Advanced 14
Aerospace Applications of Nano-Second-Laser-Pulse-Induced Pressure Modulation

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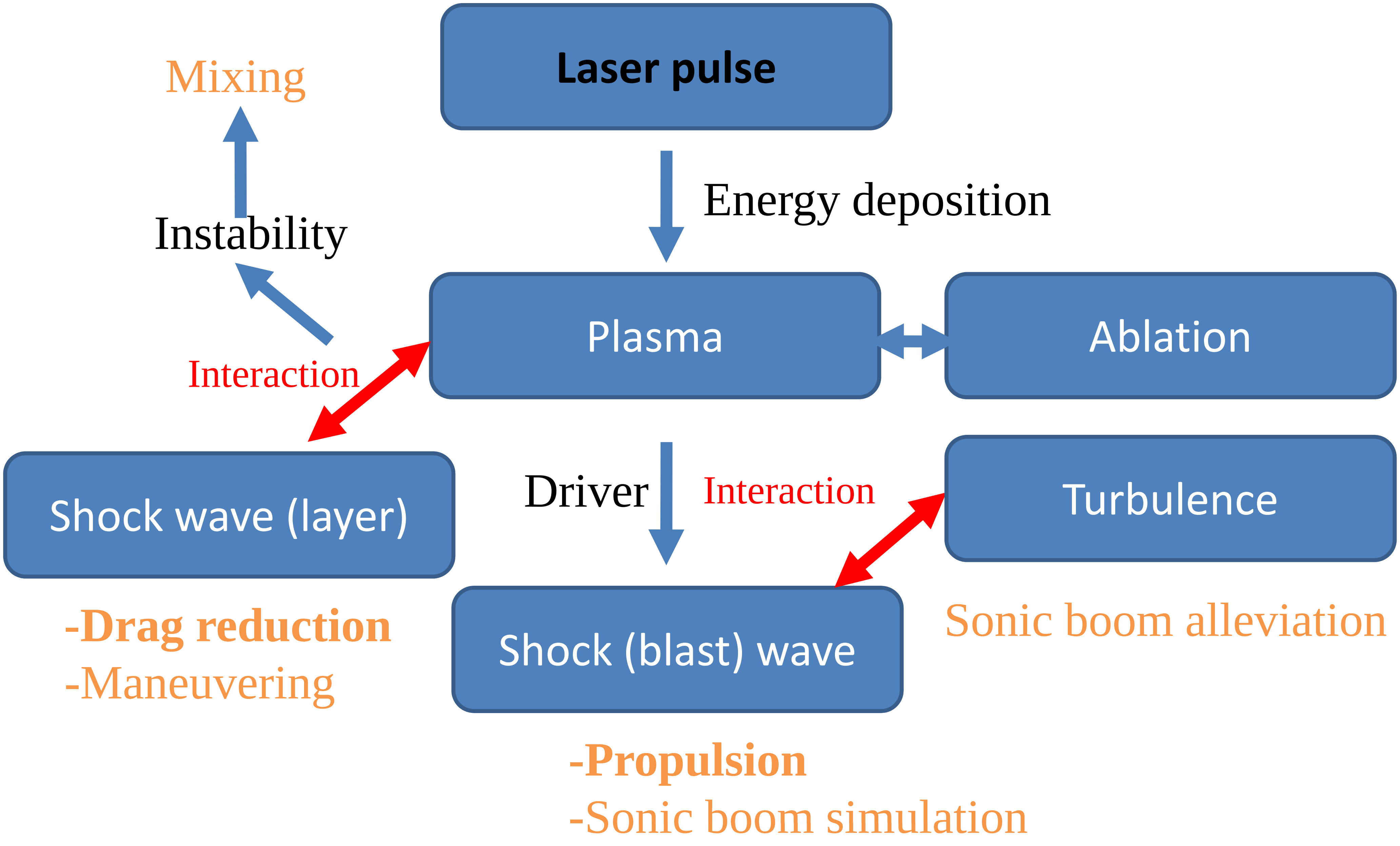
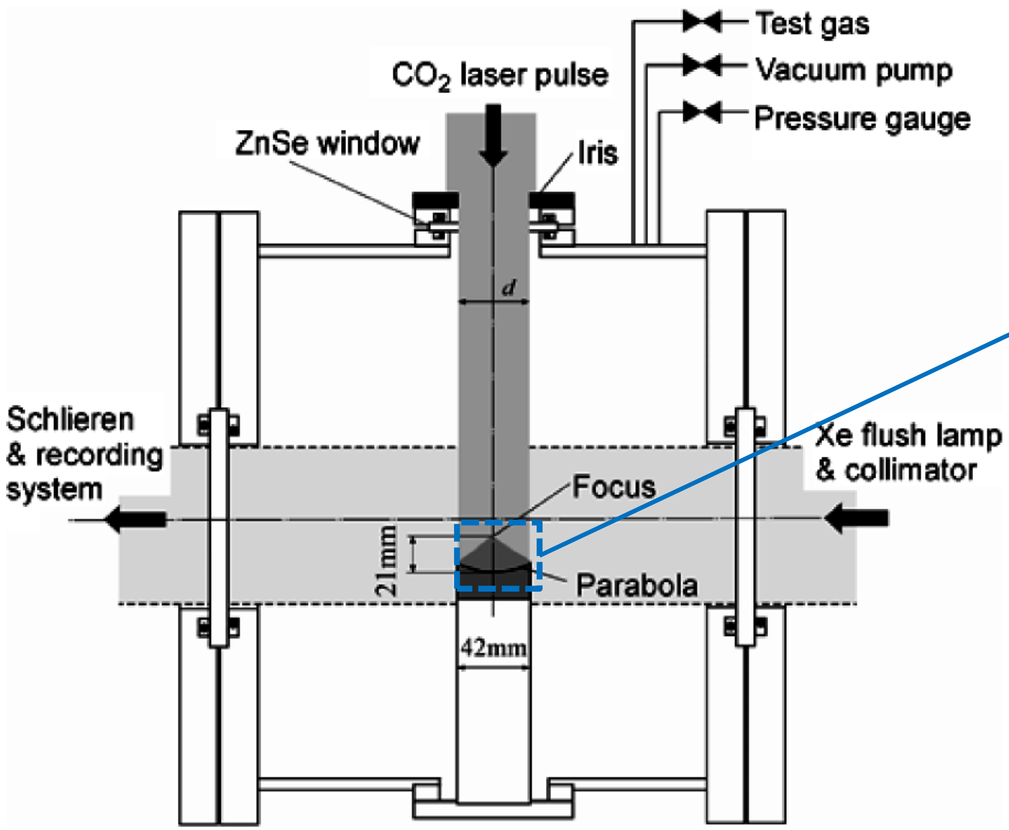
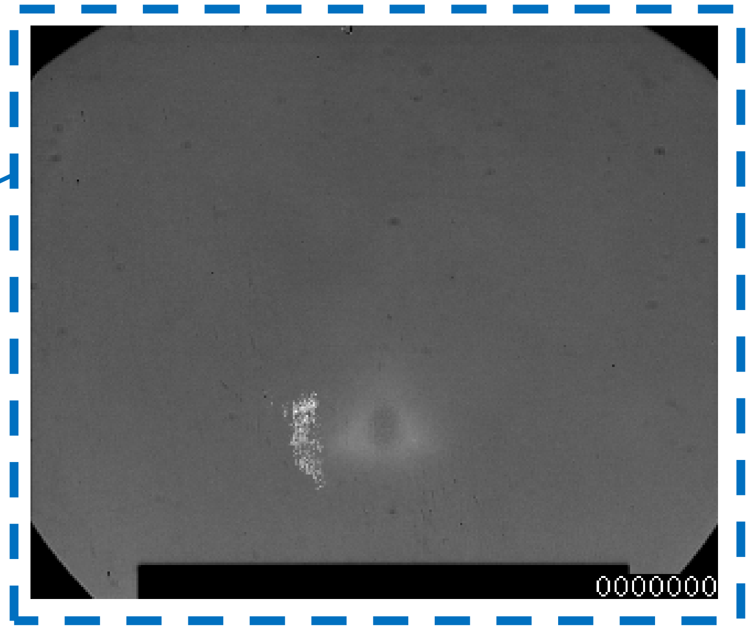
Laser-Pulse-Induced Pressure Modulation



Impulse Generation by Laser-Pulse-Induced Blast Wave





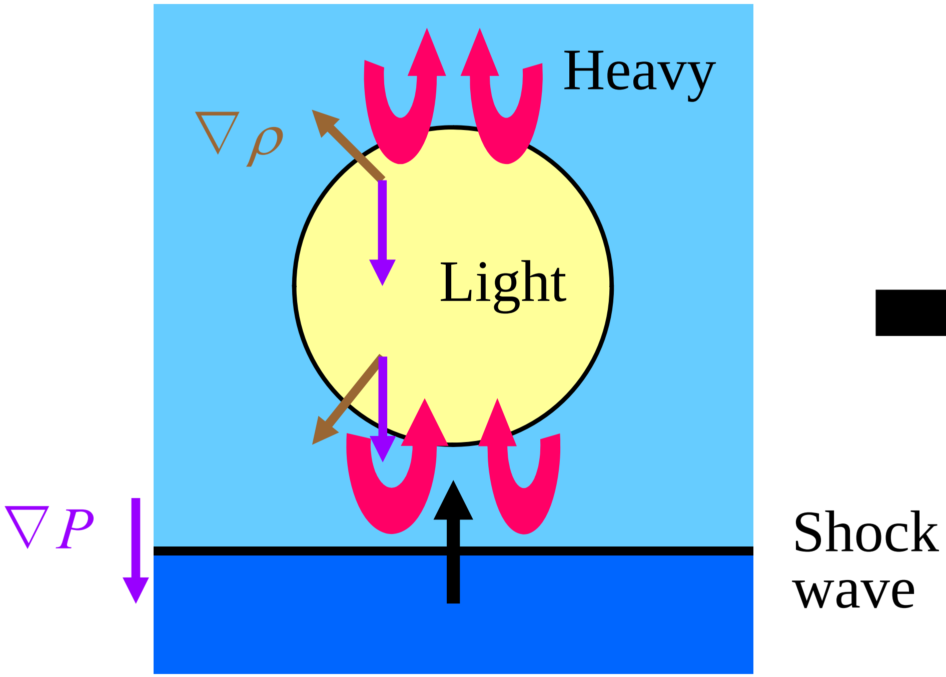
Species: Kr,
Ambient pressure=40kPa
Laser energy=3.6J

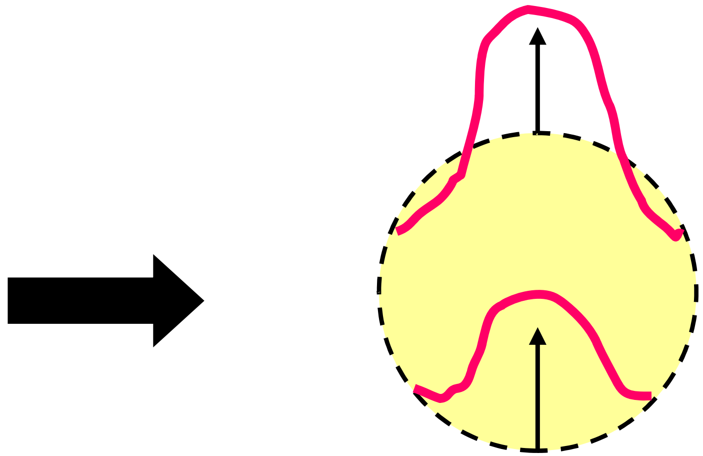
Baroclinic Vortex Generation
Initiation of Richtmyer-Meshkov Instability

Richtmyer 1960, Meshkov 1969

$$\frac{d\omega}{dt} = (\omega \cdot \nabla)\mathbf{u} - \omega(\nabla \cdot \mathbf{u}) + \frac{1}{\rho^2} \boxed{\nabla\rho \times \nabla P}$$

Baroclinic effect

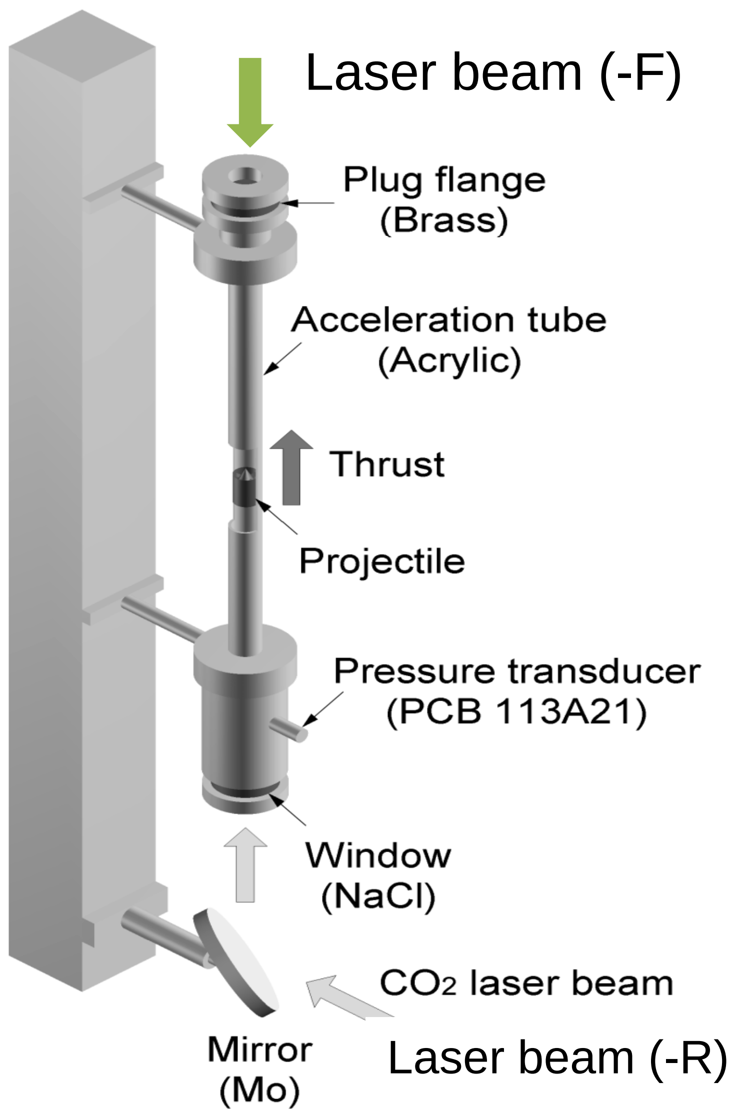


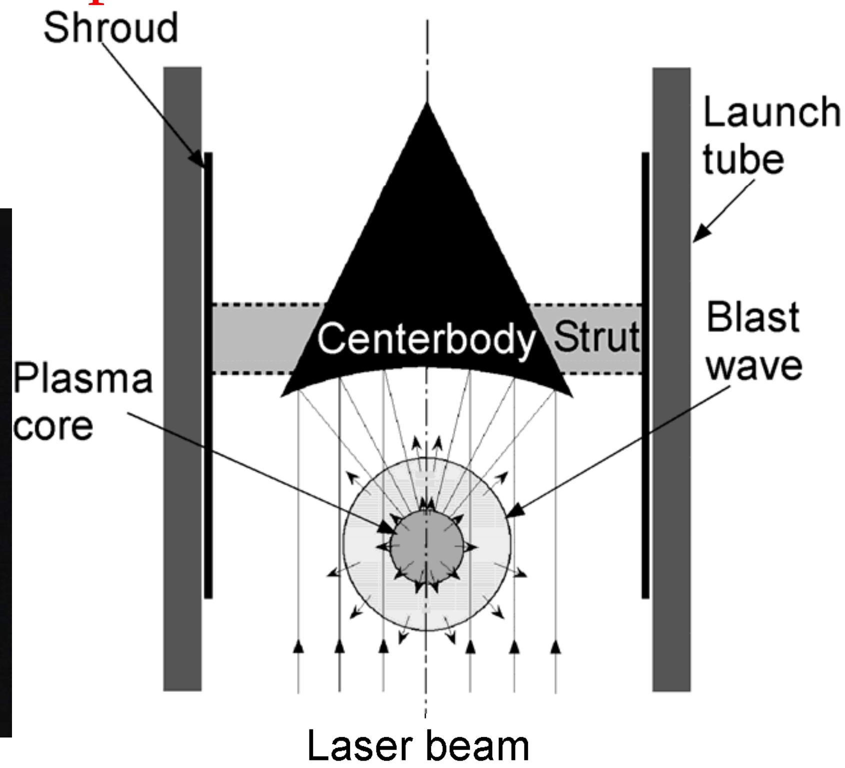


Laser Propulsion

Laser-driven, In-Tube Accelerator (LITA)

Propellant in-tube but off-board



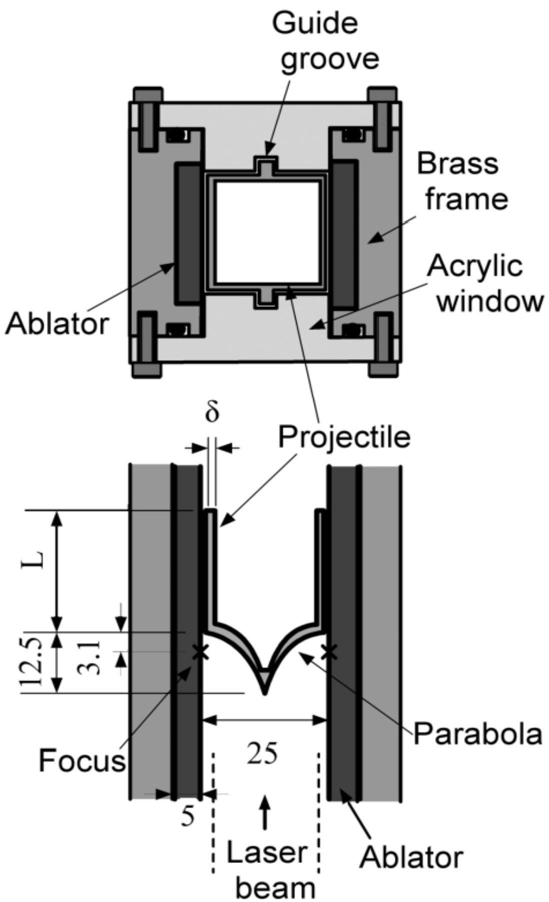


- Bore: 25mm
- Propellant: Xe
- Fill pressure: 100kPa
- 2.6 J/pulse, 60Hz

Wall-Ablative LITA

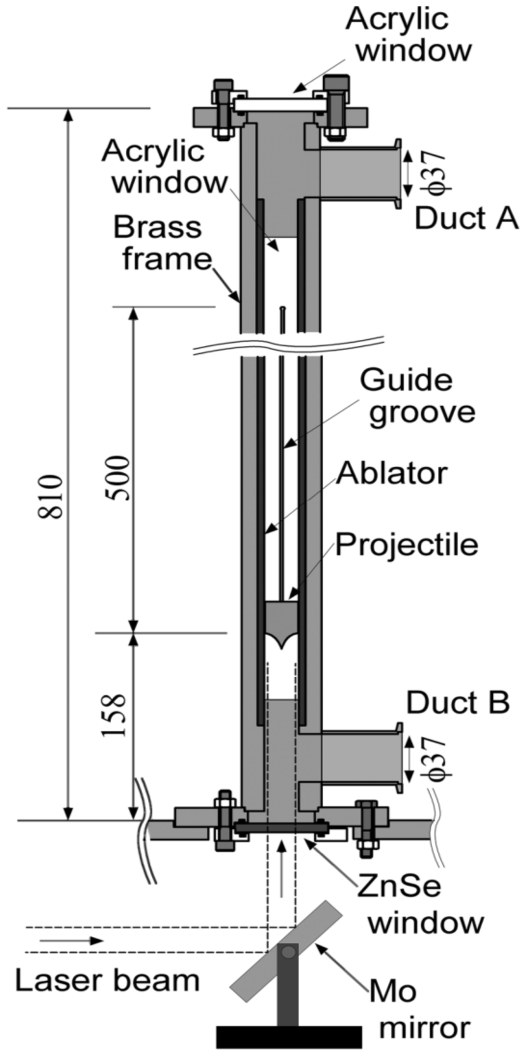
(propellant on tube wall → Large payload)

Cross sections over projectile

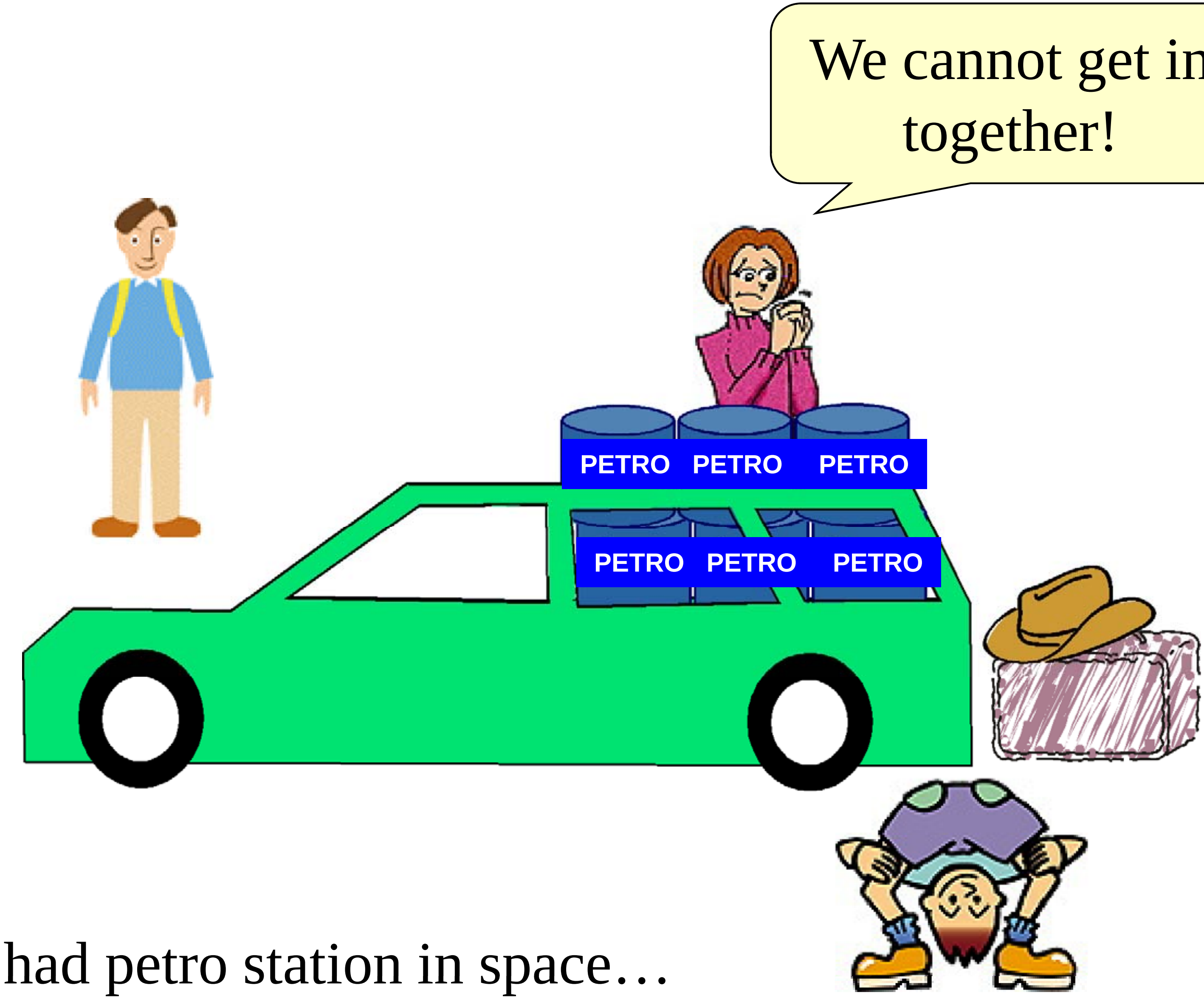


*Length unit in [mm]

Launch-tube system

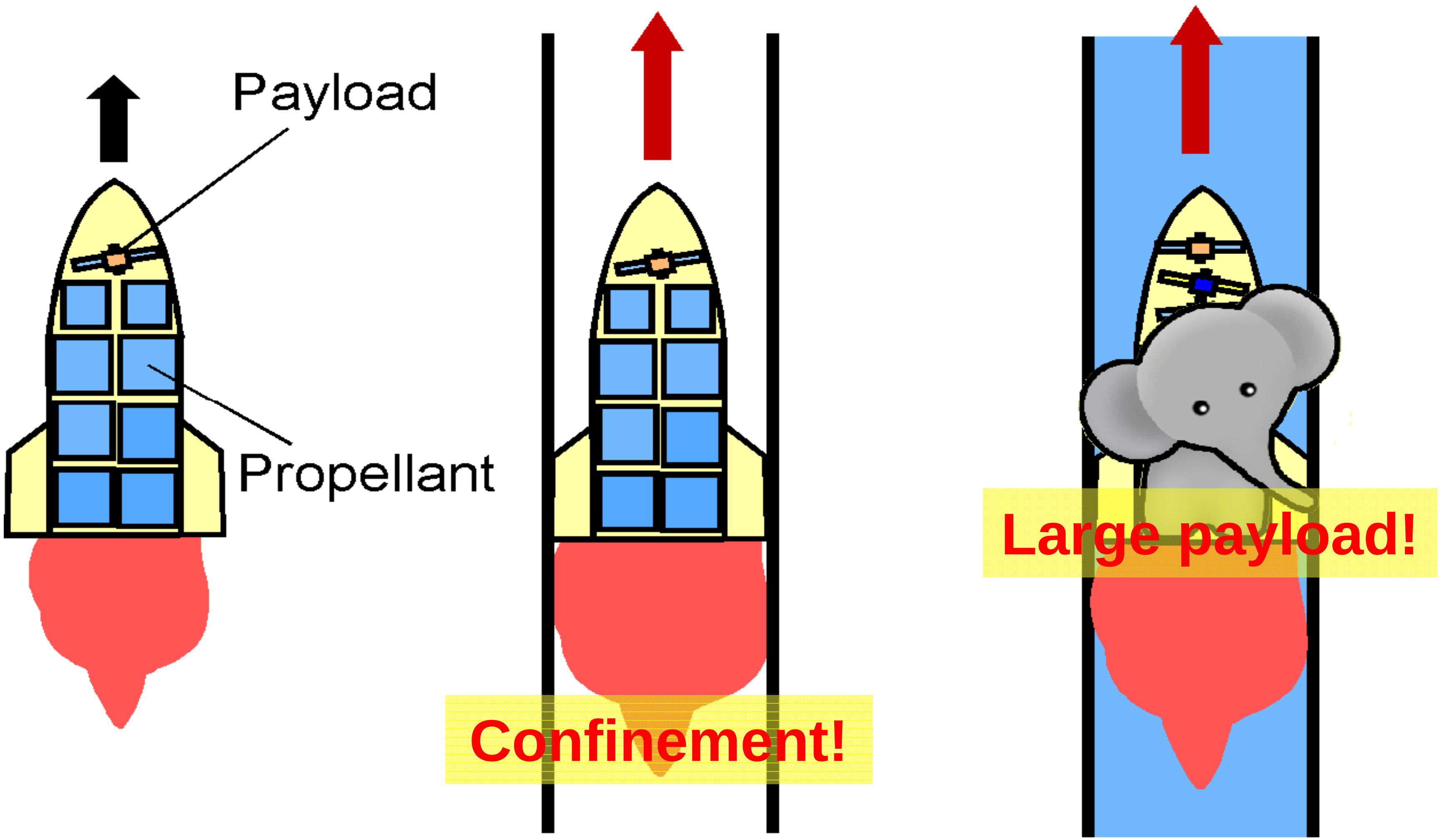


This is a rocket!



Wish we had petro station in space…

In-Tube Propulsion



(A) Rocket (B) In-tube rocket (C) In-tube propulsion (**Propellant off board**)

Pressure Variation in Laser Ablation Measured Using Velocity Interferometer

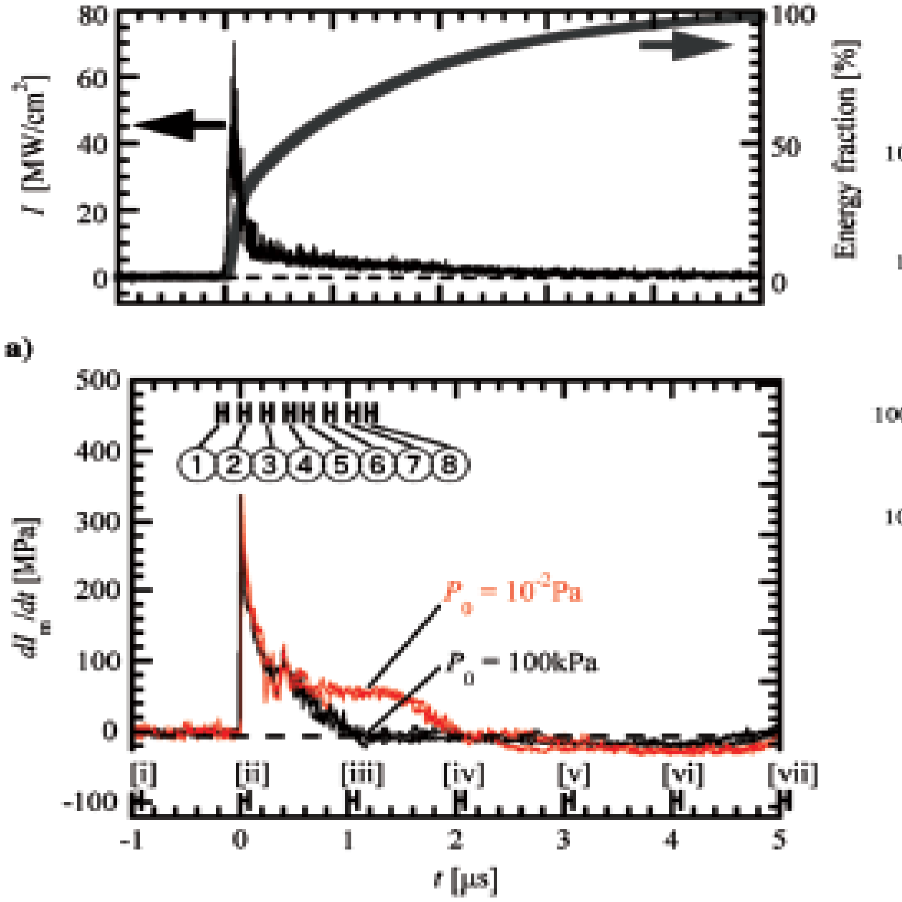
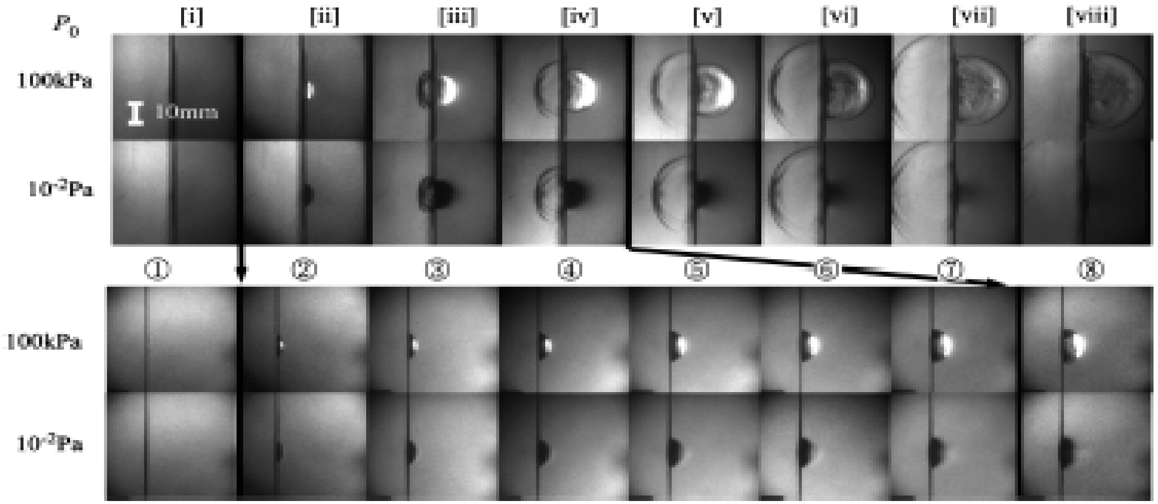


Fig. 11 Impulse generation processes on POM target with TEA CO_2 laser, $E = 9.0$ J ($\phi = 17.9$ J/cm^2), $\delta = 12$ μm, same conditions as in Fig. 6c: a) time variation of I and integrated energy fraction, b) time variation of overpressure which is measured with the target rear surface backed by the acrylic block.



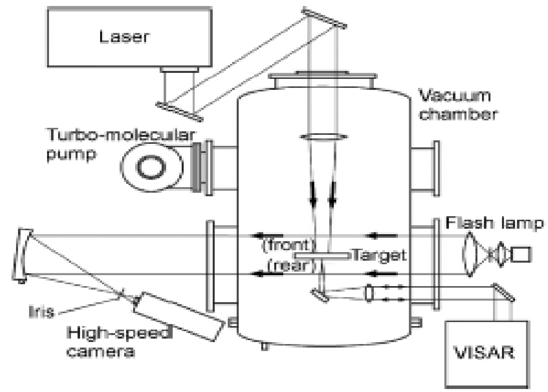
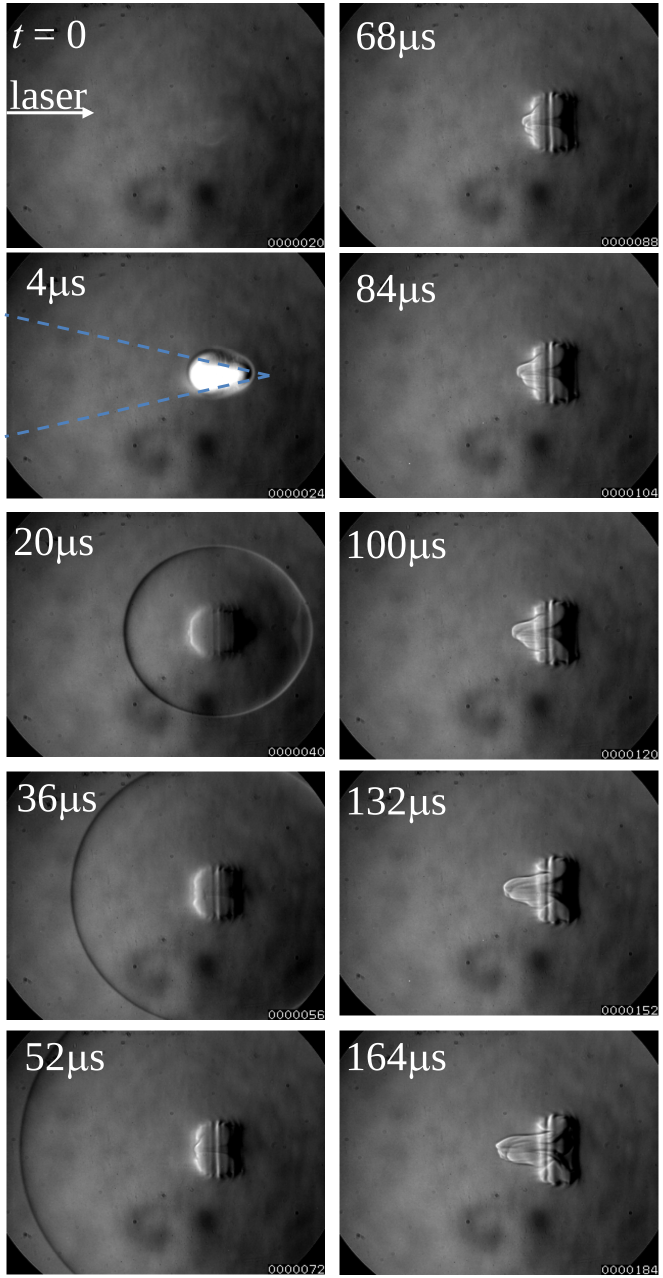


Fig. 1 Experimental setup.

Self Instability of Laser-Pulse -Induced Plasma

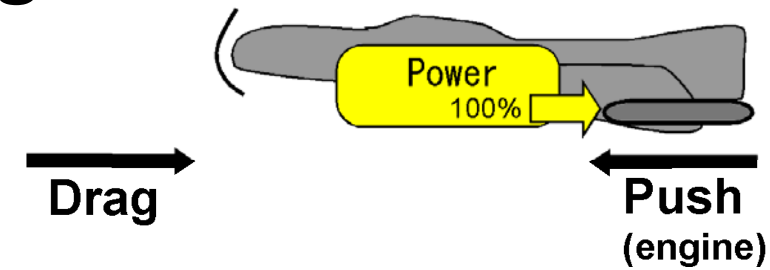
Nd:YAG laser pulse
Wavelength=1,064nm
Duration=10ns (FWHM)
Energy=140mJ

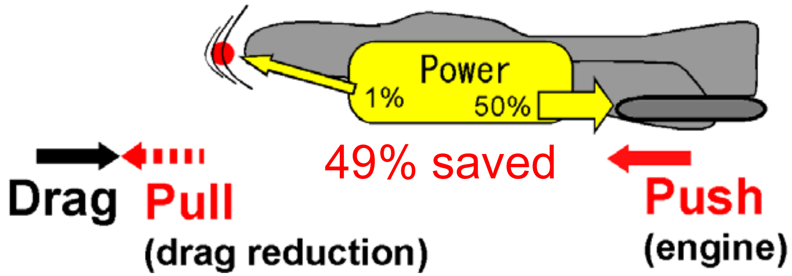


Fly By Light Power

Flight control using laser energy depositions

-Drag reduction





-Maneuvering

-Sonic boom mitigation

- Other possibilities

What Were Done/Known

- Wave drag over blunt body is vastly reduced owing to baroclinic vortex formation.

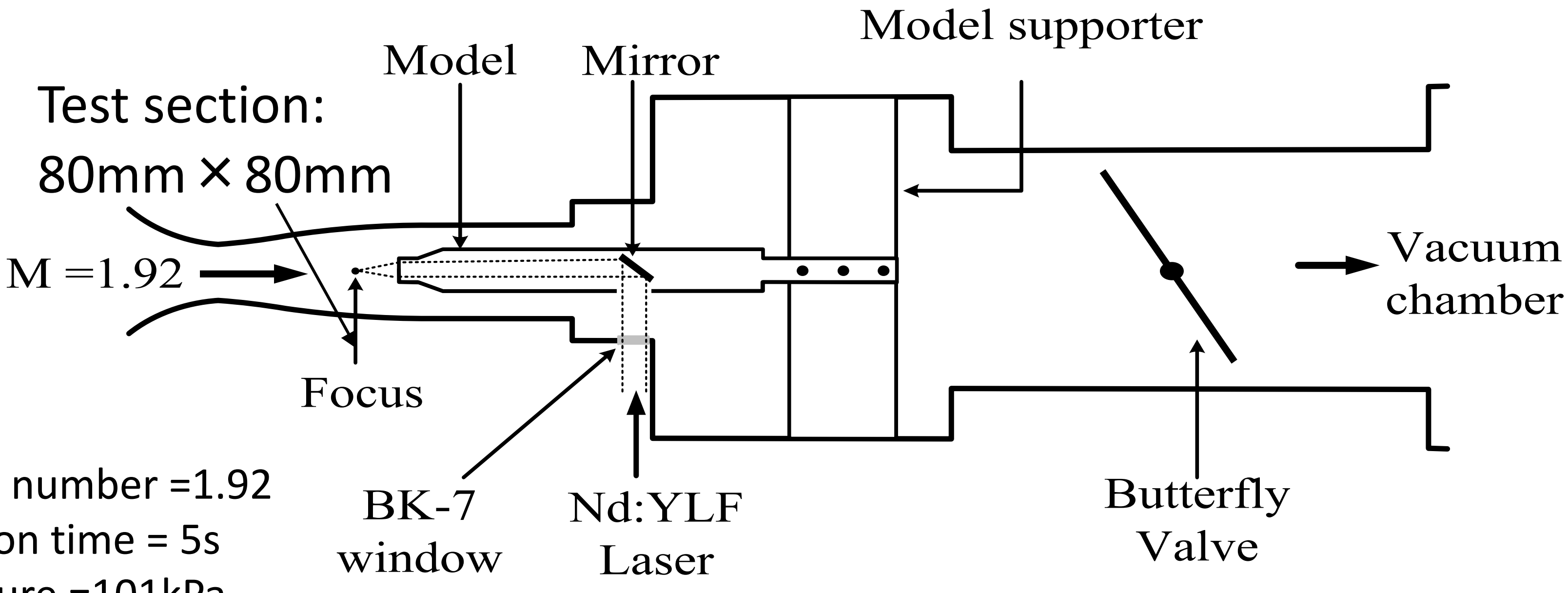
  Georgievsky and Levin (1993), Borzov et al. (1994) , Riggins et al.(1999), Kandala and Candler (2004), Adelgren et al. (2005), Kremeyer et al. (2006), Taguchi et al.(2007), Zheltovodov et al. (2007), Sakai et al. (2008) & many others

- Tret'yakov et al. (1996) demonstrated up-to-45 % steady-state drag reduction using 100 kHz laser pulses, yet without energy saving.
- Knight's characterization using dimensionless parameters (2008)
- Effect of interactions among repetitive pulses (Georgievsky & Levin 2004)

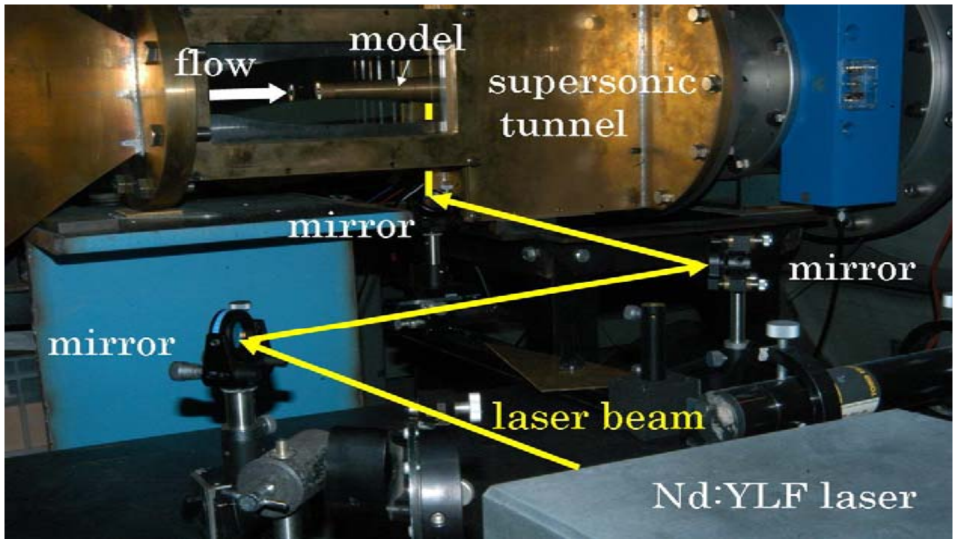
What Are Not Well Done/Known

- Lower-than-steep-nose drag & energy saving
- Such operation is possible using a truncated cone (Sakai 2009, CFD), not validated experimentally.

Experimental Setup

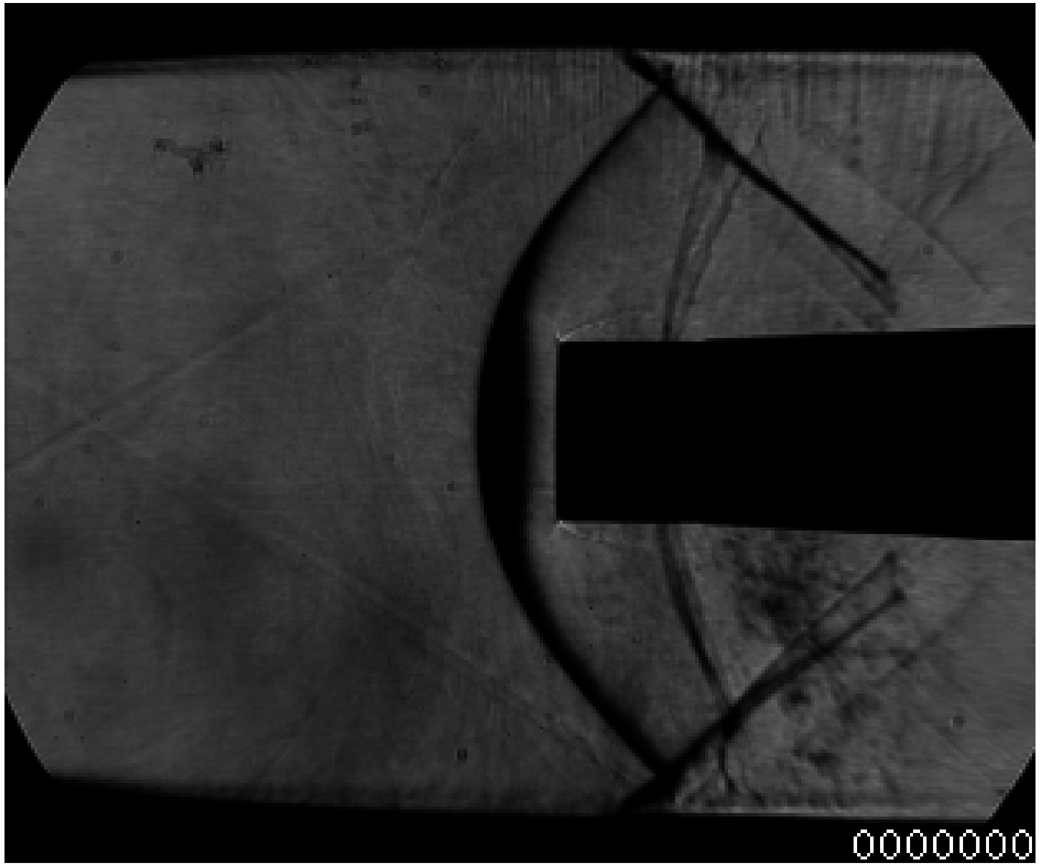


Flow Mach number =1.92
Test duration time = 5s
Total pressure =101kPa
Static pressure = 14.7kPa



Nd:YLF laser (PowerEdge co.)
- Wavelength = 1047nm
- Repetition frequency = 10 kHz max.
- Average power = 80 W max.
- Beam cross-section; 5 mm×5mm

Schlieren Video of Laser-Plasma and Bow Shock Layer Interactions



in μs

M=1.92, L/D=1.06, f=4kHz

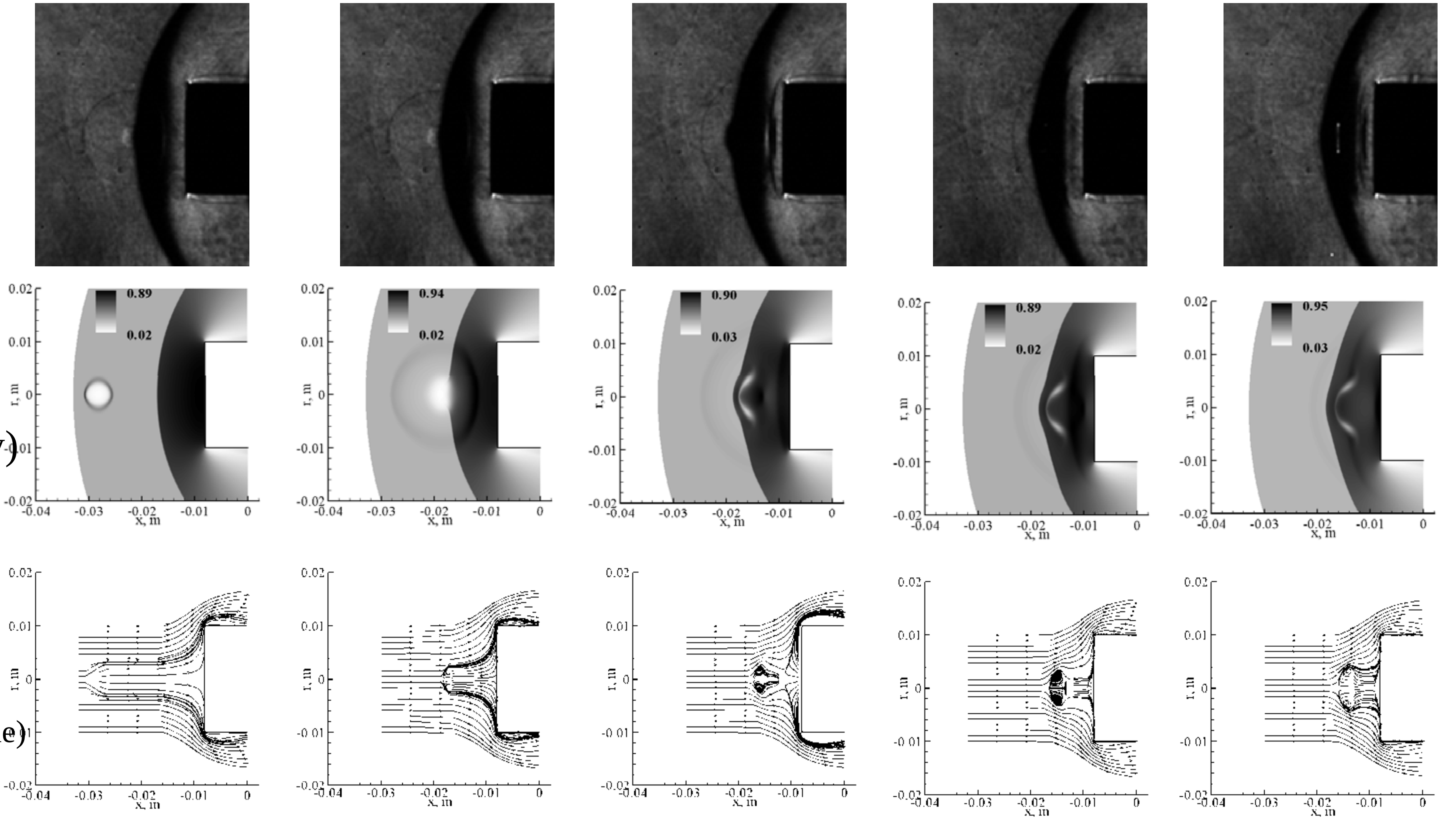
W=48.4W (12.1 mJ/pulse ave.)

Interactions between Laser-Plasma & Bow Shock Layer

EXP

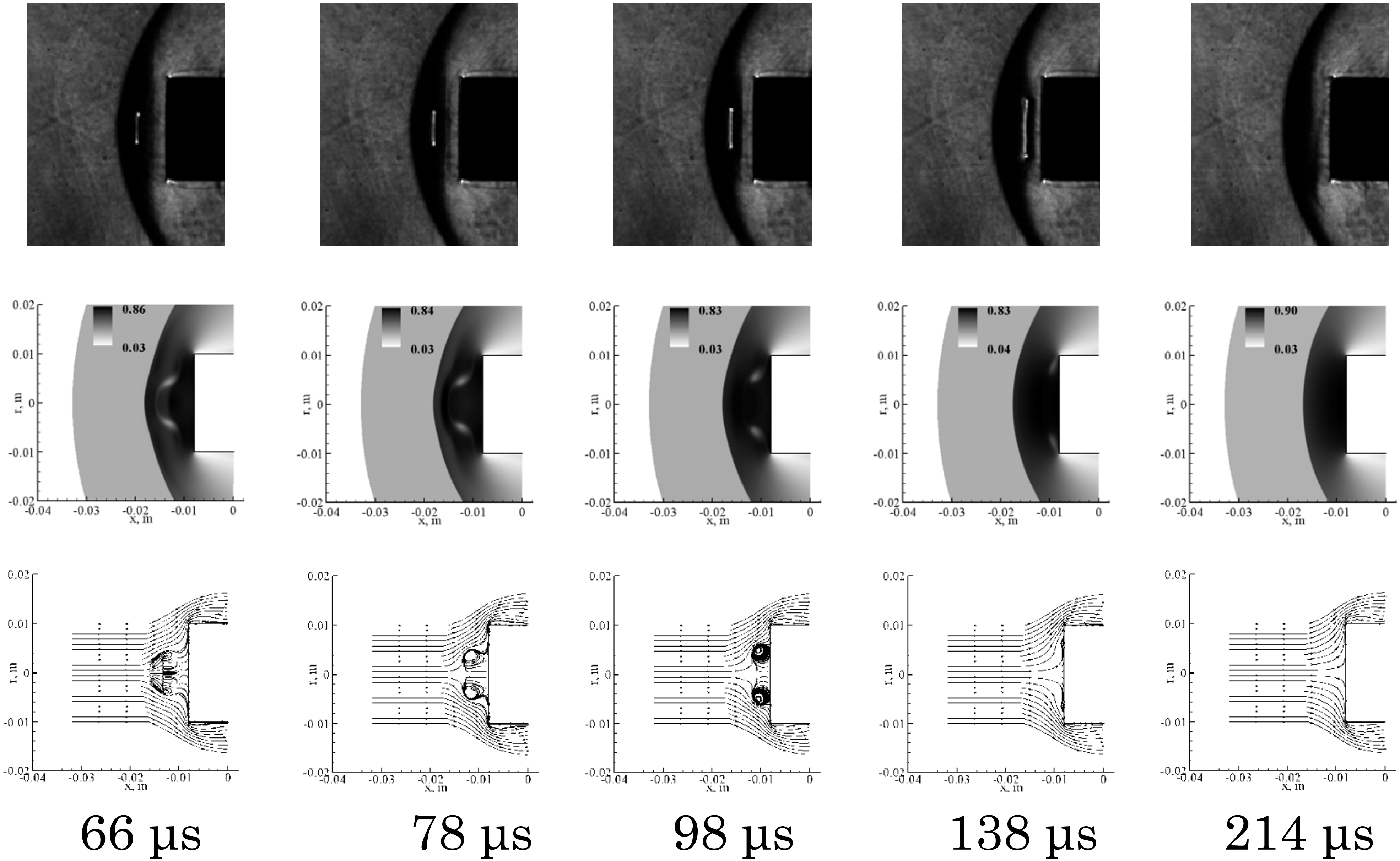
CFD
(density)

CFD
(streamline)



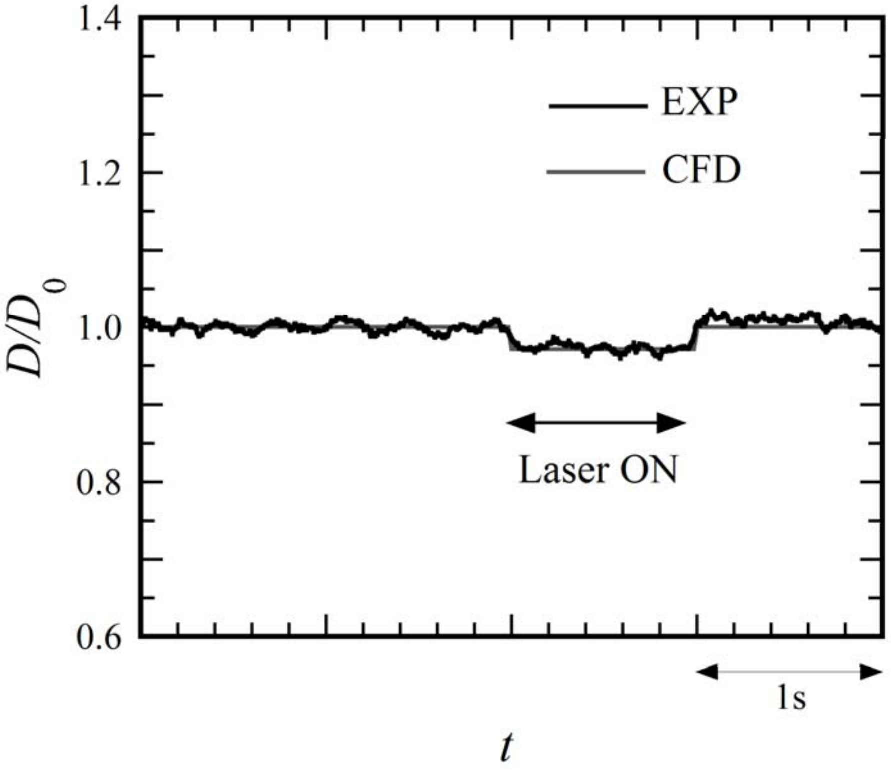
t=2 μs | 22 μs | 38 μs | 46 μs | 54 μs

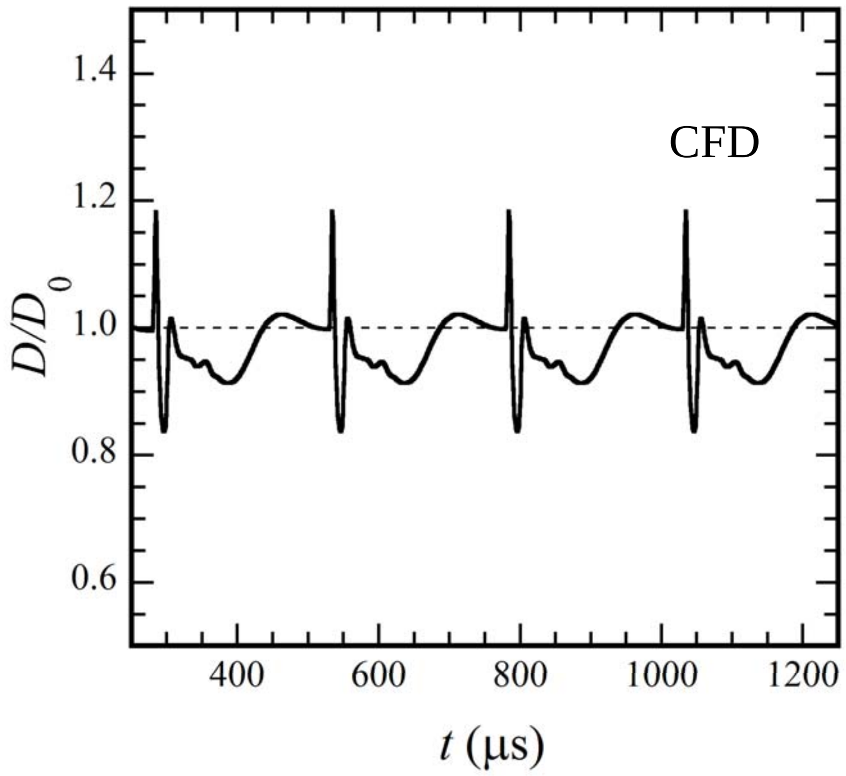
Pressure modulation period is determined by vortex residence time -- long over blunt body.



Drag History: An Example

l/d=1.06, f=4kHz, E=11.9mJ/pulse, W=47.8W,
EXP: D_0=22.4±0.3N,
CFD: D_0=20.6 N, E_{eff}/E=0.3.



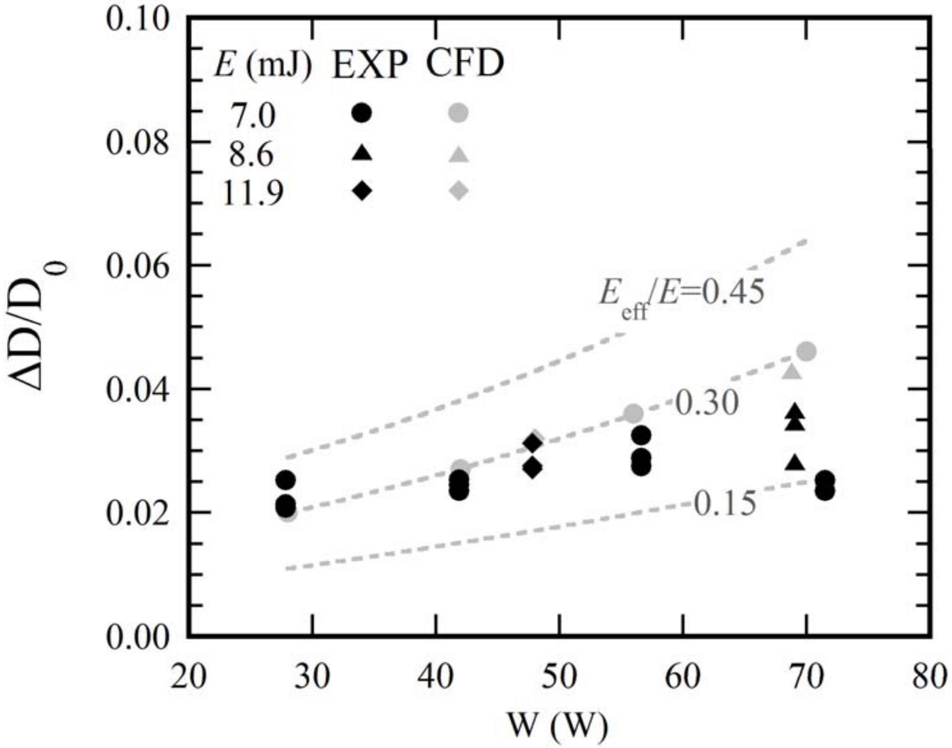


Time resolution; 0.5 ms

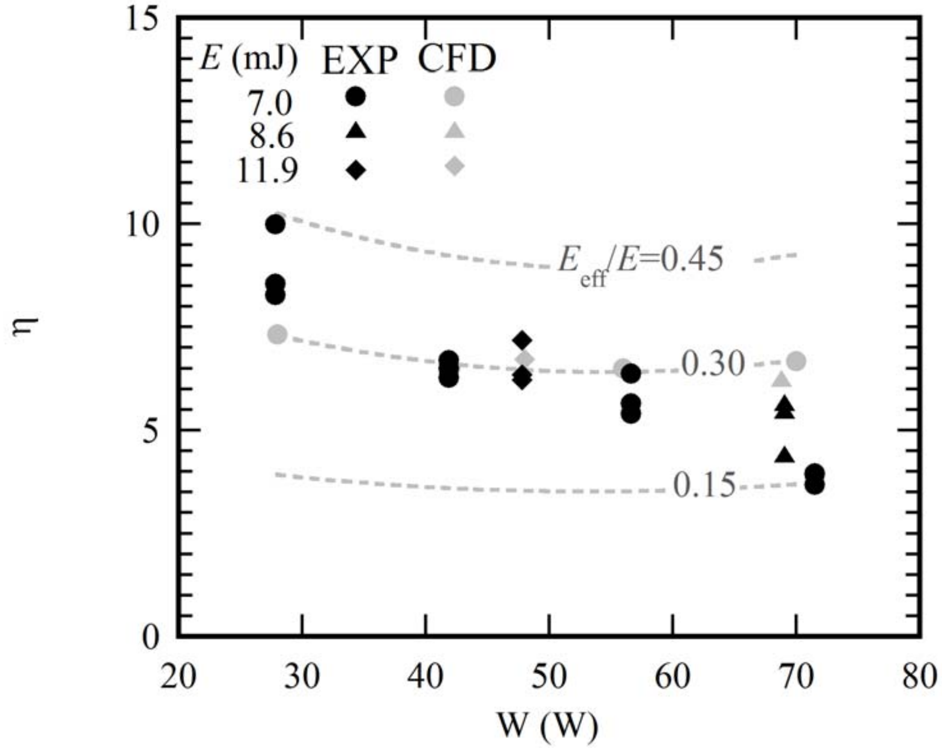
Time resolution; 30 ns

Drag Reduction Performance

Normalized drag reduction



Efficiency of energy deposition



(flow speed) (drag decrement)

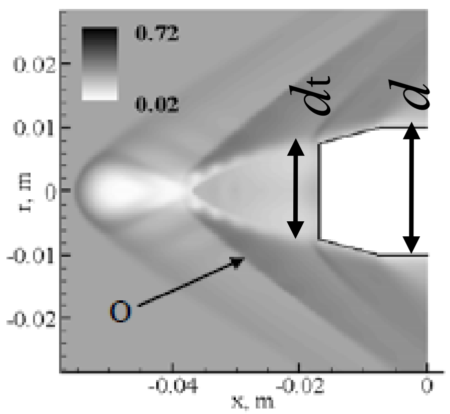
$$\eta \equiv \frac{U_0 \Delta D}{fE} = \frac{U_0 \Delta D}{W}$$

(repetition frequency) (laser energy/pulse)

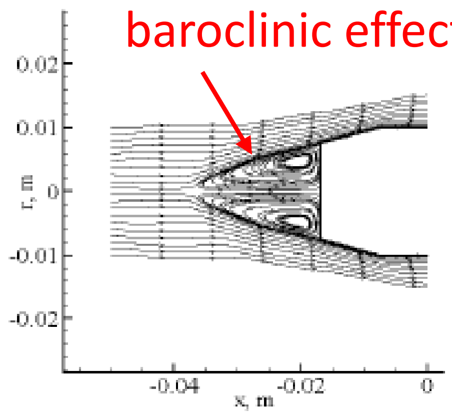
Truncated Cone (Sakai 2009)
- lower-than-cone drag & energy saving -

Quasi-steady flow field
(Q=3mJ, f=100kHz)

Virtual spike due to baroclinic effect



Isopycnics

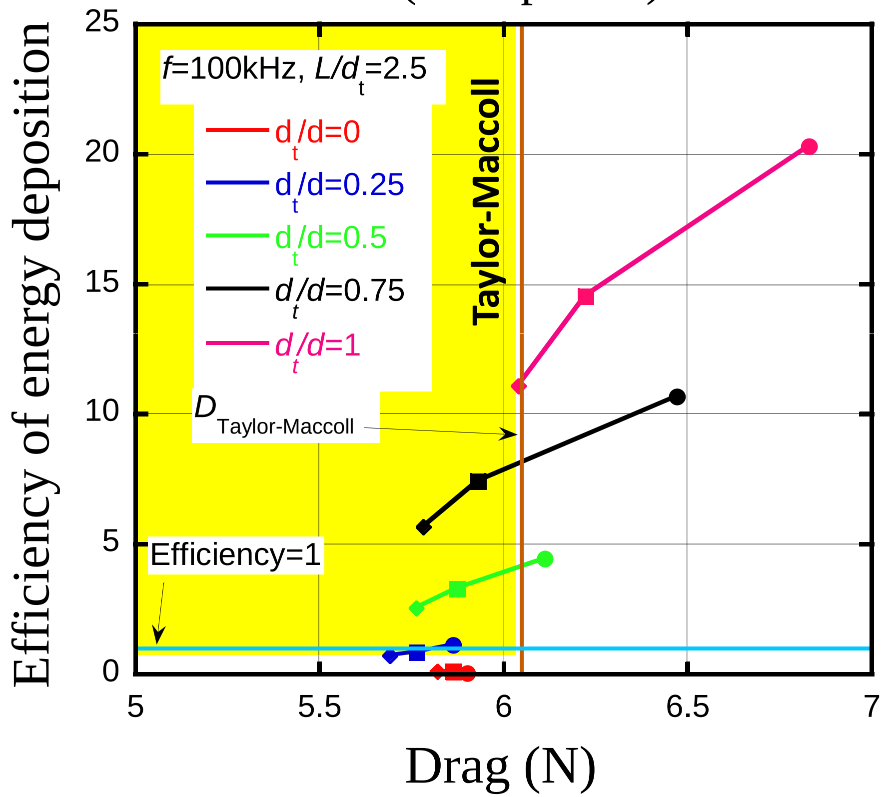


Streamlines

*Promising but necessary for experimental validation.

Drag vs. efficiency trade-off

$$\eta \equiv \frac{\text{(flow speed)(drag decrement)}}{\text{(laser power)}}$$



Repetitive Pulses Interactions

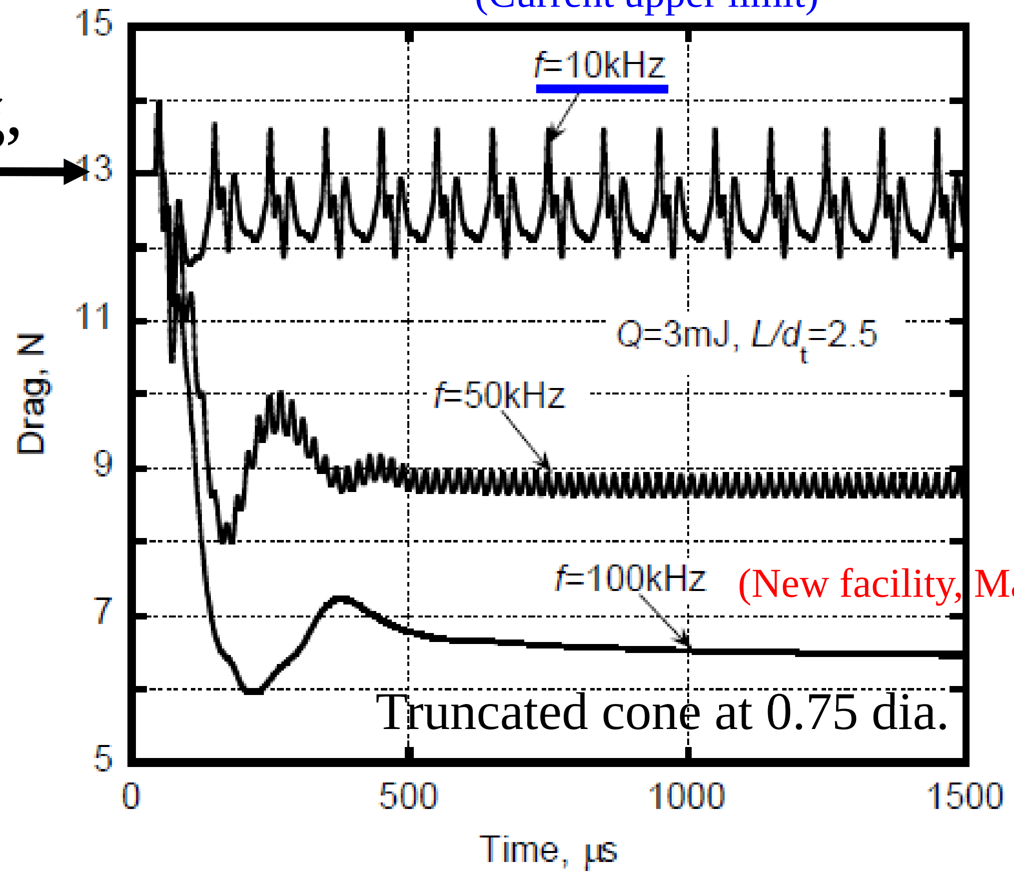
Drag reduction is enhanced when the repetition frequency is high enough to obtain strong pulse-to-pulse interactions

(Current upper limit)

Sakai et al 2008)

Q=3 mJ

D_0 (baseline drag, Q=0) 100%



96% (-4%)

67% (-33%)

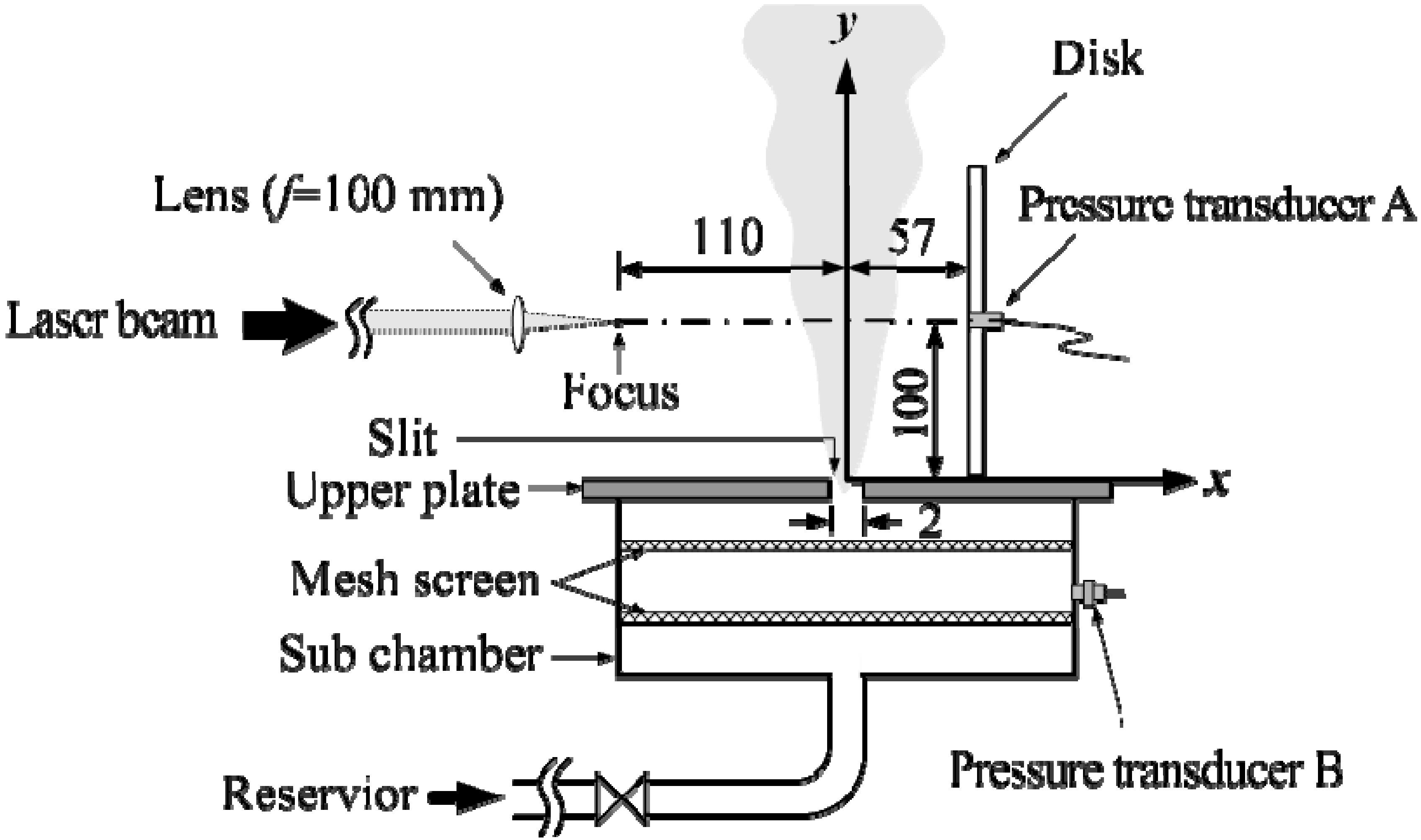
(New facility, March 2010)

50% (-50%)

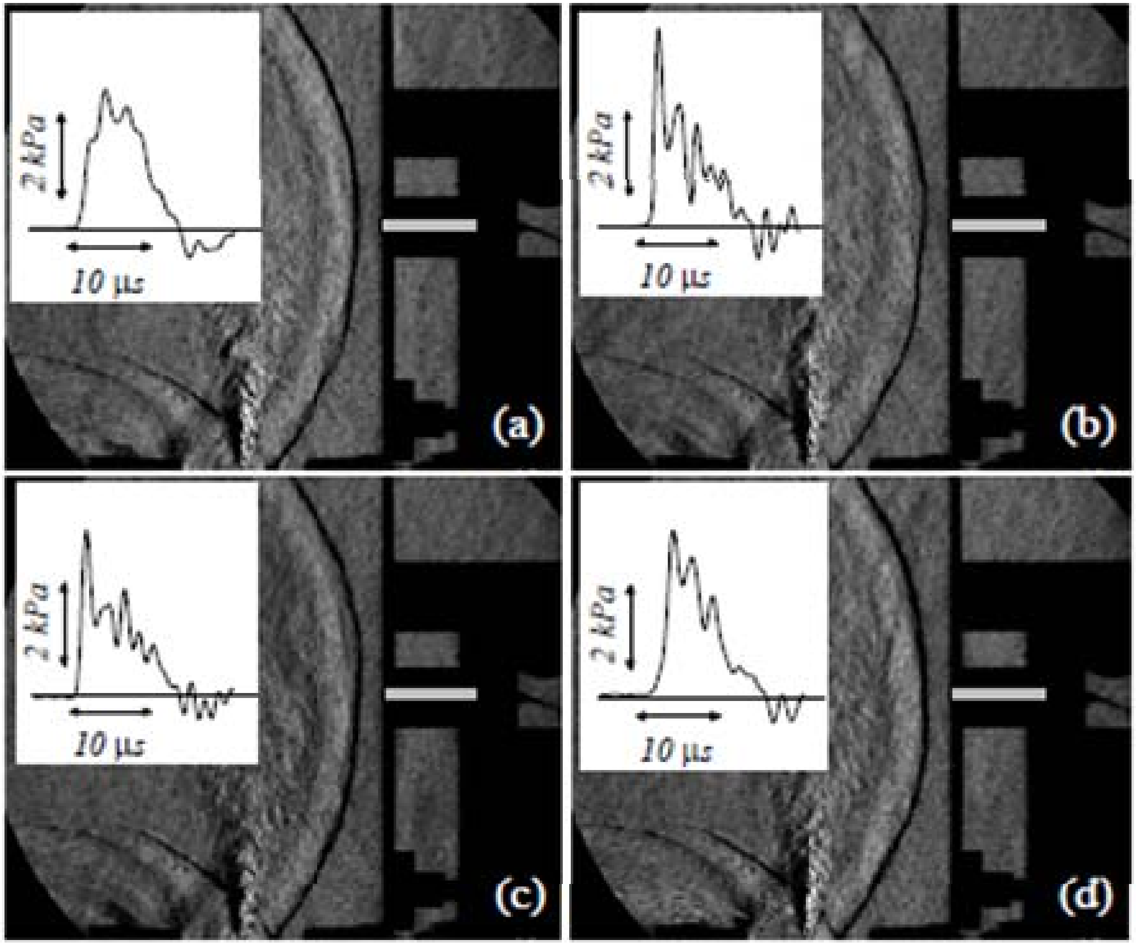
Experiment Using ISAS/JAXA Blow-Down Wind Tunnel

Photo, Sept. 15, 2009

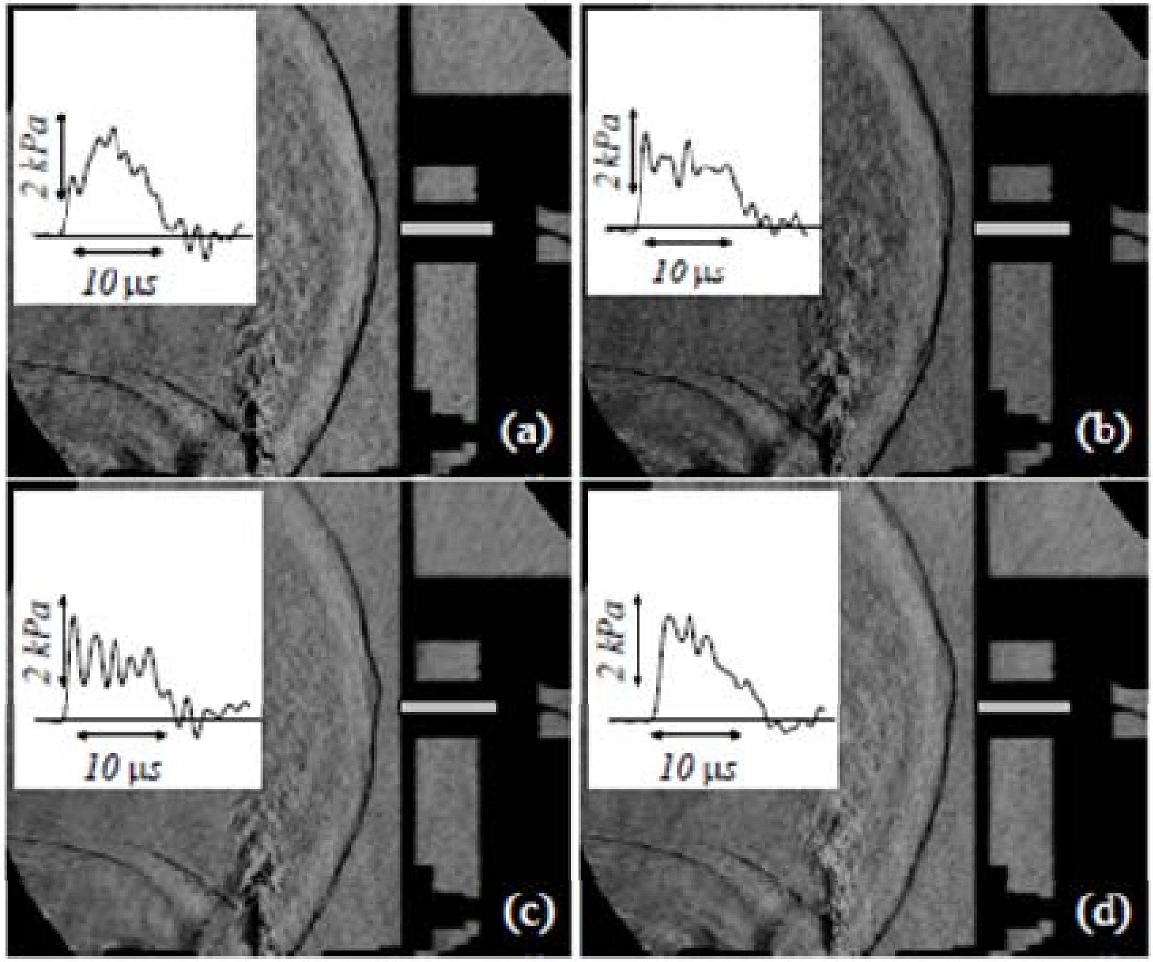
3. Interaction between Laser-Induced-Shock Wave and Turbulent-Jet



Enhanced Modulation

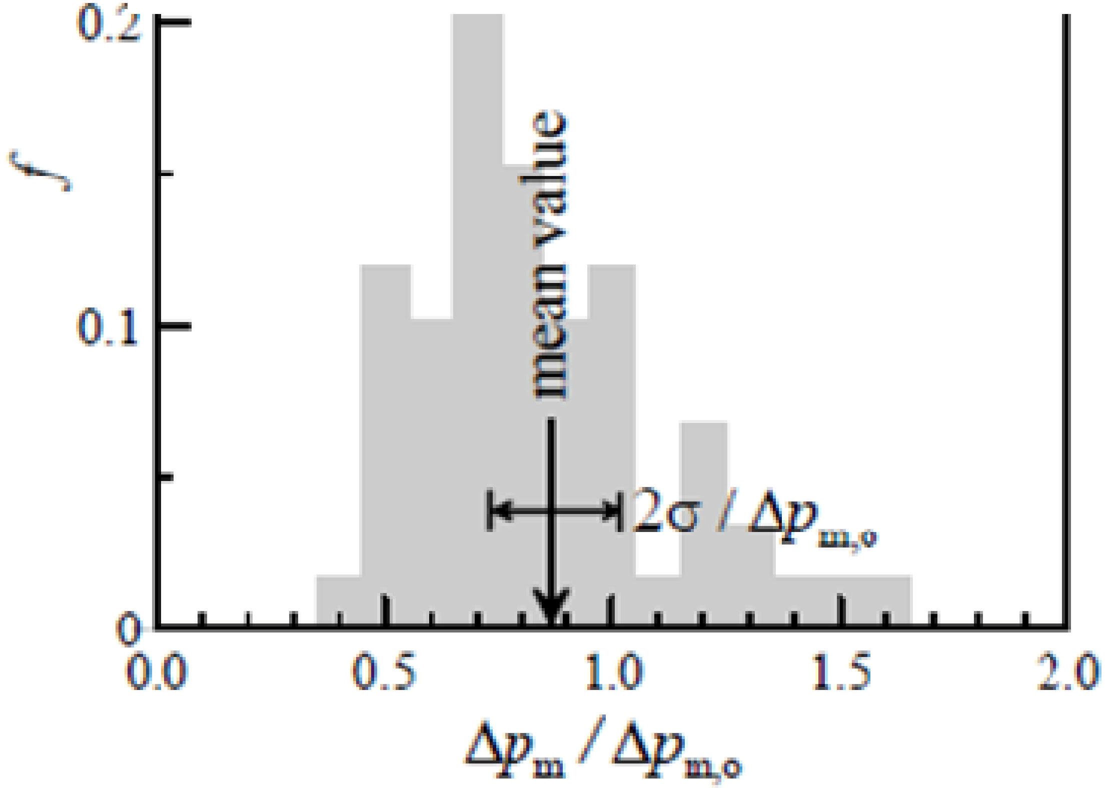


Weakened Modulation



Pressure Modulation is NOT Deterministic

	Mean value (kPa)	σ
Without slit jet	3.11	0.03
With slit jet	2.73	0.85



Last Remarks

- Laser pulses can induce drastic modulation in flow motion which has a much larger power.
- This is equivalent to a Judo discipline “A small can beat a big.”

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