

# **Experimental Investigation of a Long Rise-Time Pressure Signature through Turbulent Medium**

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**Boeing Executive Seminar**

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Tohoku University

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# Super Sonic Transport (SST)

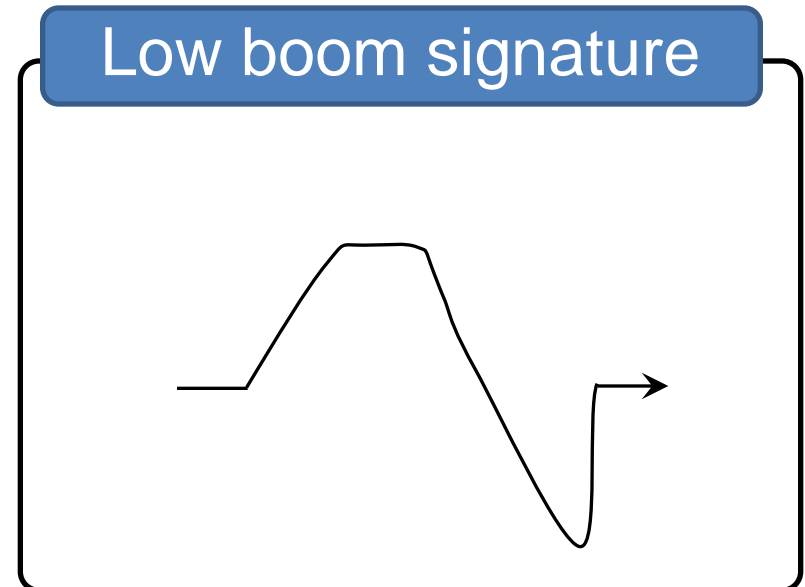
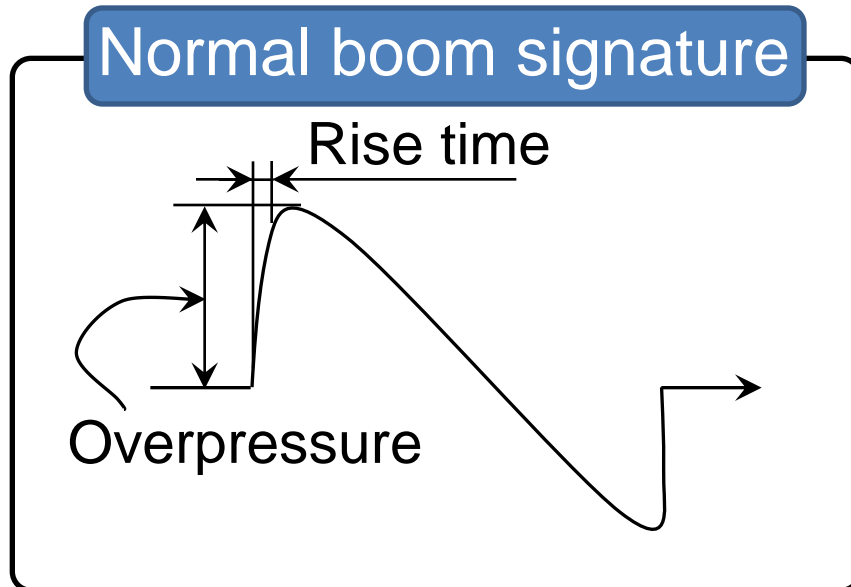
## ➤ Requirements for SST

- ✓ Sonic boom reduction
- ✓ Low-fuel consumption



Concorde SST, <http://www.concordesst.com/home.html>, (cited 19 January 2010)

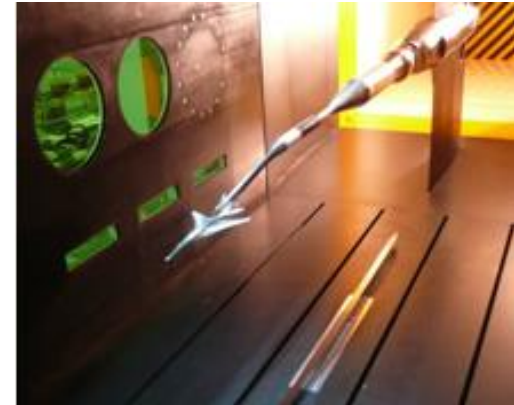
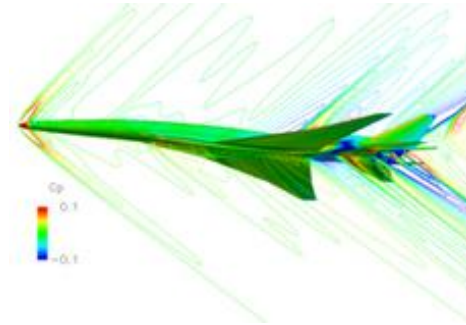
## ➤ Sonic boom signatures



# Sonic boom estimation

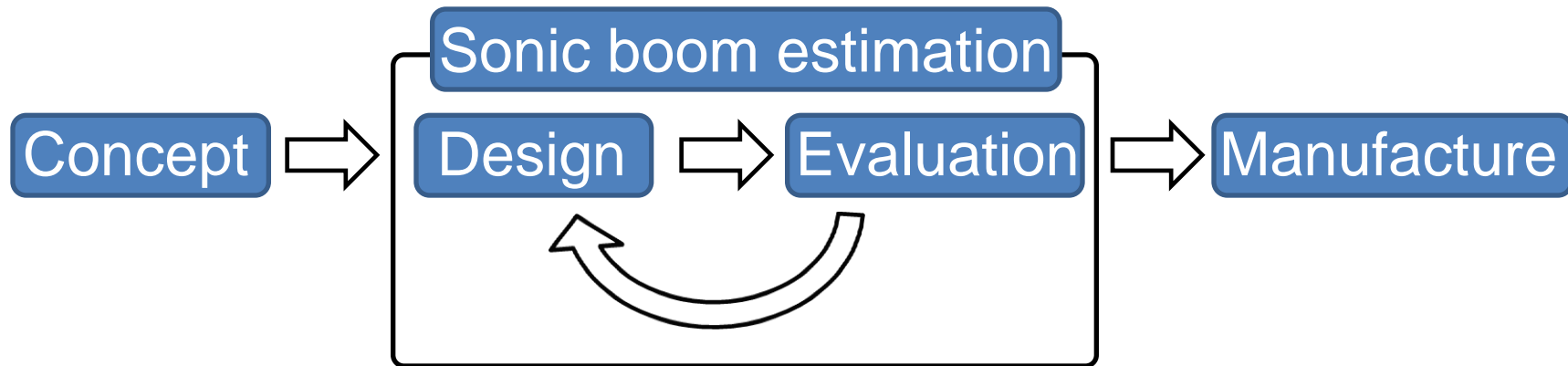
## ➤ Estimation tools

- ✓ Numerical simulation
- ✓ Wind tunnel testing



JAXA HP <http://www.aero.jaxa.jp/research/kitaisystem/cyoonsoku/co-index.html>

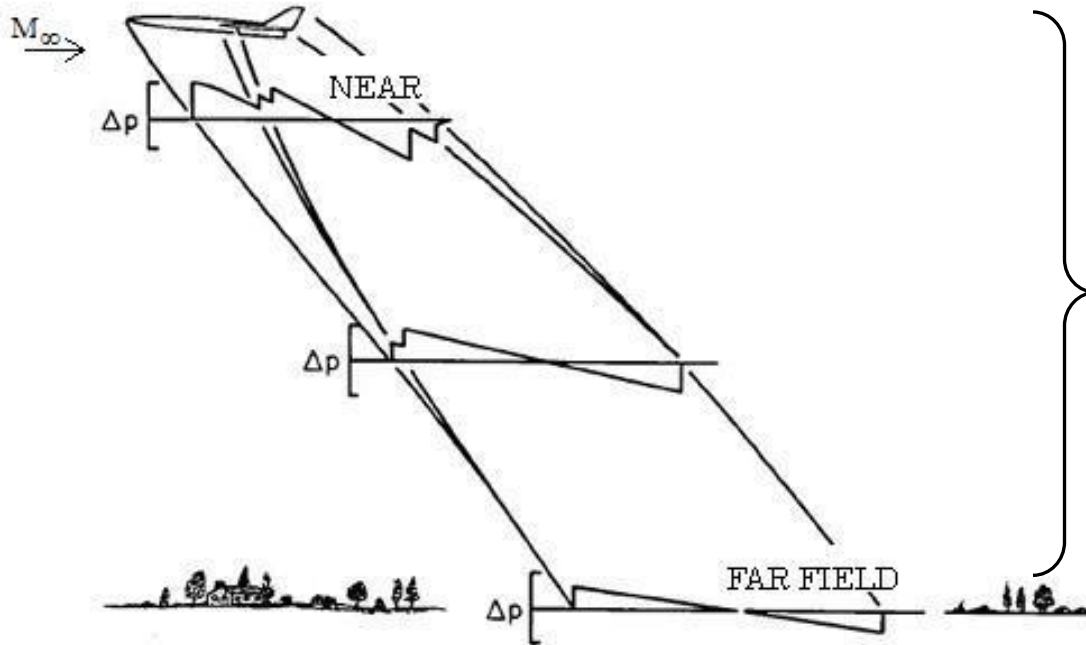
## ➤ Design procedure



Sonic boom estimation is important to realize SST

# Effect of the real atmosphere

## ➤ Sonic boom propagating



Carlson, NASA SP-147, p.10, (1967)

Real atmosphere  
Various conditions

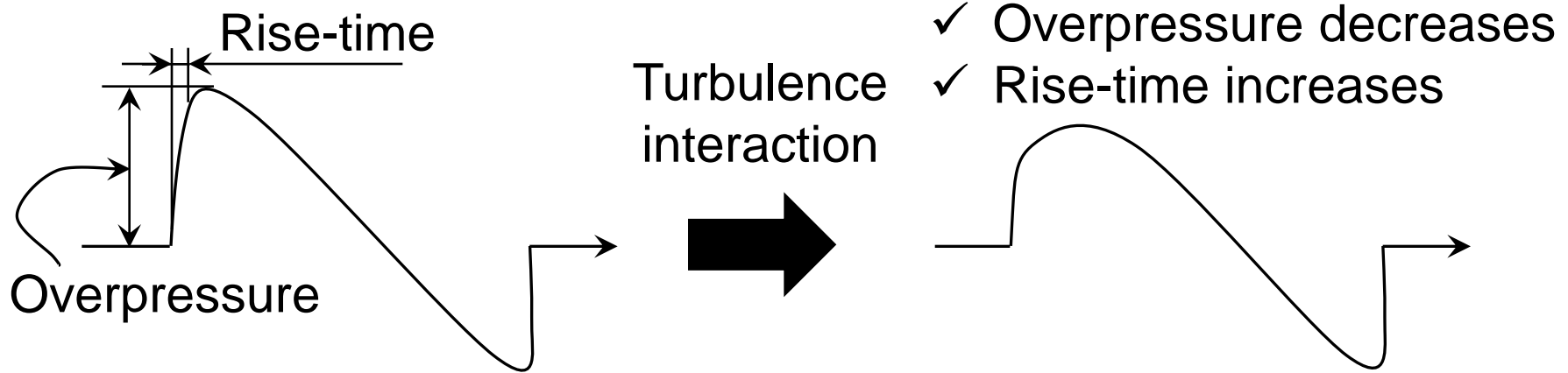
- ✓ Turbulence
- ✓ Humidity
- ✓ Temperature

## ➤ The pressure waveforms affected by turbulence



Lee *et. al*, AL-TR-1991-0099, (1991)

# Effect of turbulence



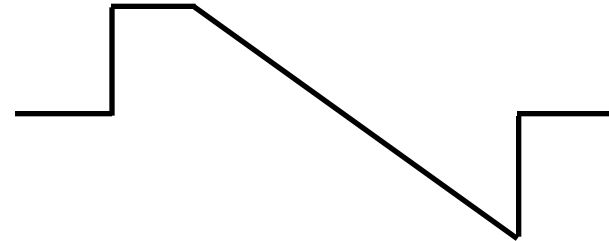
	<b>Normal</b> sonic boom signature	<b>Low</b> sonic boom signature
Typical waveforms		
Turbulence effects	<b>Known</b>	<b>Unknown</b>

# Phenomenon observed in flight tests

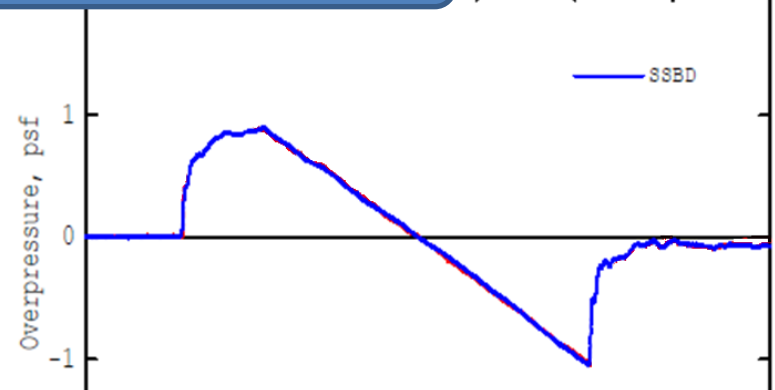
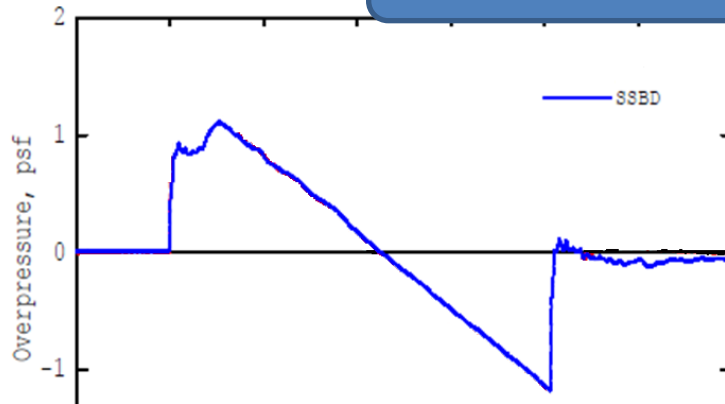


Kenneth *et al.* AIAA paper 2004-2923 (2004)

Estimated waveform



Measured at the ground



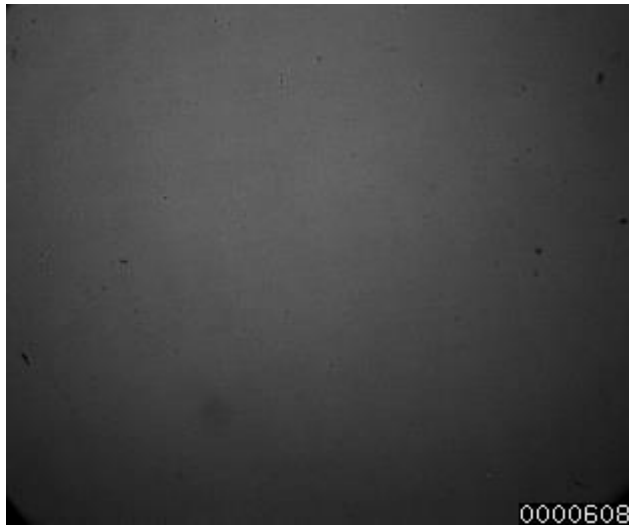
The low sonic boom signature is also affected by turbulence

Time, seconds from bow shock

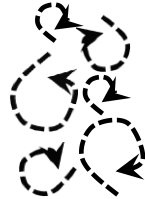
Time, seconds from bow shock

# Laboratory-scale experiments

## Ballistic range

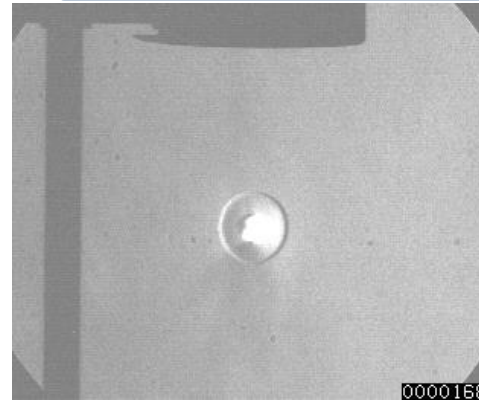


Controllable turbulence

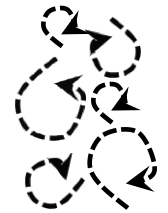


Arbitrarily shaped Waveform

## Spark generator

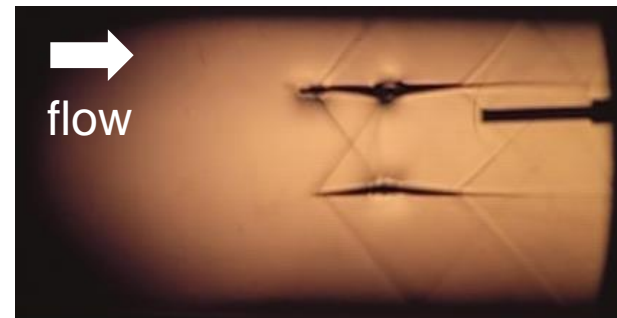


Controllable turbulence

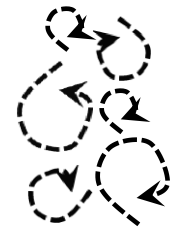


Waveform with N-shape

## Wind tunnel



Uncontrollable turbulence



Ballistic ranges have ability to simulate turbulence interaction with a low sonic boom

# Objective

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Investigate the effect of turbulence on a pressure signature with the long rise time in a ballistic range facility

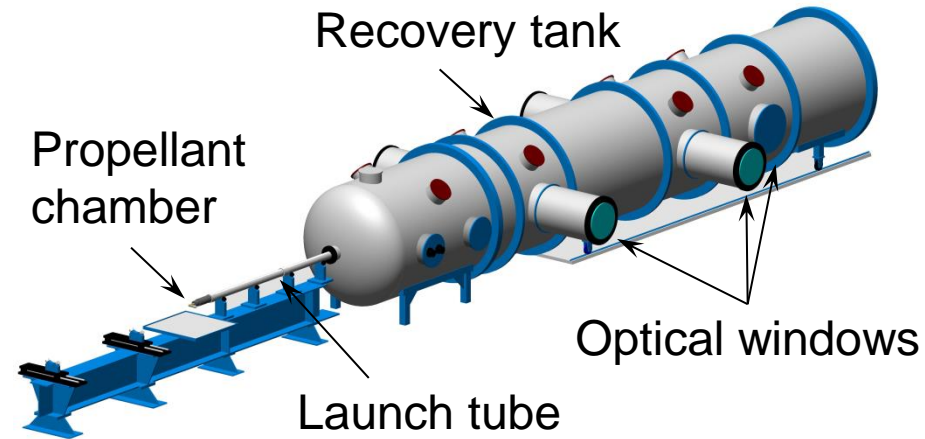
- Evaluate a distortion of a waveform with N-shape
- Evaluate a distortion of a waveform with the long rise time



# Experimental setup

## ➤ Ballistic range in Institute of Fluid Science, Tohoku Univ.

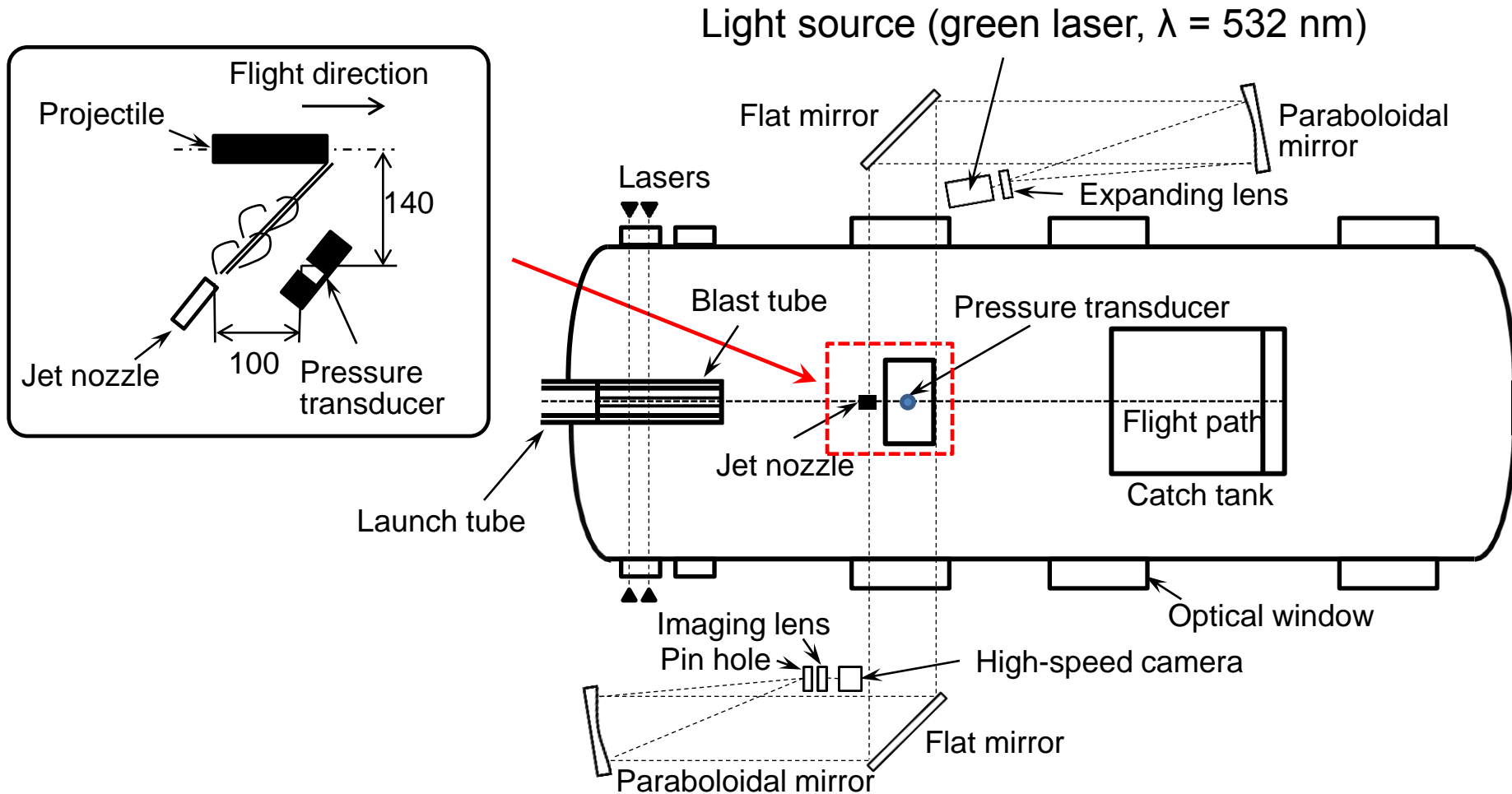
- ✓ Flight Mach number up to 7.2
- ✓ Projectile diameter of 15 mm
- ✓ Test section:  $L = 12$  m,  $D = 1.66$  m



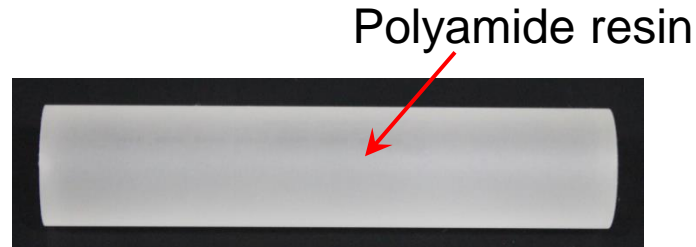
## ➤ Measurement techniques

- ✓ Pressure transducer: Pressure waveform  
PCB Piezotronics, INC. Model-113B28  
Rise time under  $1 \mu\text{s}$ , resolution of 7 Pa
- ✓ Schlieren photography and point diffraction interferometry : Density field  
HPV-X Shimadzu Corp., high-speed camera  
200 kfps and the exposure time of  $1 \mu\text{s}$

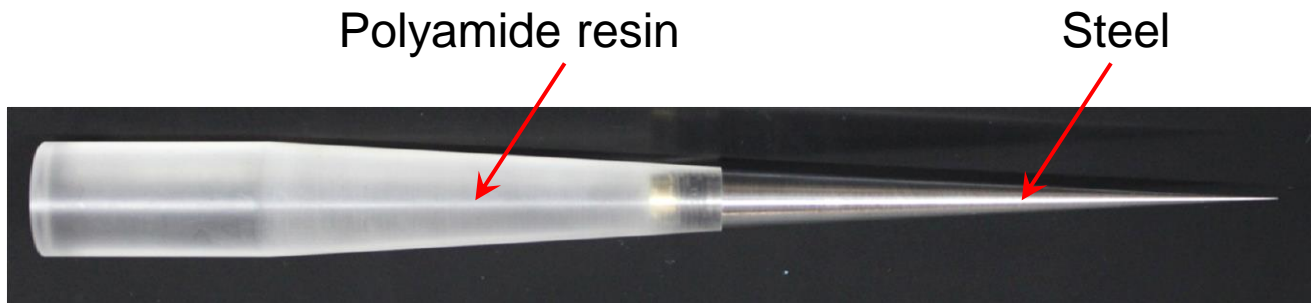
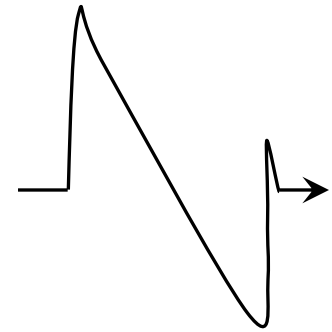
# Test section



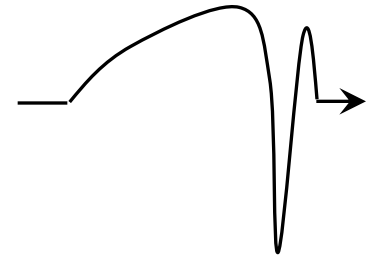
# Projectiles



Cylindrical projectile

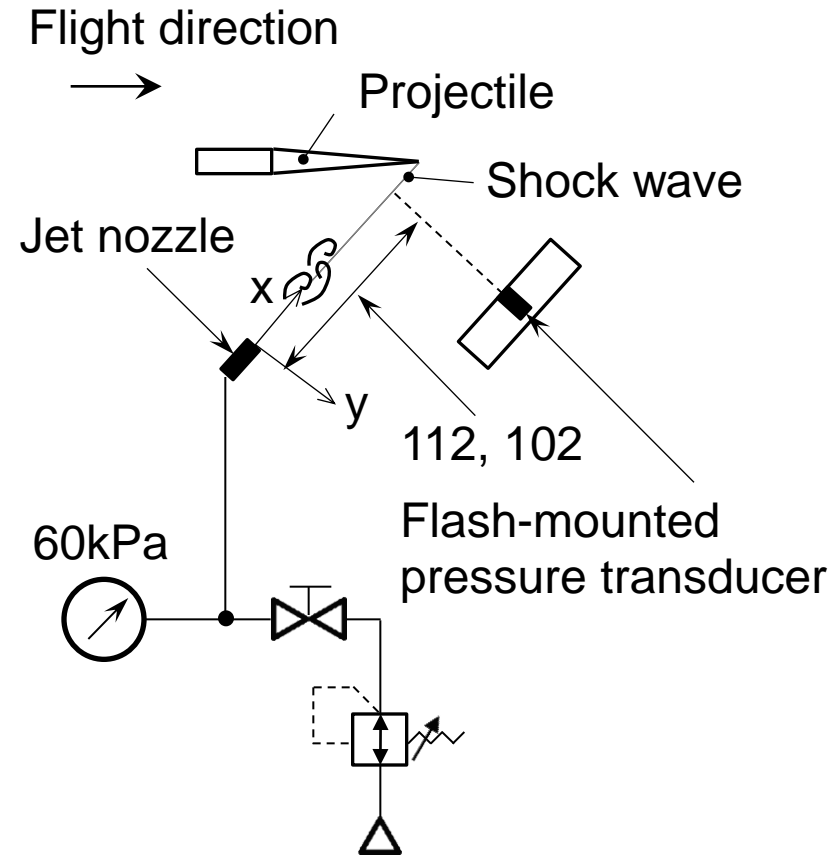
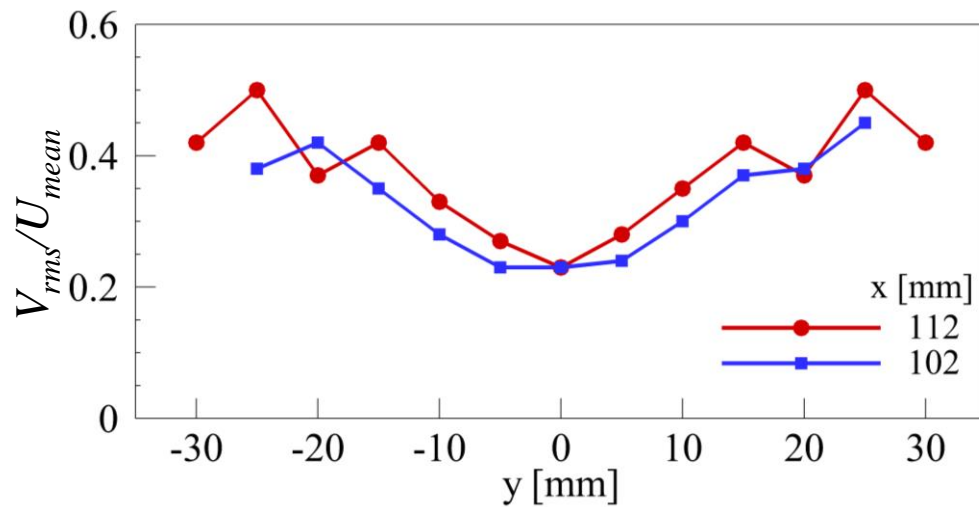
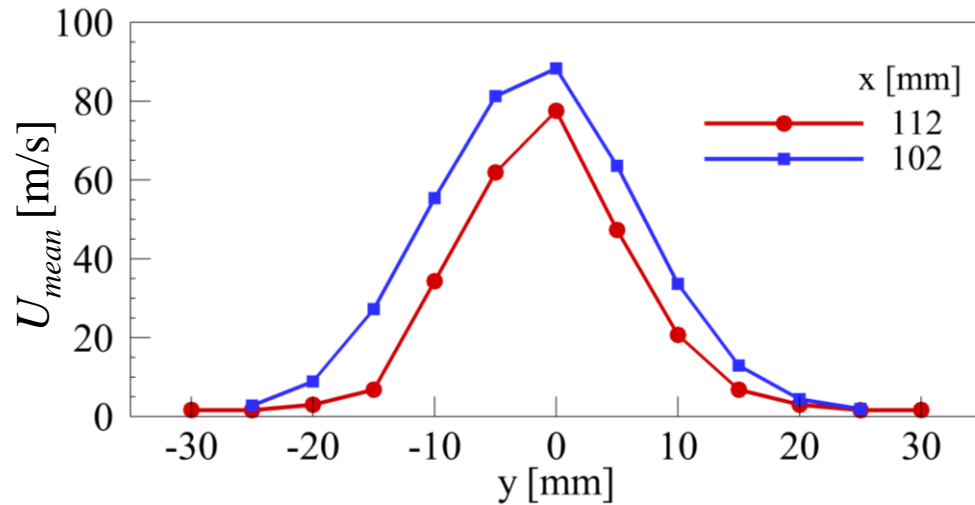


Conical projectile



- ✓ Setup flight Mach number of 1.4 and 1.5

# Specification of jet impingement



- ✓ Jet nozzle: 4.5 mm in inner diameter
- ✓ Jet gas: Dry air

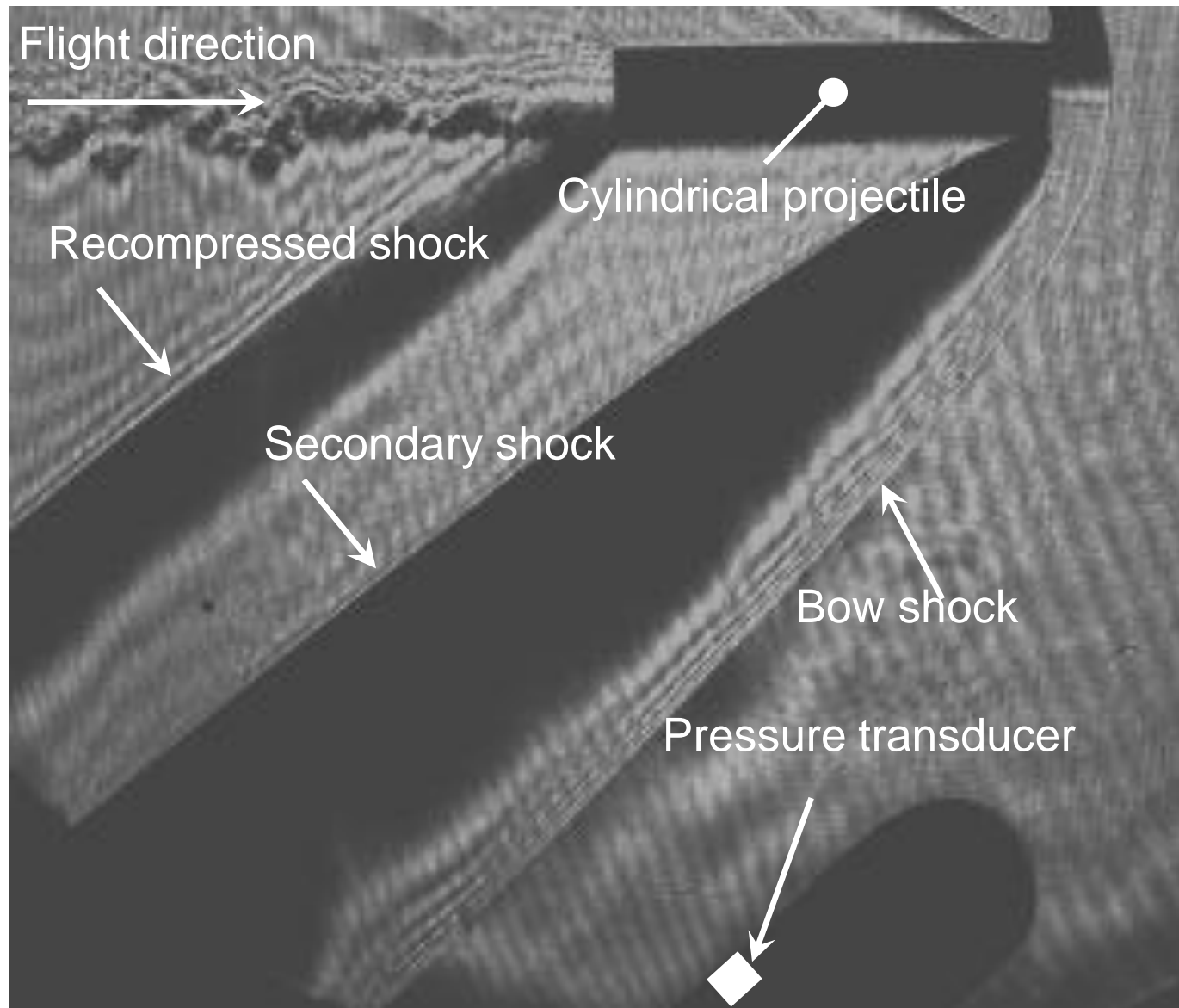
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# Results

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# Schlieren image (Cylindrical projectile)

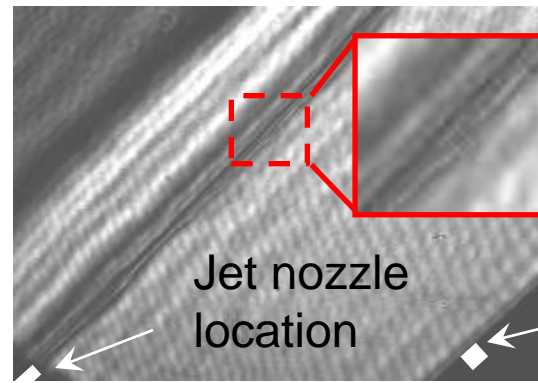
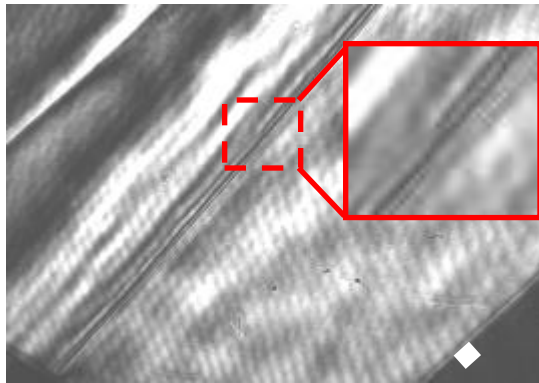
12



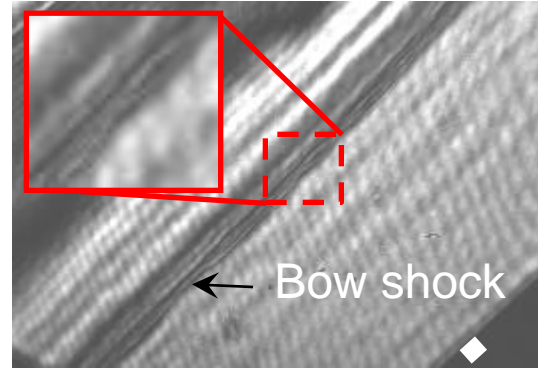
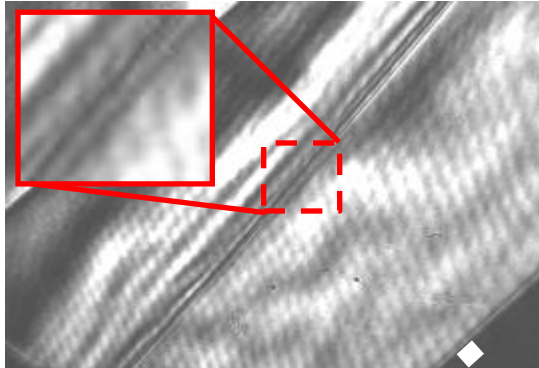
Without shock-turbulence interaction,  $M = 1.50$

# Sequential PDI images

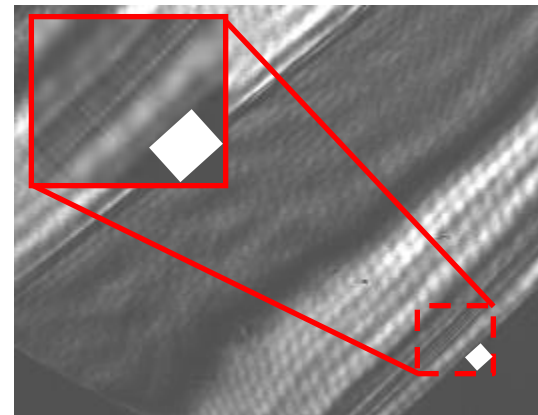
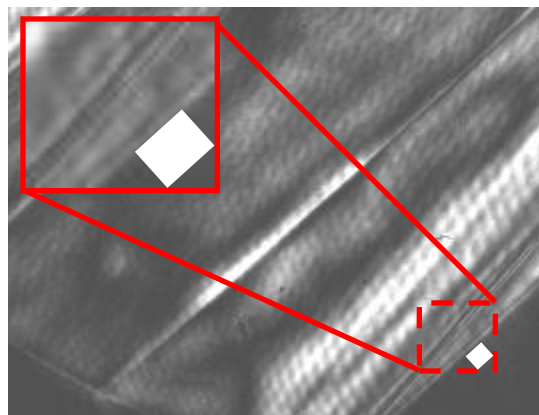
$\Delta t = 0 \mu\text{s}$



$\Delta t = 25 \mu\text{s}$



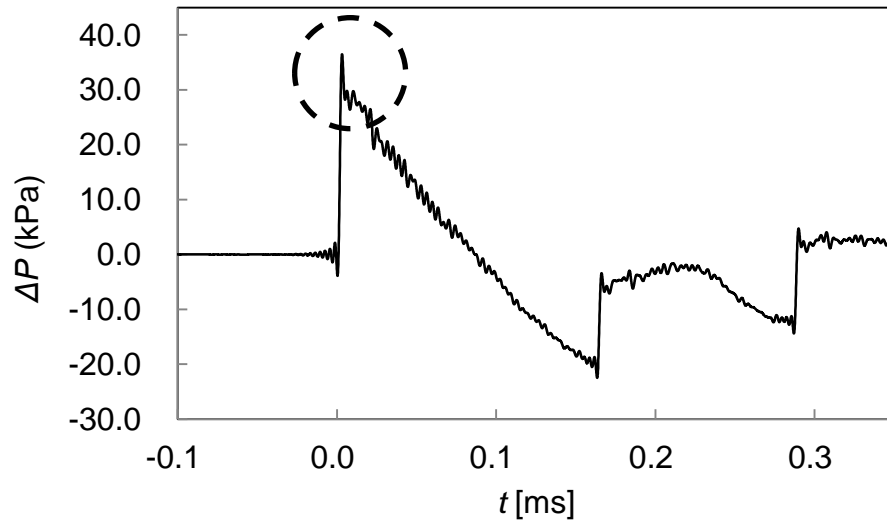
$\Delta t = 125 \mu\text{s}$



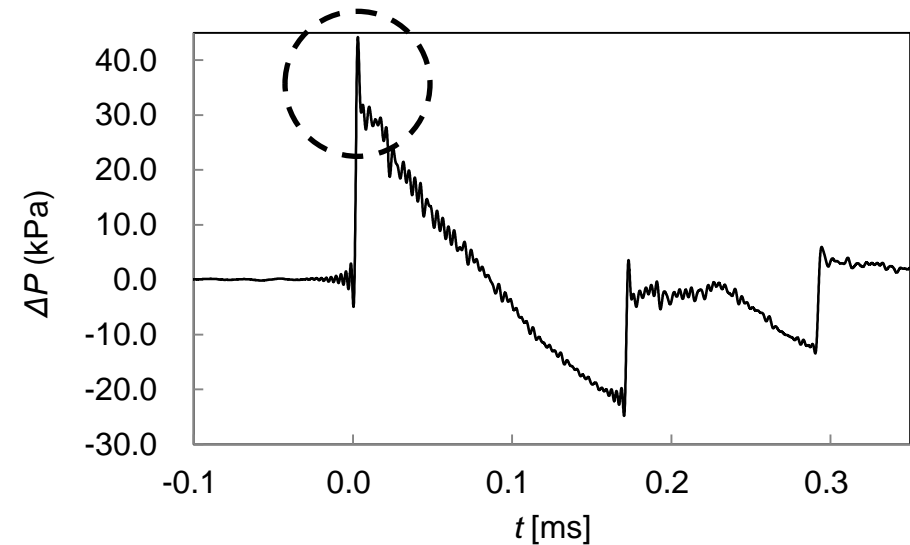
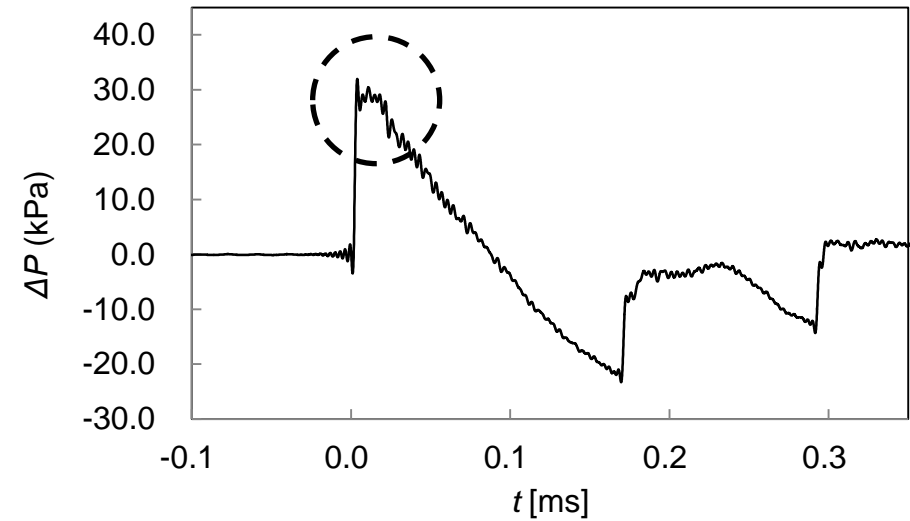
Without interaction

With interaction

# Processed pressure waveforms



Without turbulence

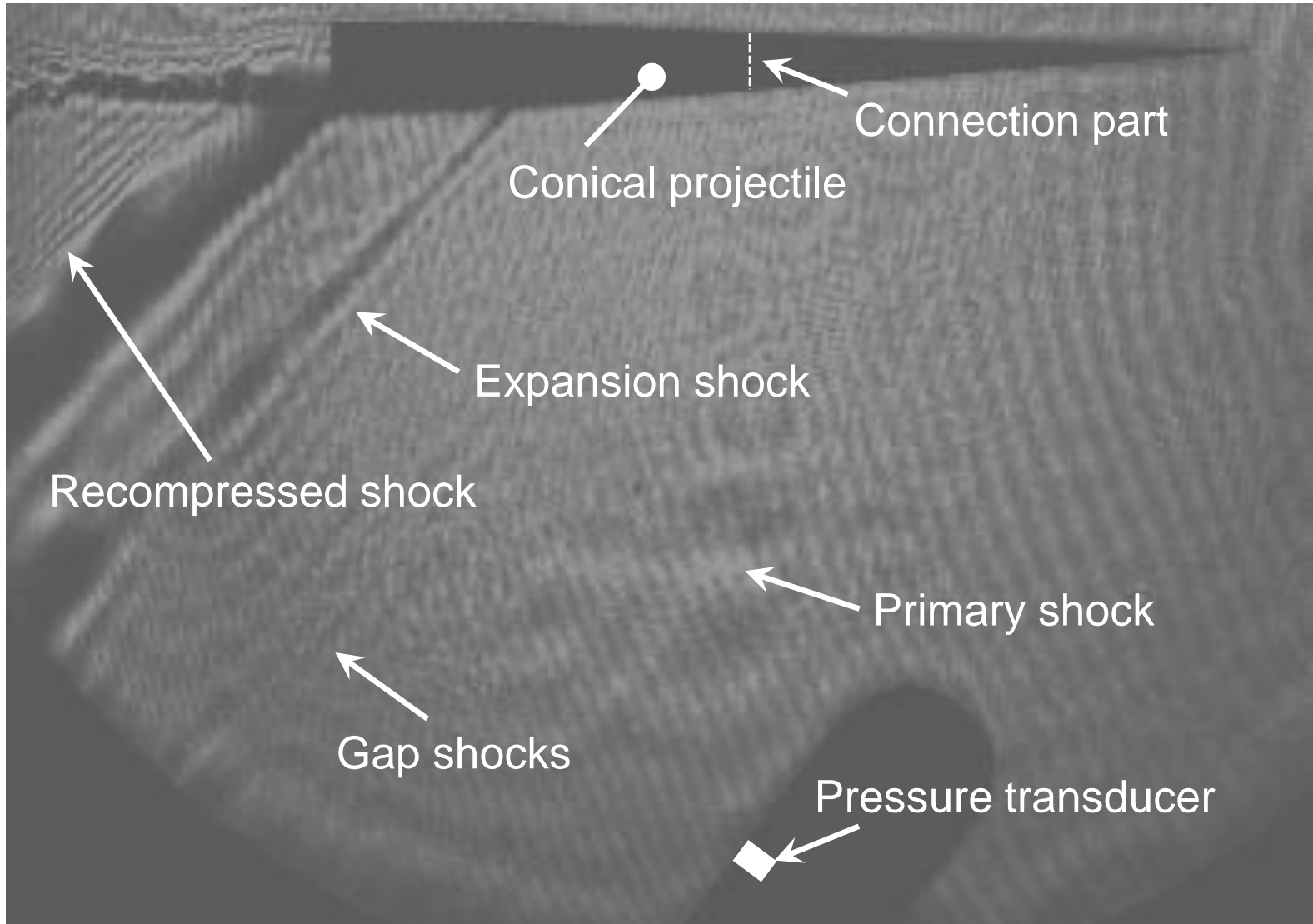


With turbulence



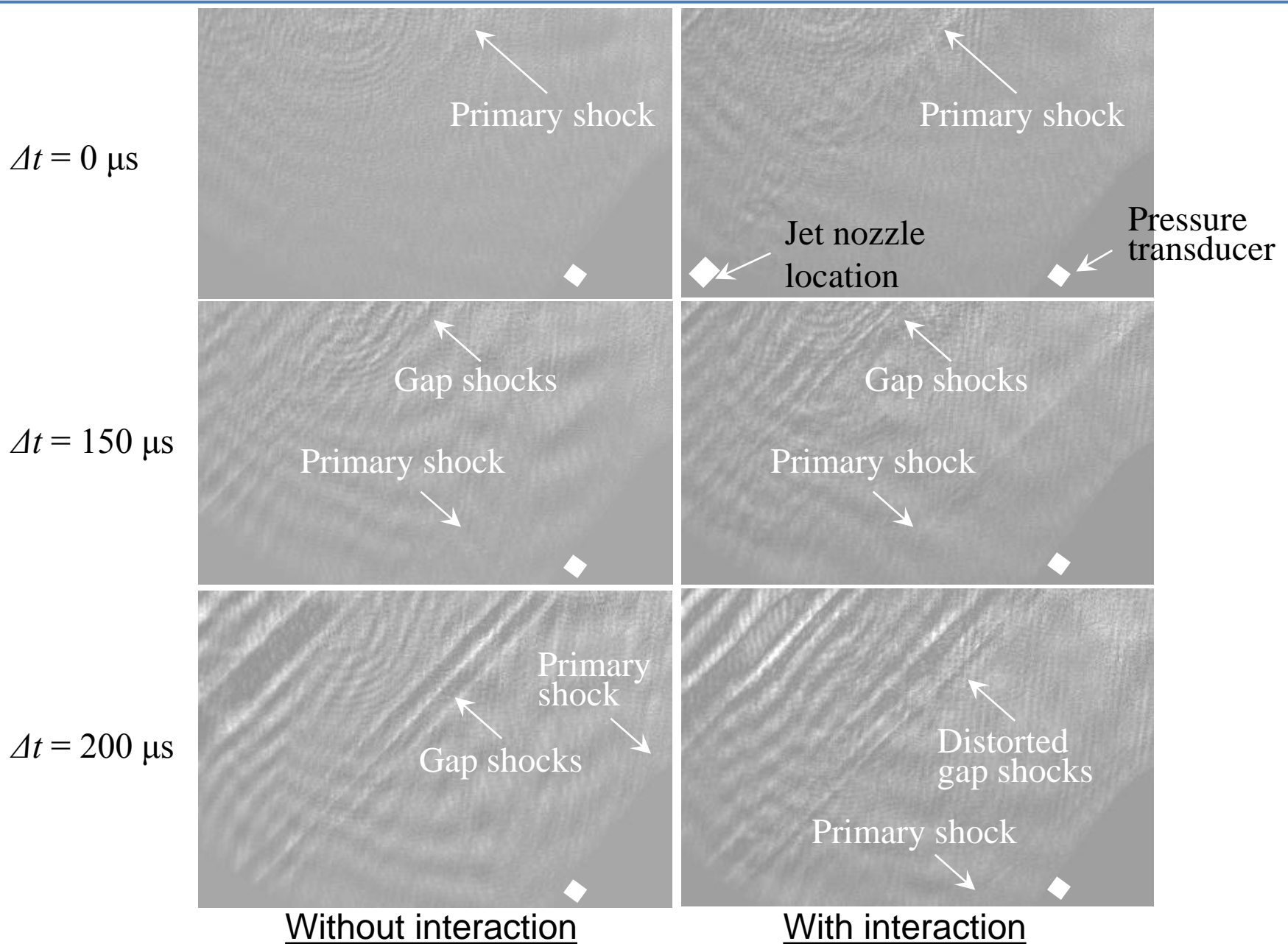
# Schlieren image (Conical projectile)

Flight direction  $\longrightarrow$

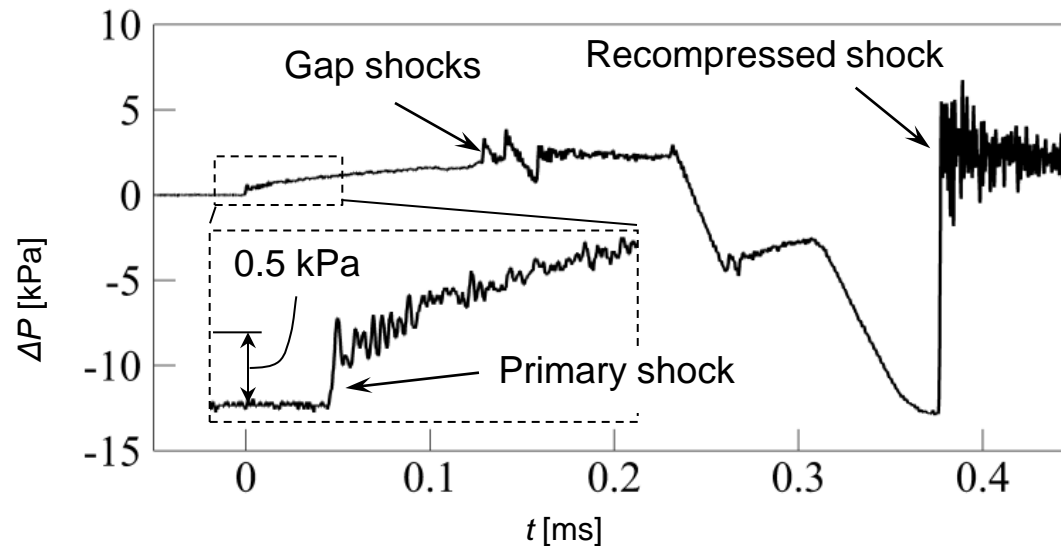


Without shock-turbulence interaction,  $M = 1.35$

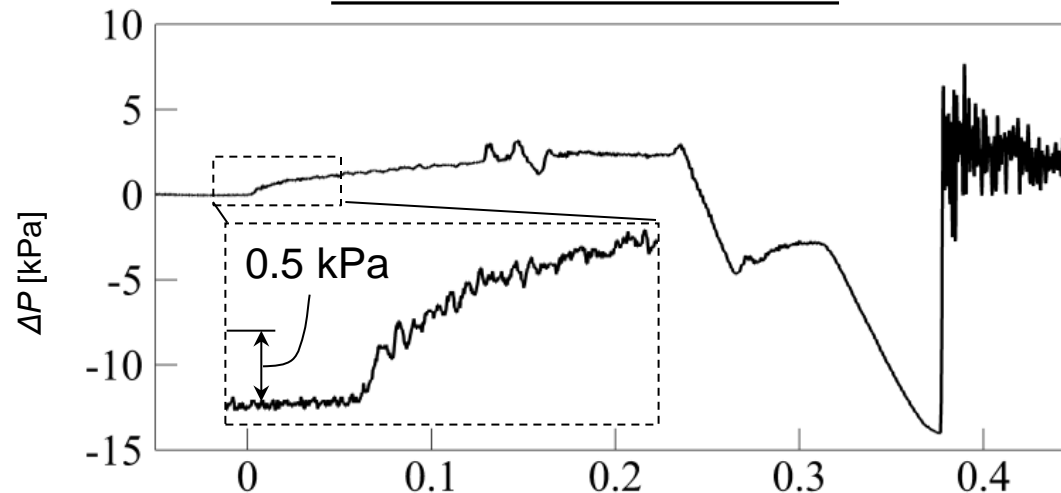
# Sequential schlieren images



# Pressure waveforms



Without interaction



The turbulence effect was not critical issue for the long rise time pressure signature

With interaction

# Summary

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Turbulence effect on a pressure signature with the long rise time was experimentally investigated in a ballistic range facility

- ✓ The effect of turbulence on the N-shape waveform can be investigated in present experiment because of consistent with previous observation.
- ✓ The shock wave front was distorted by turbulence.
- ✓ The turbulence might not affect the pressure field generating the long rise time.

## ➤ **Future works**

- ✓ Evaluate statistics value for the effect of turbulence on the long rise time pressure signature.
- ✓ Define the standard for evaluation of the long rise time pressure signature.

Thank you for your attention

**Questions?**