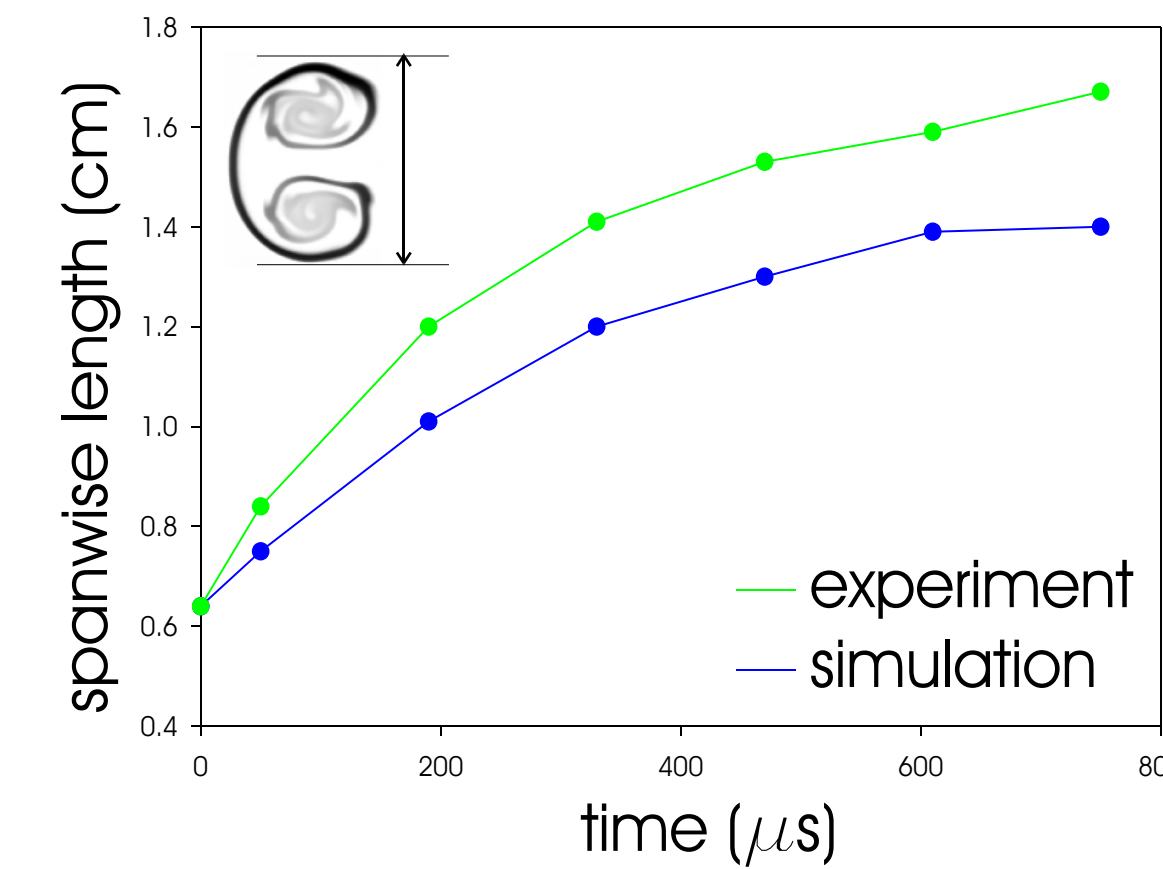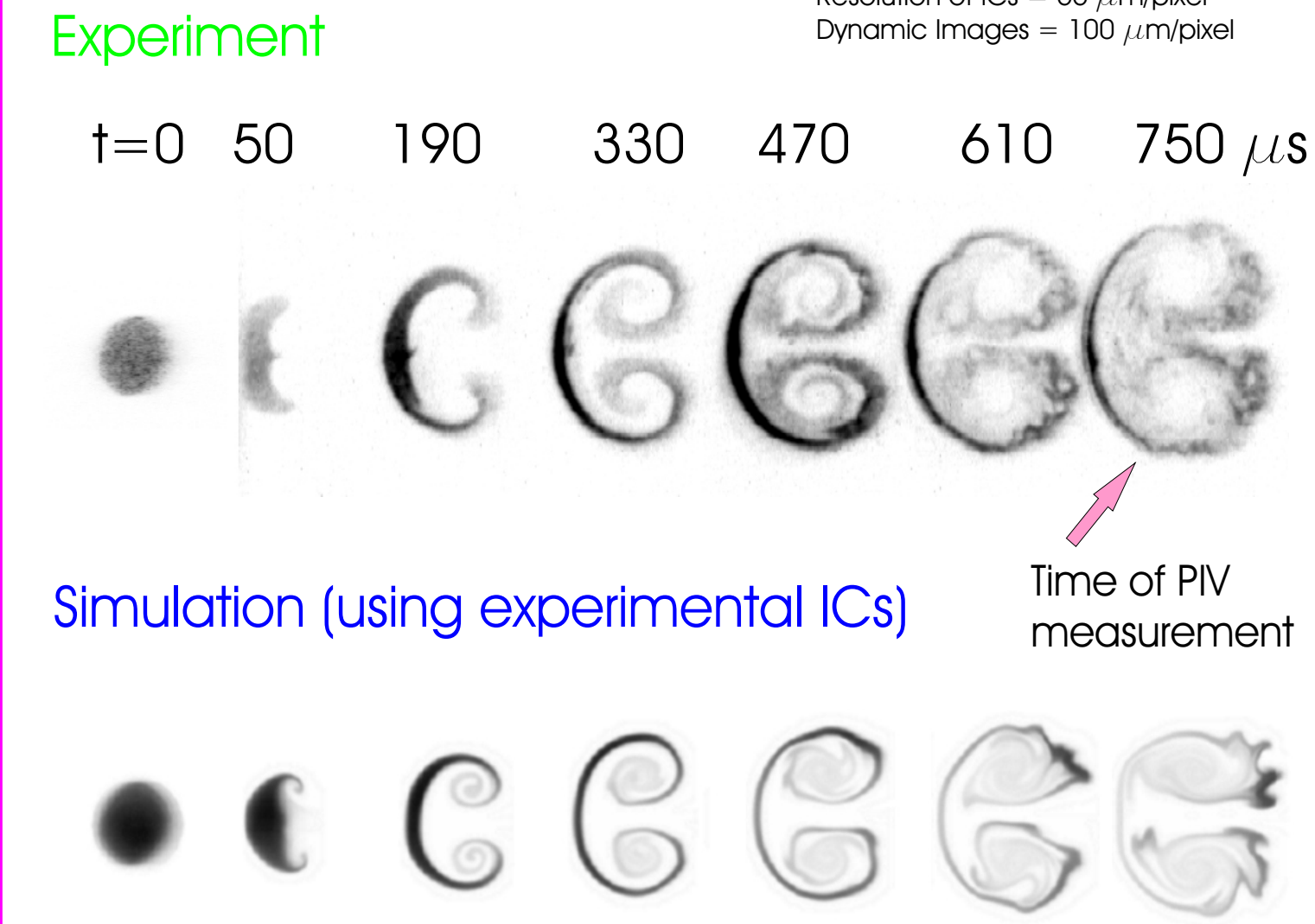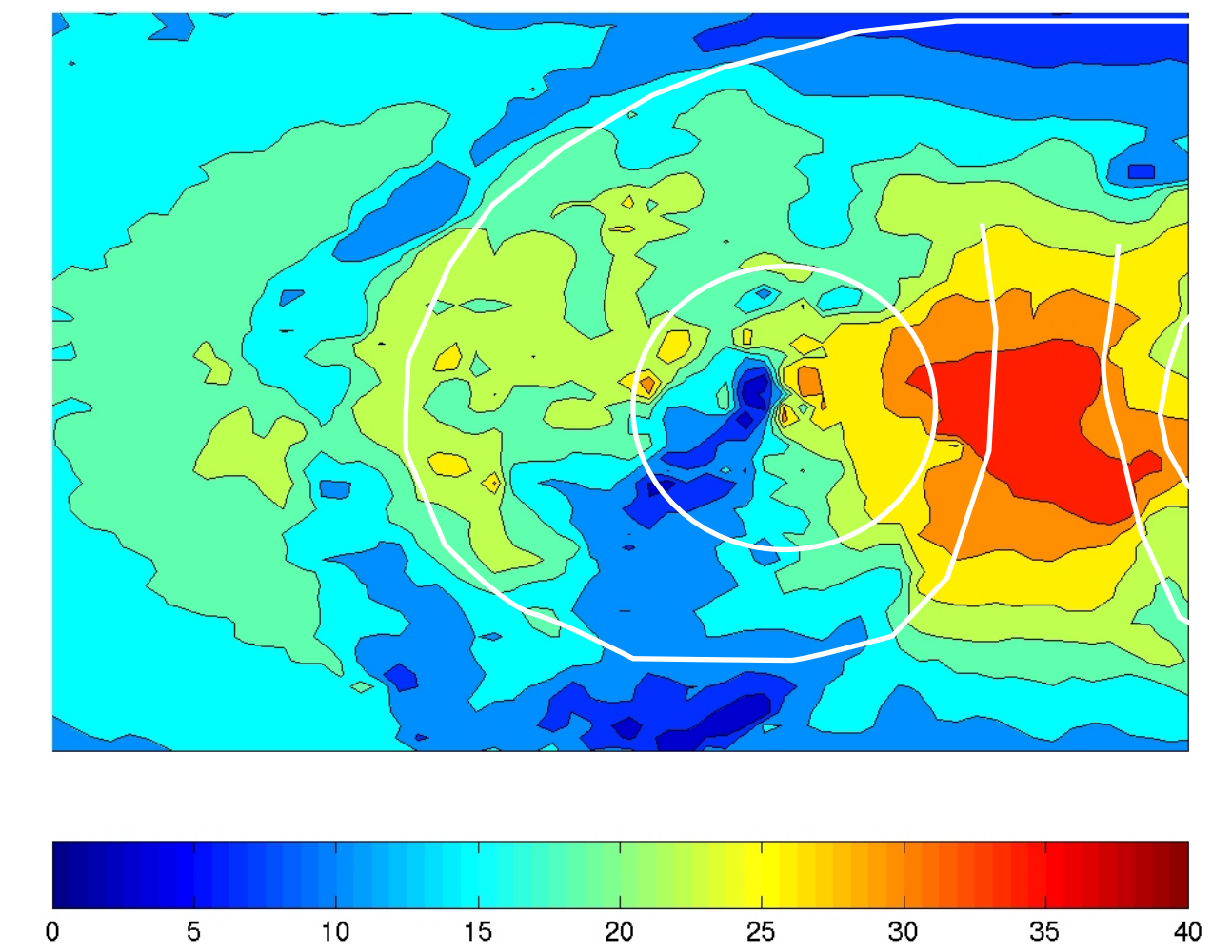
Shock Tube Facility

1.28 m   3.20 m   0.23 m   0.69 m

shock

Driver section   Driven section   Test section   End section

laser sheet

Diaphragm

Settling chamber

Fog generator

IC   PIV

Gas cylinder

laser sheet

SF

air   air

suction

DYN

Particle Image Velocimetry

(m/s)
35.5
33.3
31.1
28.9
26.7
24.6
22.4
20.2
18.0
15.8
13.7
11.5
9.3
7.1
5.0

Fluctuating velocity field for single cylinder with 0.75 cm nozzle.
Flow top to bottom; convection velocity of 98.6 m/s subtracted.
Shot 14. Spacing between vectors is 0.187 mm.
Contours of fluctuating velocity magnitude also shown.

Streamwise (mm) vs Spanwise (mm)

Density Fields

Resolution of ICs = 55 μm/pixel
Dynamic Images = 100 μm/pixel

Experiment

t=0   50   190   330   470   610   750 μs

Time of PIV measurement

Simulation (using experimental ICs)

spanwise length (cm) vs time (μs)
— experiment
— simulation

streamwise length (cm) vs time (μs)
— experiment
— simulation

Velocity Magnitudes

Experiment

0   5   10   15   20   25   30   35   40

Simulation

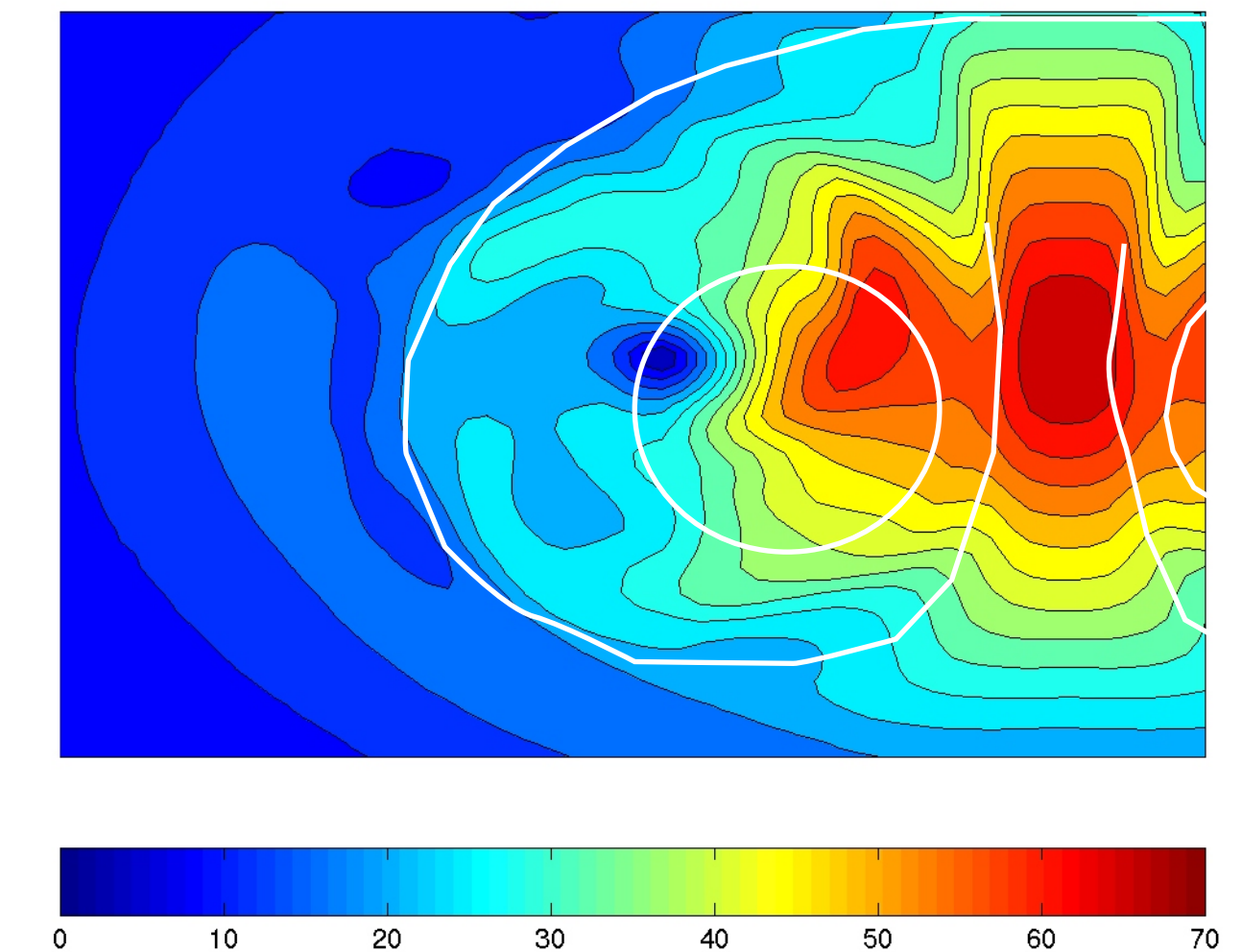0   10   20   30   40   50   60   70

count vs velocity magnitude (m/s)
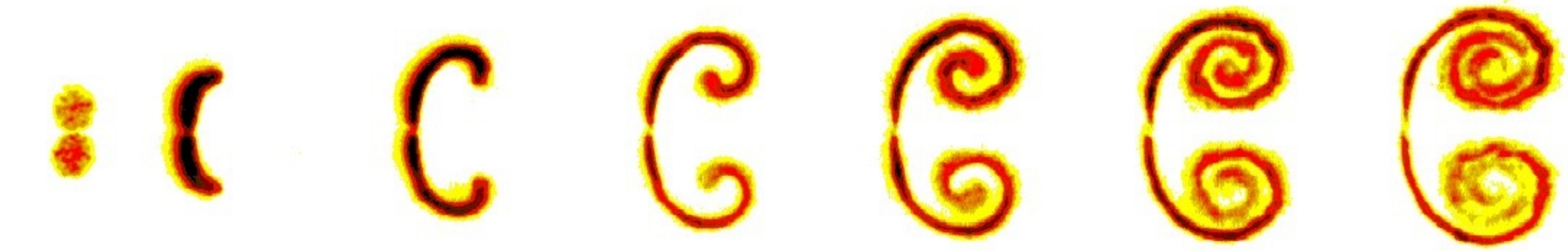— experiment
— simulation
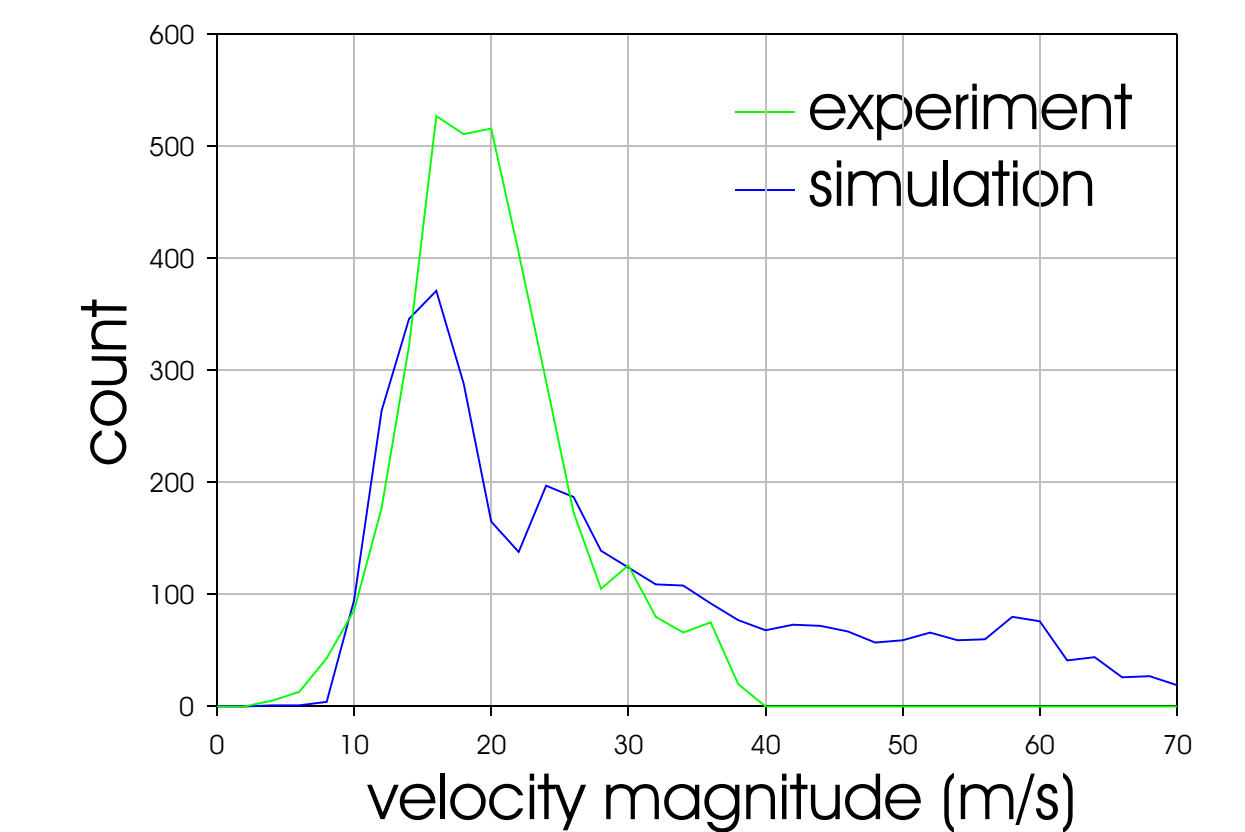
Pairs of cylinders

Experimental Density Fields

Single Cylinder

SF₆ → Air

S/D = 1.2

REPRODUCIBILITY

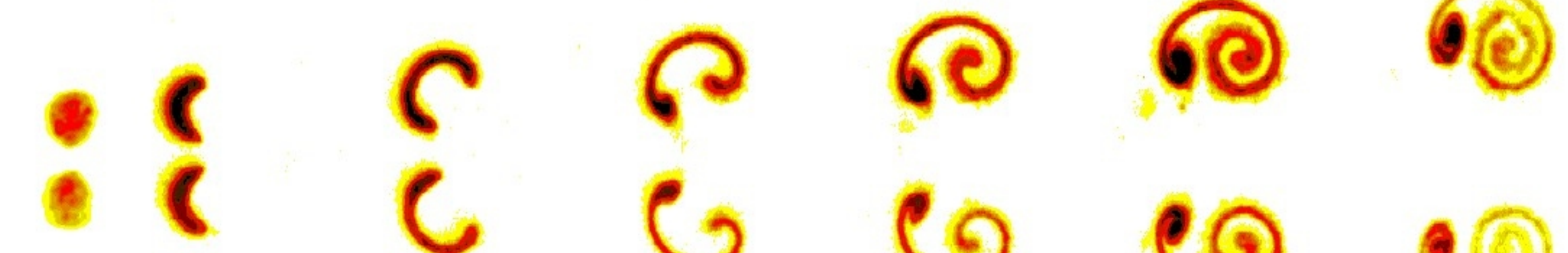S/D = 1.4

S/D = 1.5

S/D = 1.6

S/D = 1.8

S/D = 2.0

shock

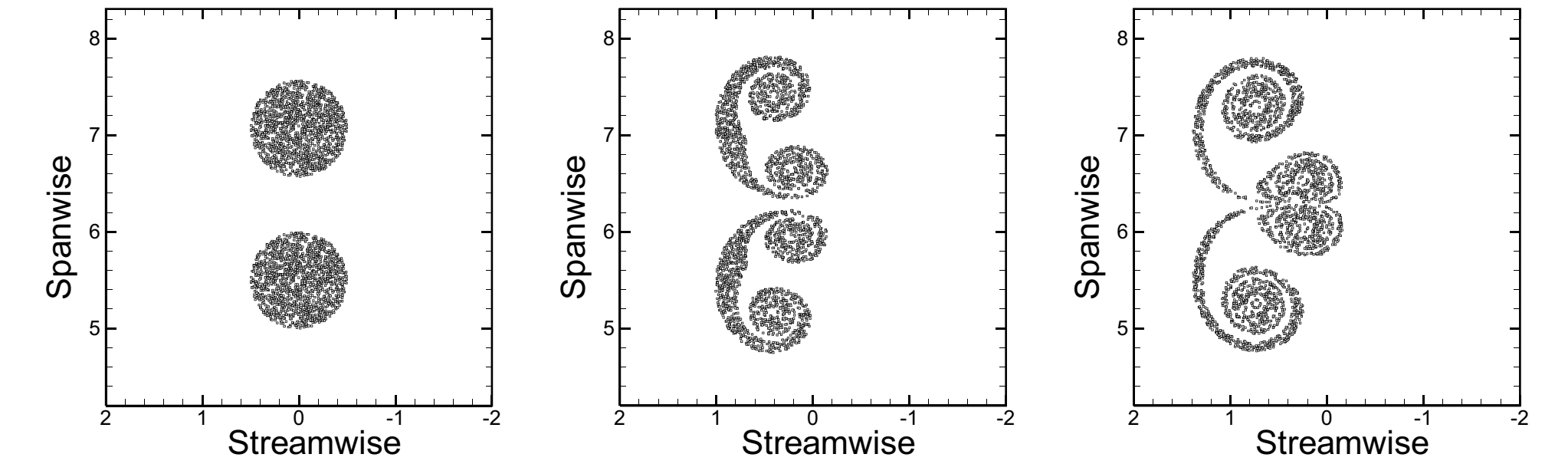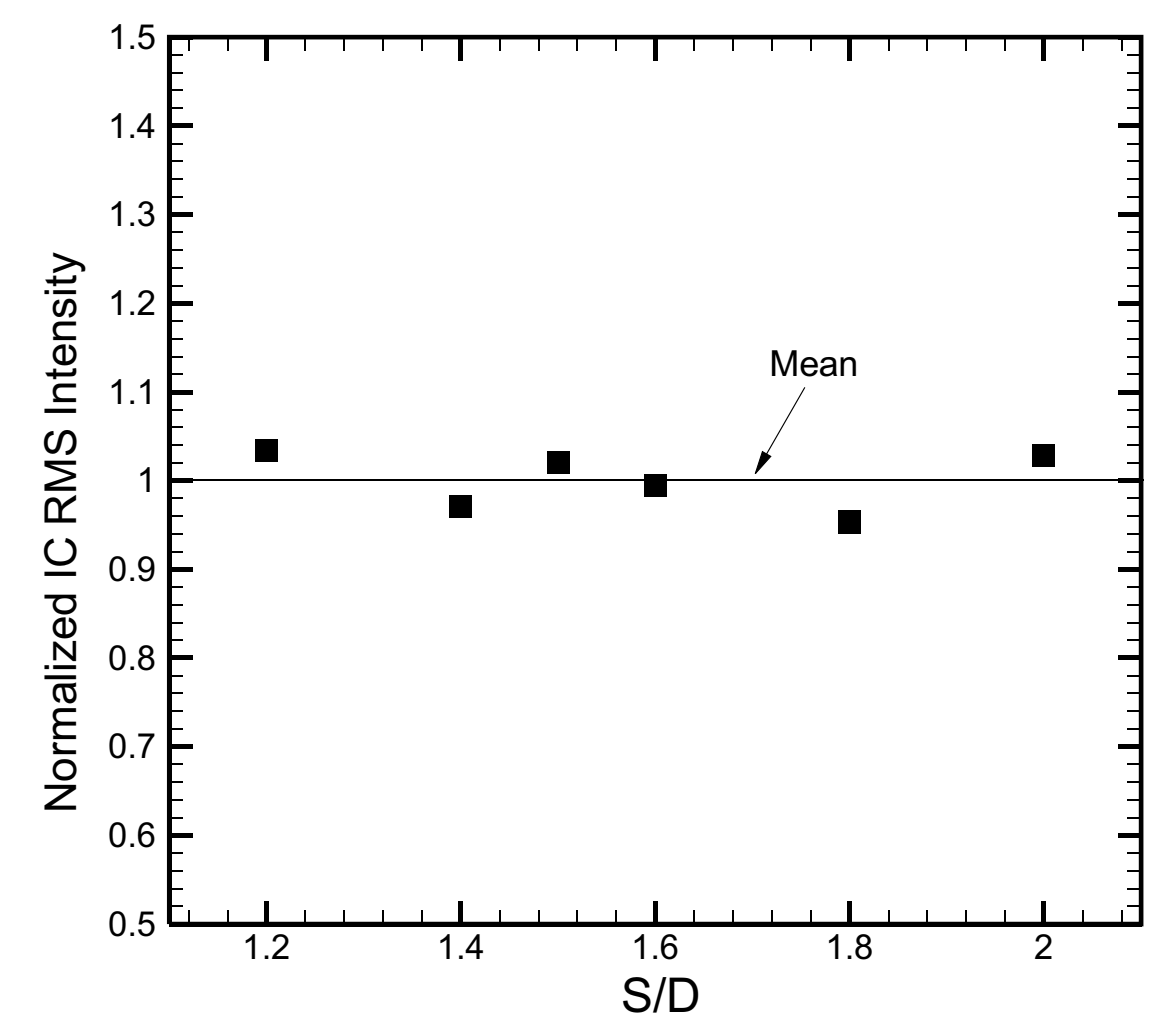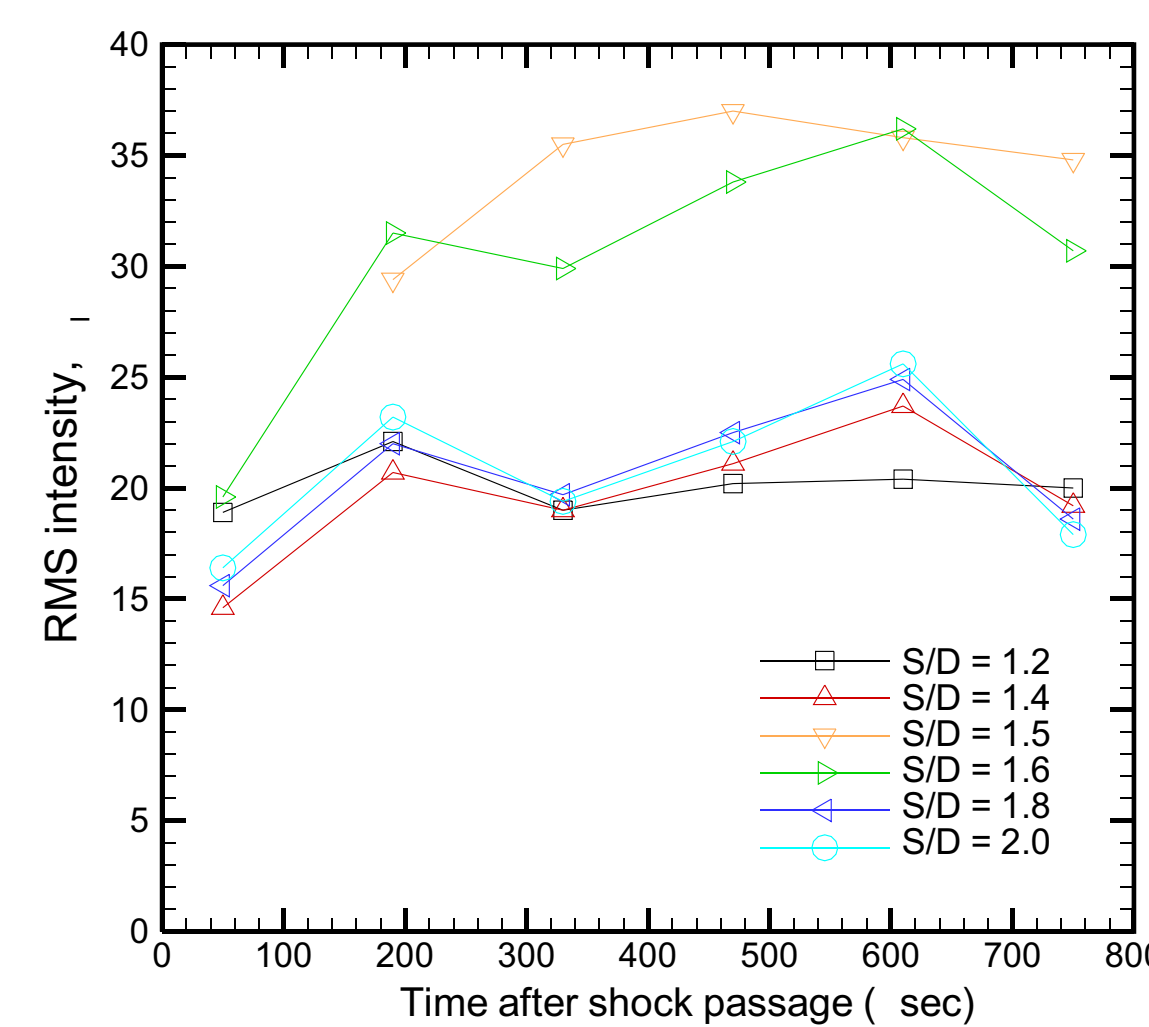M=1.2

S

D
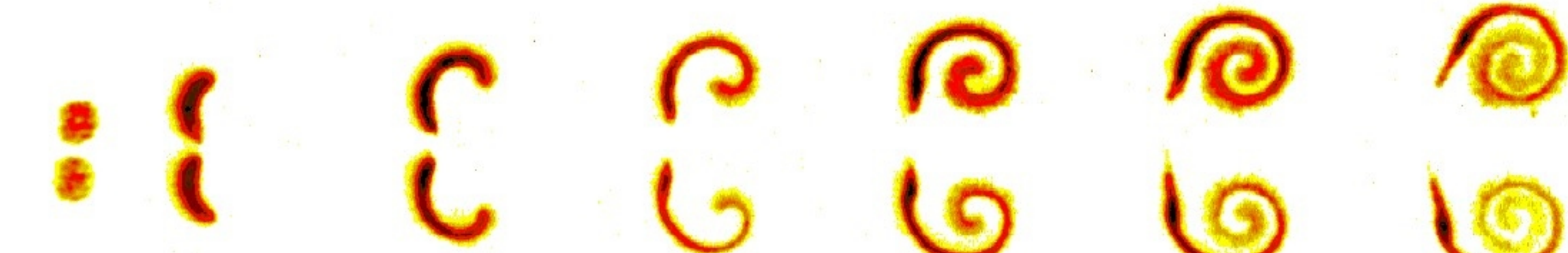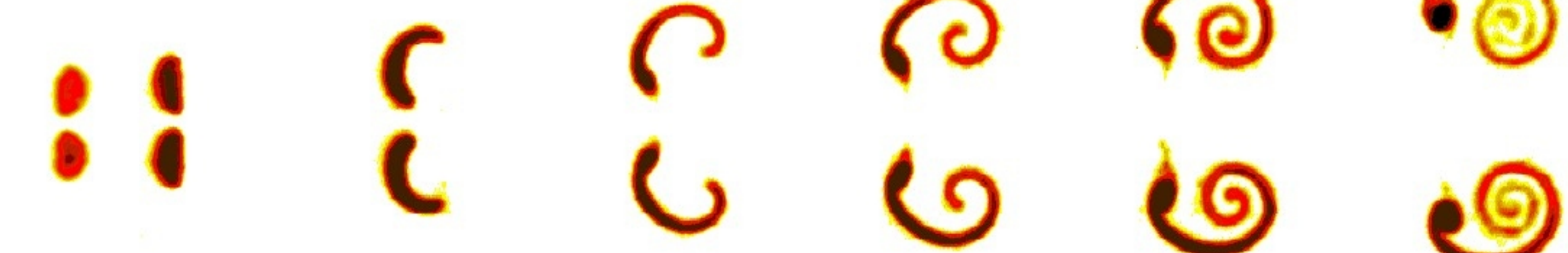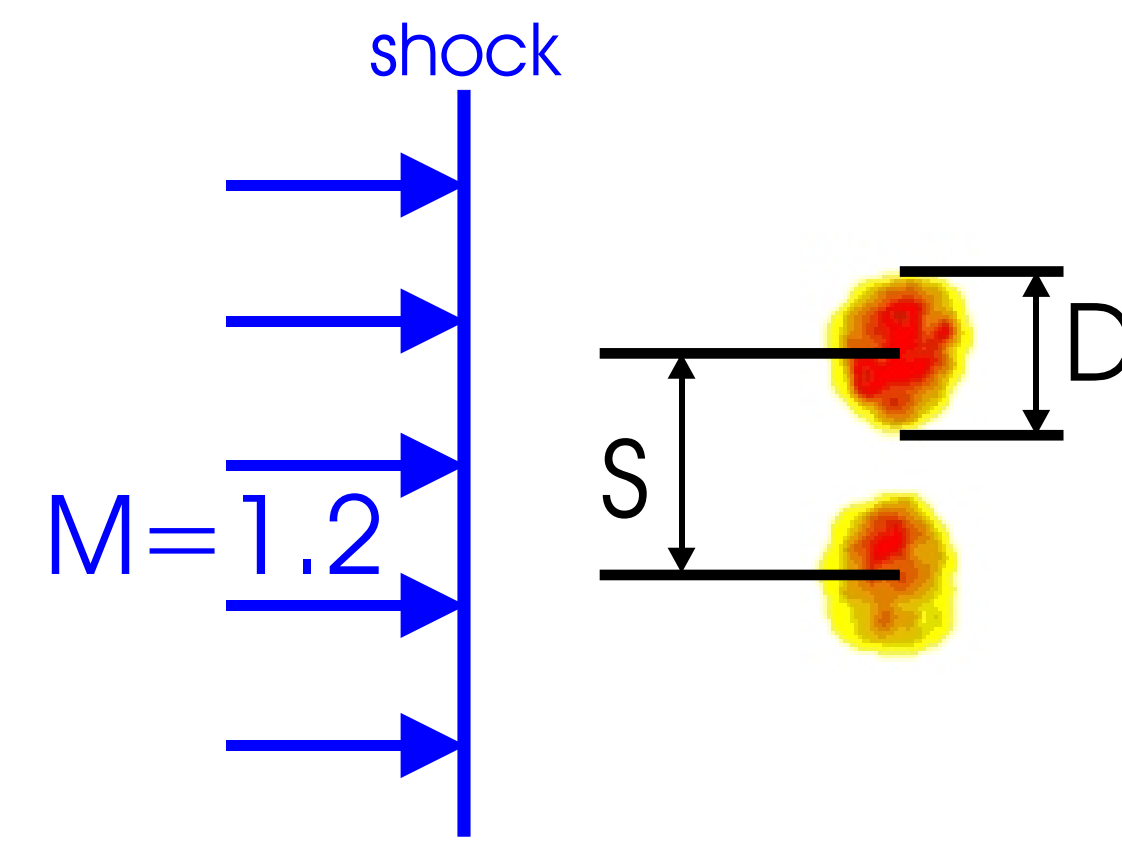
Anticipated results from a simple vortex blob model: Assumes 2 pairs of equal-strength counter-rotating vortices deposited by shock passage.

Ensemble-averaged over many shots—large-scale features preserved

Variation in Mixing and ICs with S/D

RMS intensity, I

Time after shock passage (μsec)

- S/D = 1.2
- S/D = 1.4
- S/D = 1.5
- S/D = 1.6
- S/D = 1.8
- S/D = 2.0

Normalized IC RMS Intensity

Mean

S/D

- Effects of shock impact on variably-spaced cylinders were not what we expected based on a simple model of vorticity deposition.
- There are various levels of interaction among the vortices depending upon the initial spacing of the cylinders.
- These results are highly reproducible from experiment to experiment, based on correlation-based ensemble averaging. Large-scale features are preserved.
- Particle Image Velocimetry was performed using cross-correlation and seeding of the background air.
- PIV reveals high velocity magnitudes in the region between the counter-rotating vortices and lower magnitudes in the cores.
- The vorticity field from PIV reveals a larger outer vortex with about four times the circulation of the inner vortex. Also visible is the vorticity along the outer edge of the vortex pair caused by shear.

Particle Image Velocimetry

Image (one of a pair)

Magnitude

10 m/s

$(u'^2 + v'^2)^{1/2}$ (m/s)

40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0

Vorticity

γ (1/s)

60
48
36
24
12
6
4
-4
-6
-12
-24
-36
-48
-60