Aviation 2016
Washington D.C.
June 12-17,2016

NAGOYA UNIVERSITY

Near-Field Measurement of Post-Shock Pressure Modulation Induced by Supersonic Flight Model past a Grid Turbulence

A. Sasoh , A. Iwakawa , D. Furukawa , Y. Aoki
Nagoya University
Nagoya, Japan

AIAA-2016-3583

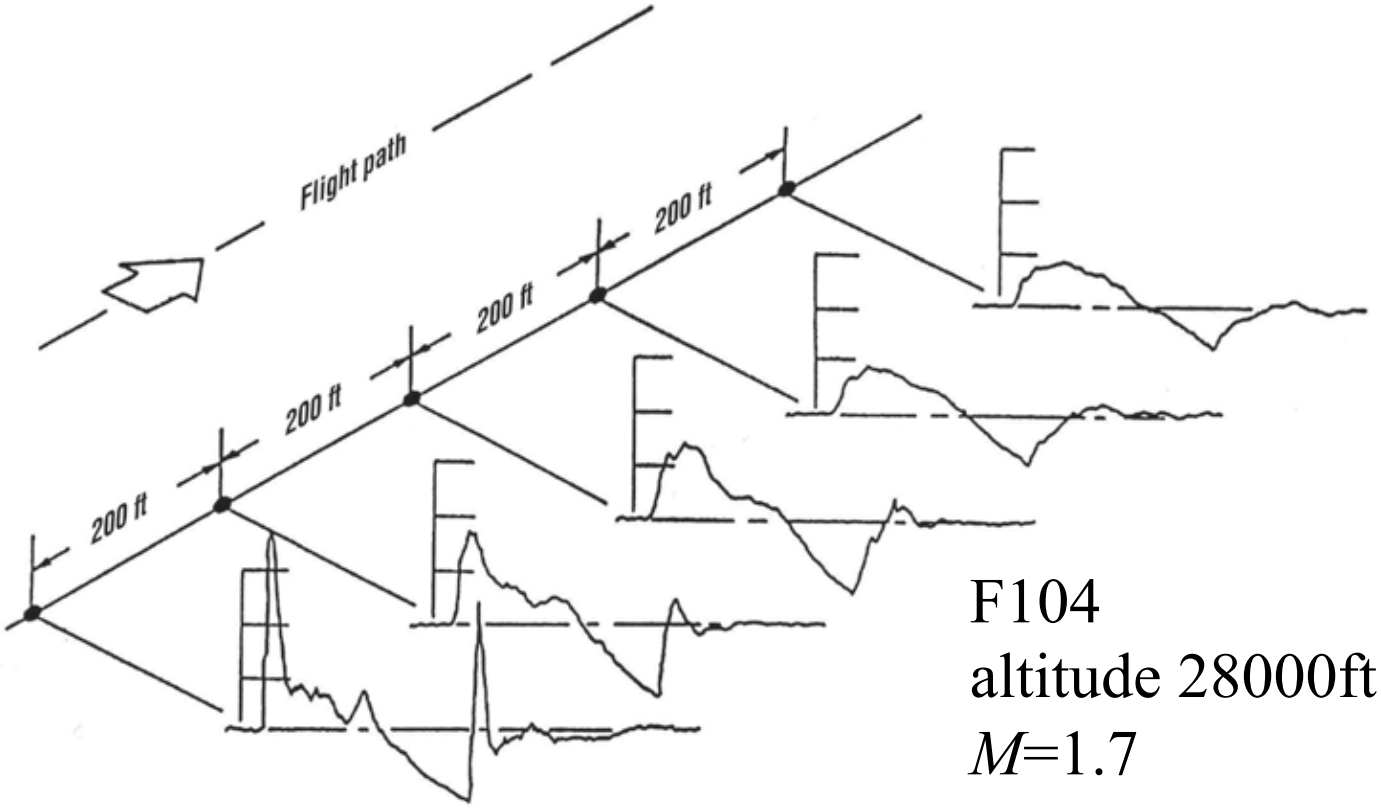
- This research is supported by JSPS (15H02321) and JAXA(27-J-J6710).

- D-SEND #2 field experiment at Esrange Space Center in Sweden, was done July 2015.

Outline

- Background
- Facility description: actively-controlled, rectangular-bore aero-ballistic range
- Results & discussions
  - Free flight through grid turbulence
  - Near-field pressure profile over D-SEND#2 body
  - Sonic boom moderation using a laser-induced thermal bubble
- Summary

Sonic boom is much affected by turbulence.



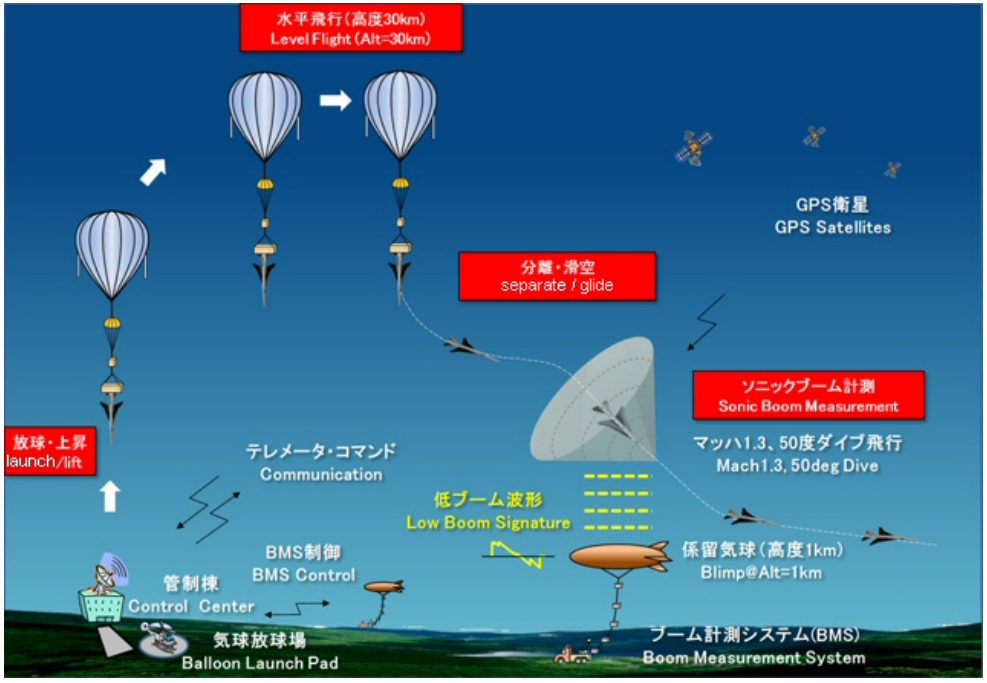
F104
altitude 28000ft
M=1.7

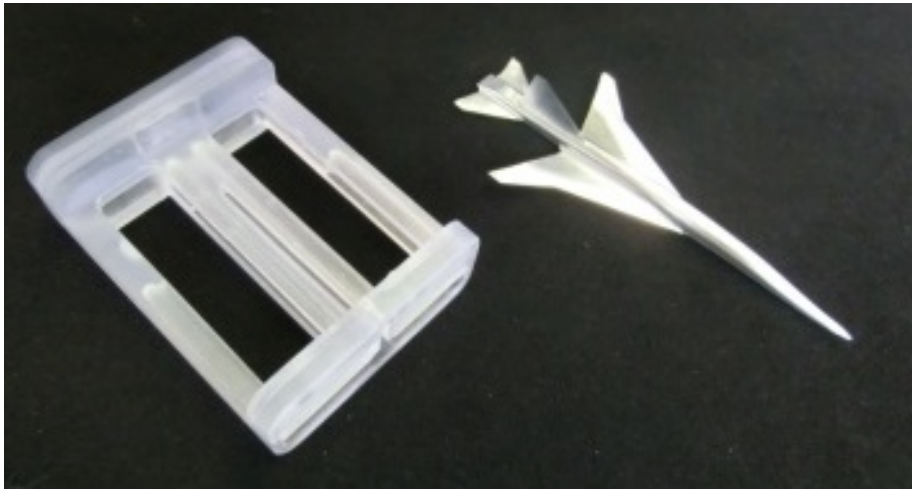
Hilton, David A. Huckel, Vera Steiner, Roy and Maglieri, Domenic J. Sonic Boom Exposures During FAA Community Response Studies Over a Six-Month Period in the Oklahoma City Area. NASA TN D-2539, 1964.

Laboratory free flight:D-SEND#2 model

D-SEND:
Drop test for **S**implified **E**valuation of **N**on-symmetrically **D**istributed sonic boom

Low boom signature during Mach 1.39 flight was measured at altitude=750m
D-SEND #2 field experiment at Esrange Space Center in Sweden,
was done in 24th July 2015.

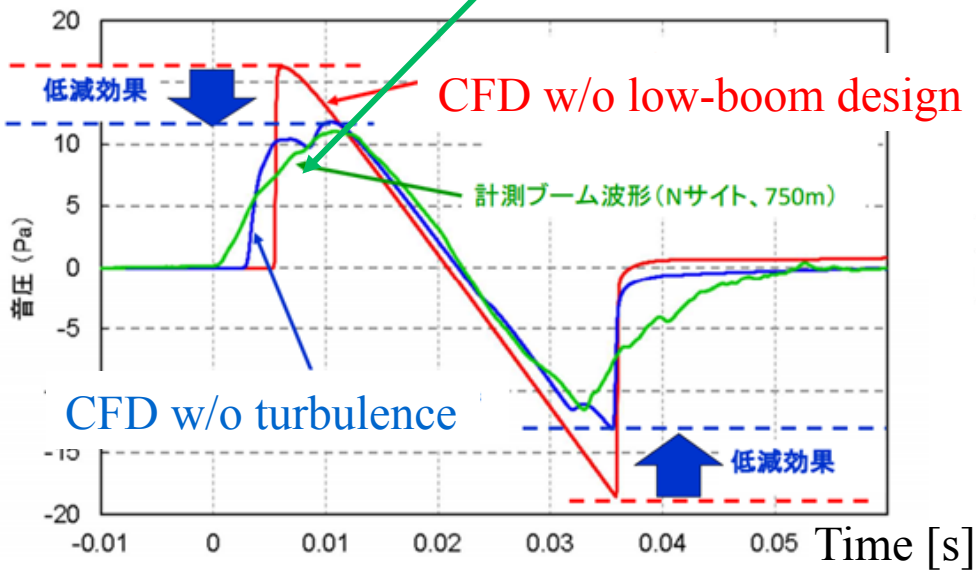


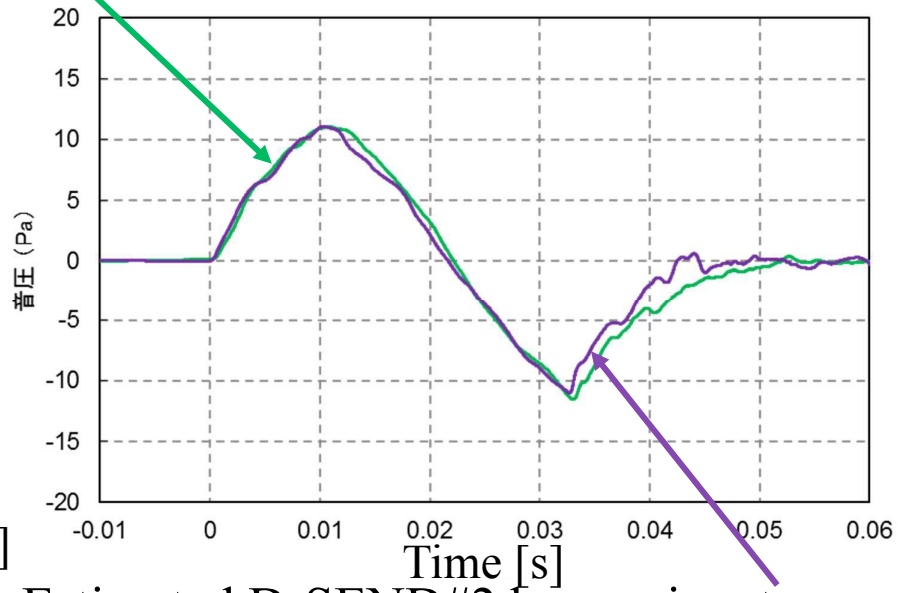


Model
length： 88.30mm
Span length： 40.02 mm

D-SEND#2 Flight Experiment, Interpretation

Experimental boom signature
(N sight, altitude 750m)





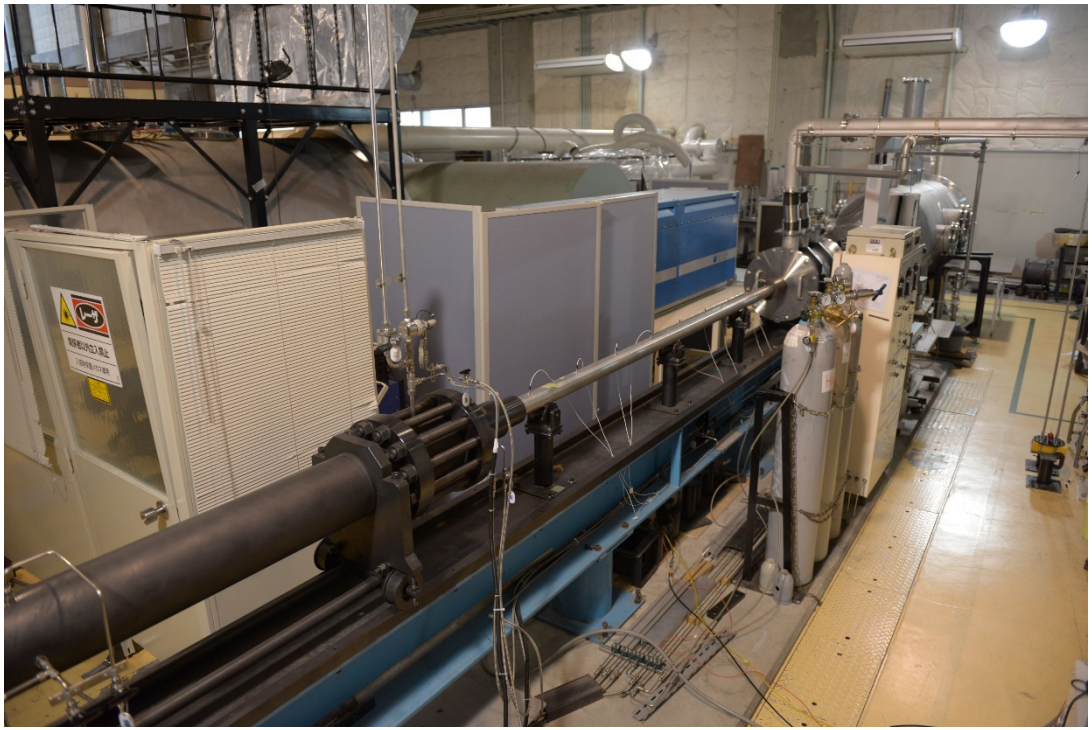
Estimated D-SEND#2 boom signature
by considering the effect of atmosphere
turbulence

Atmosphere turbulence can reproduce the measured signature.

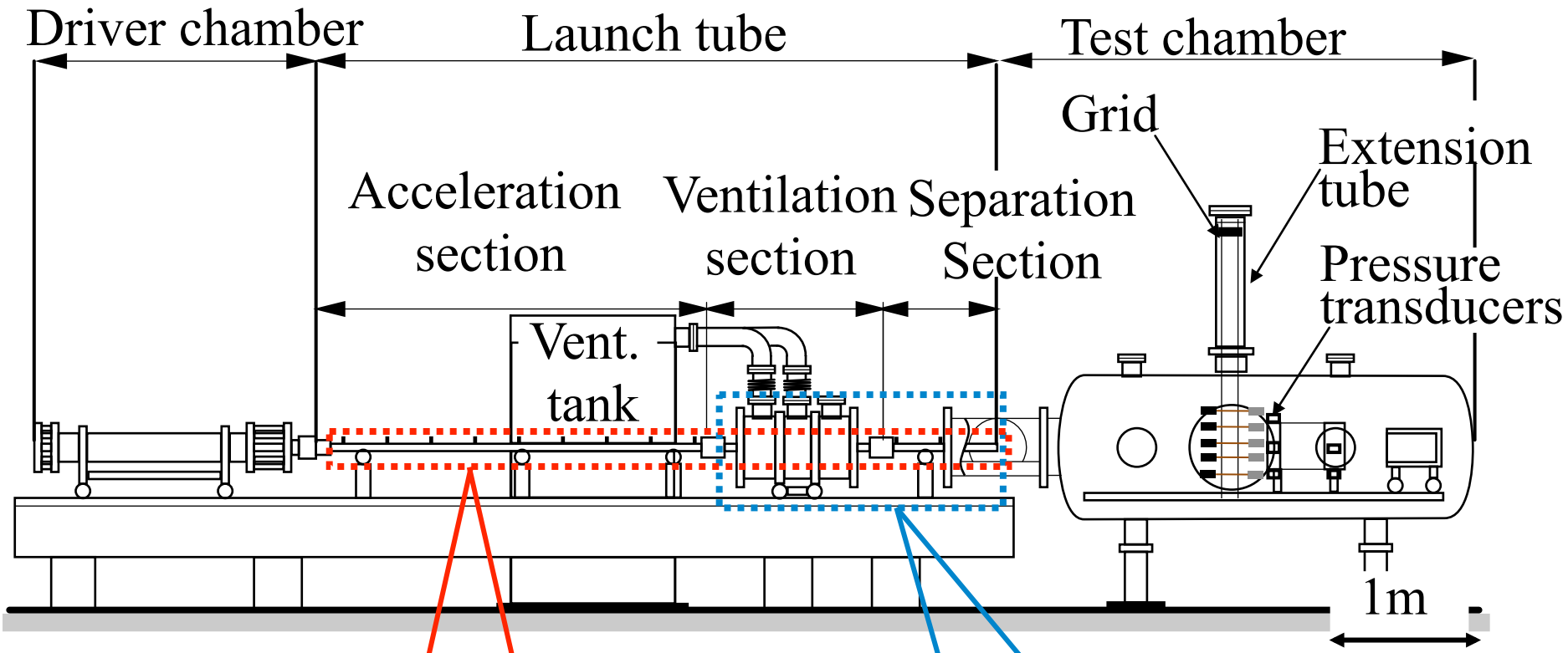
http://www.jaxa.jp/press/2015/12/files/20151224_dsend2_j_01.pdf

Objective

To evaluate near-field pressure signature over a supersonic model by free flight experiment using the aero-ballistic range. In particular, “actively-controlled” range operation system was developed to investigate impacts of artificial disturbances.

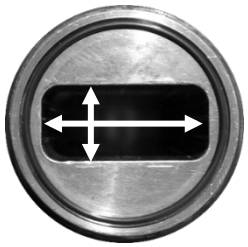


Rectangular-Bore Aeroballistic Range



Rectangular bore

→to launch airplane-like models

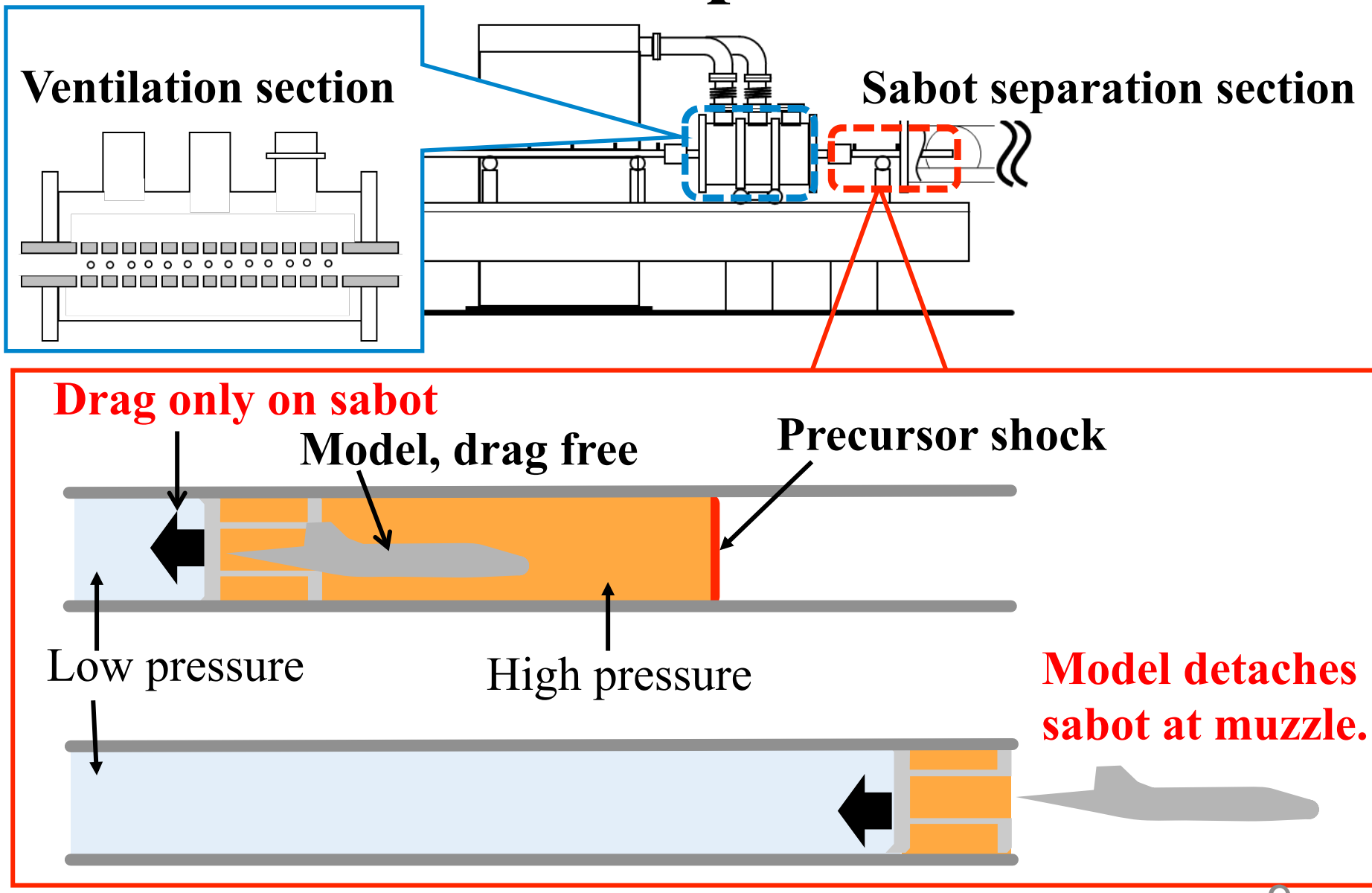


44mm×20 mm

In-tube catapult launch

→Model detached from sabot at the muzzle.

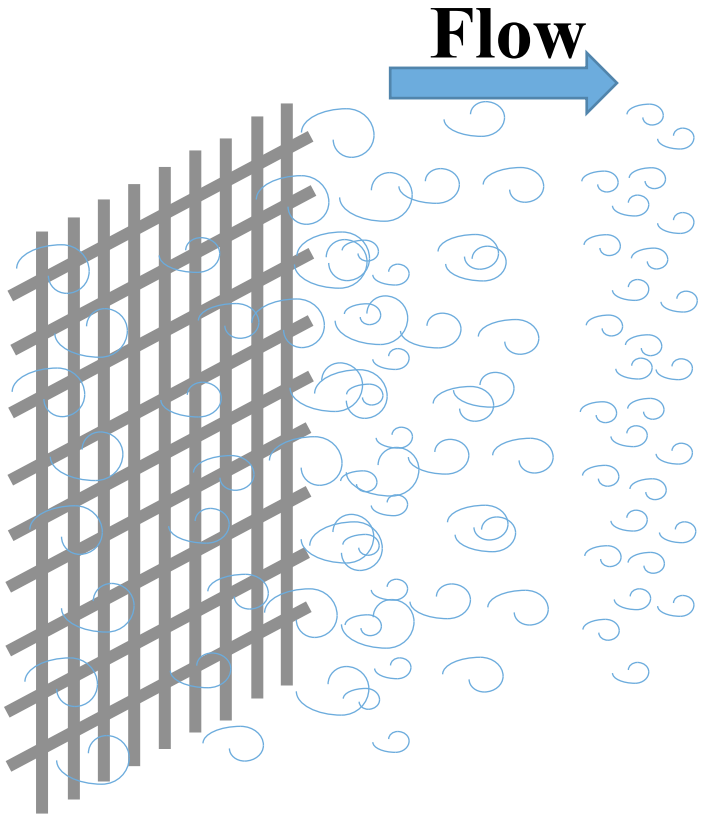
In-Tube Catapult Launch



(Sasoh, A.et al., *AIAA J.* 53, 9, 2781-2784, 2015)

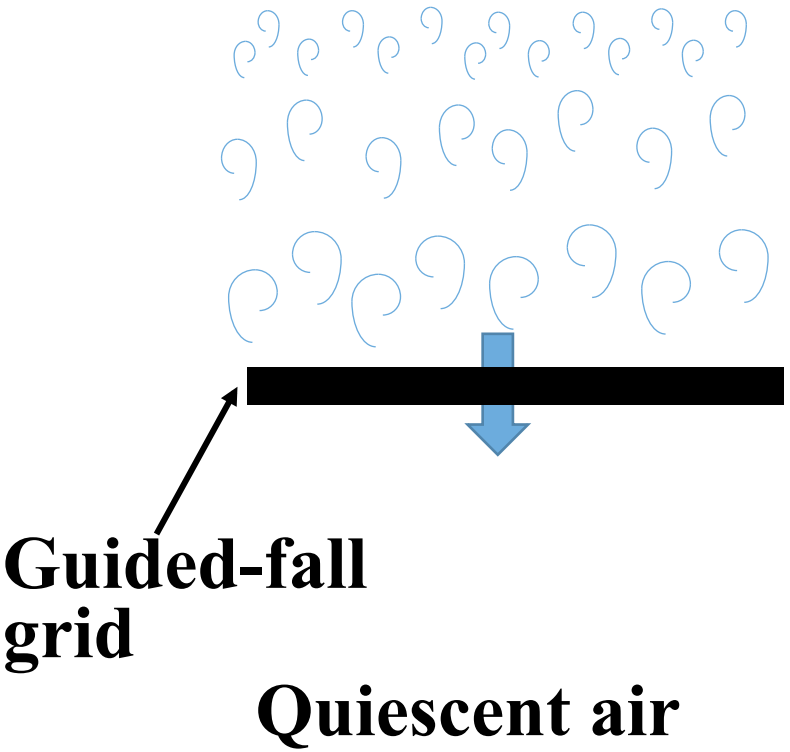
Grid Turbulence Generation

In wind tunnel

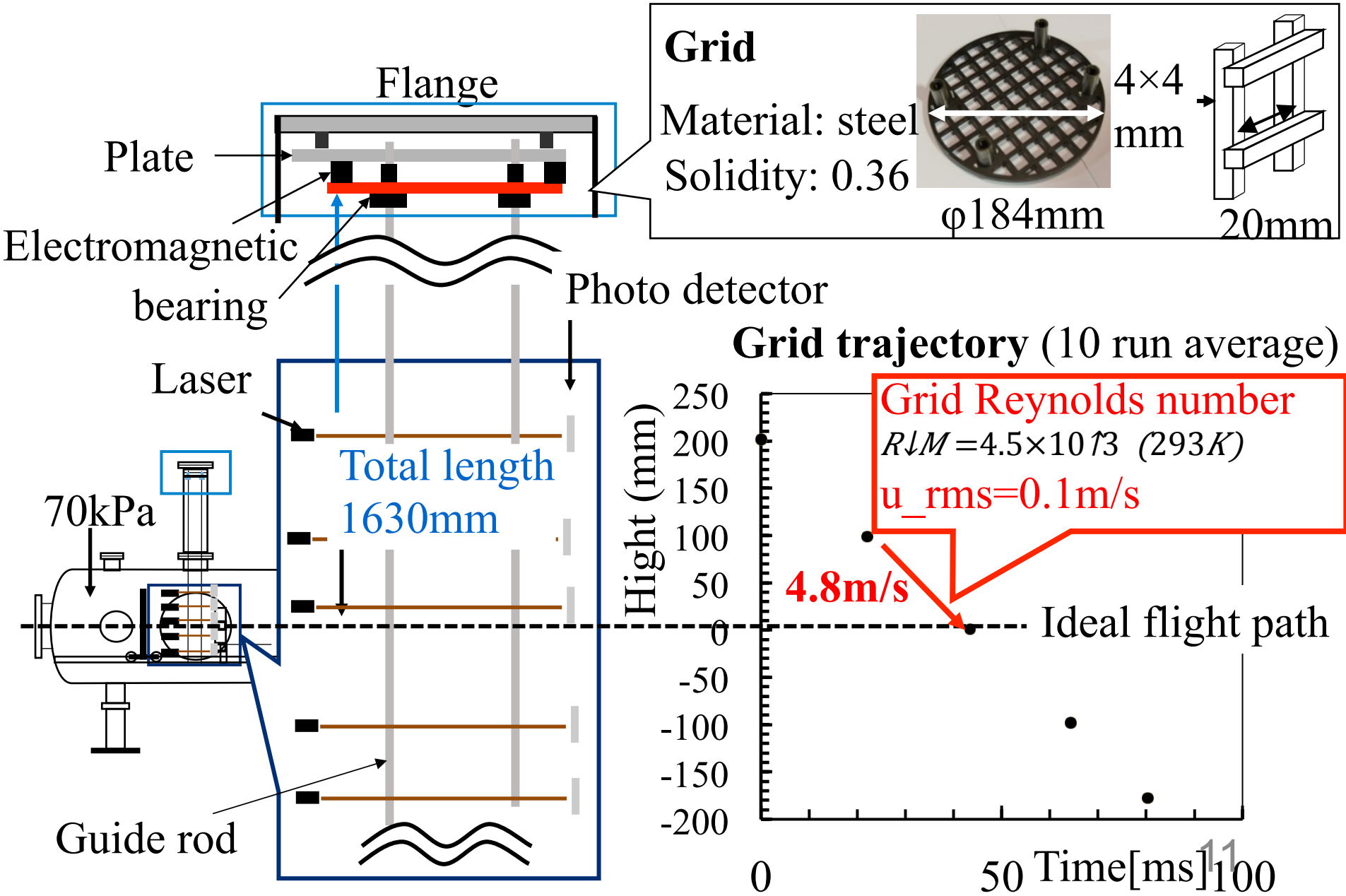


In this study

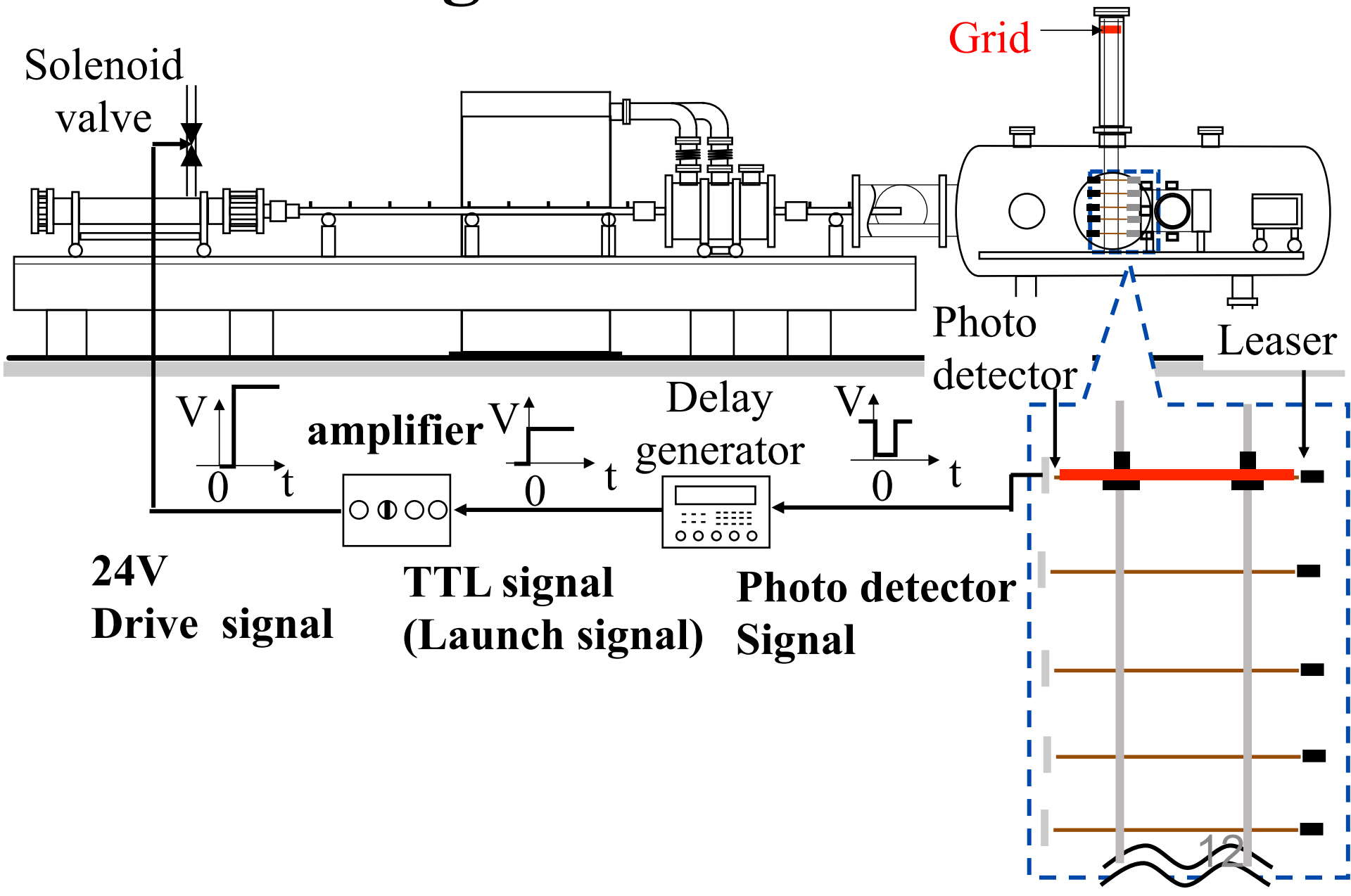
***mean flow almost-free**



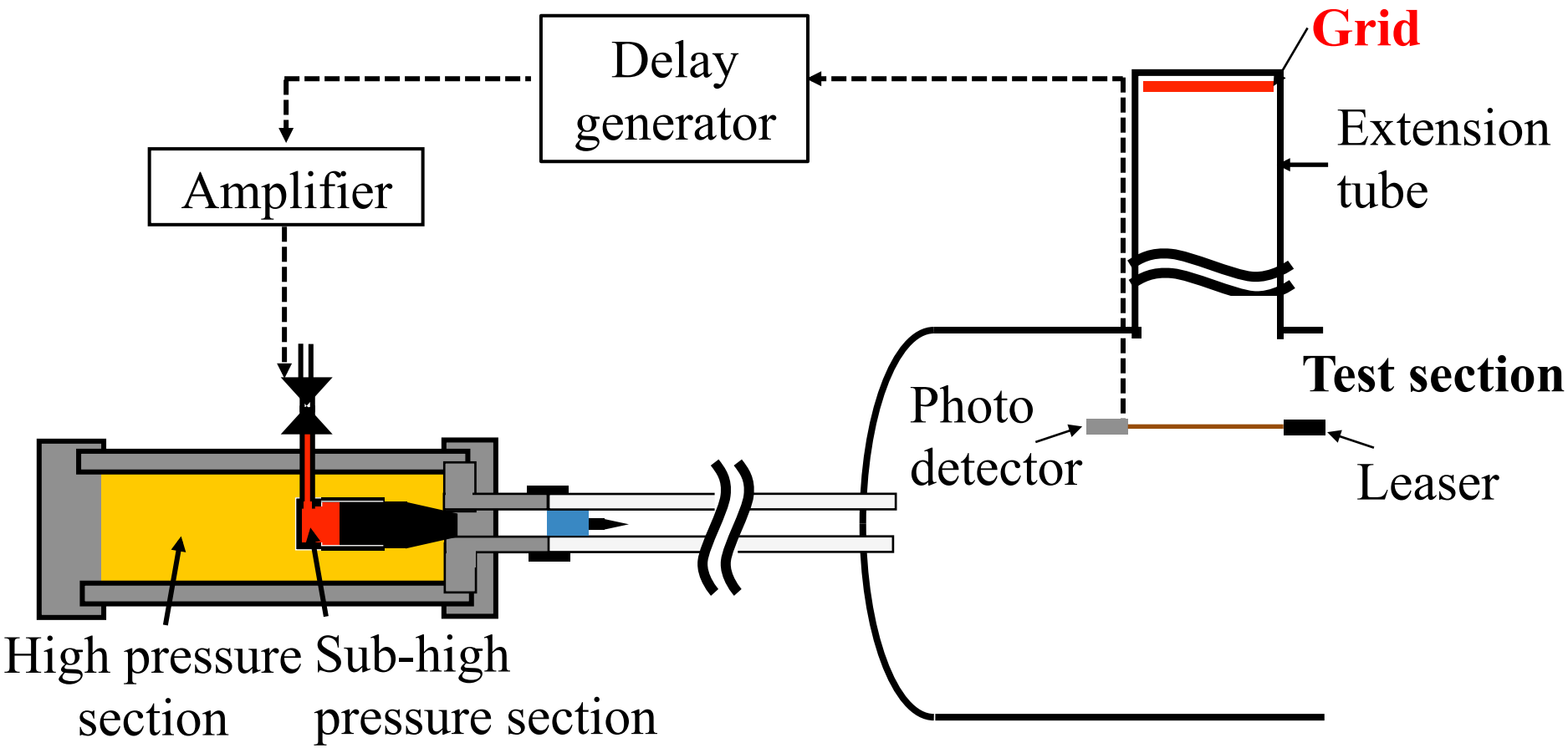
Grid Turbulence Characteristics



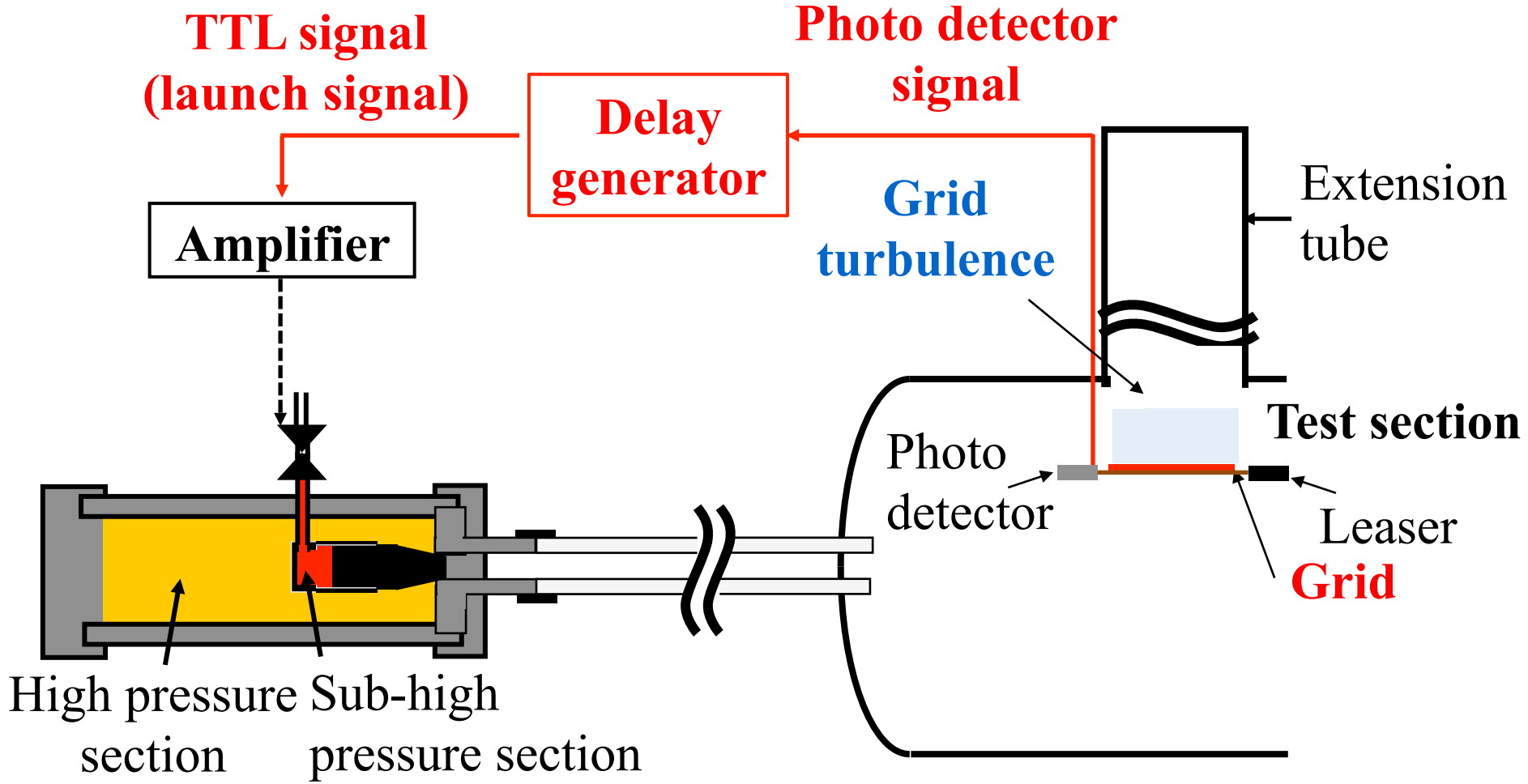
Range Active Control



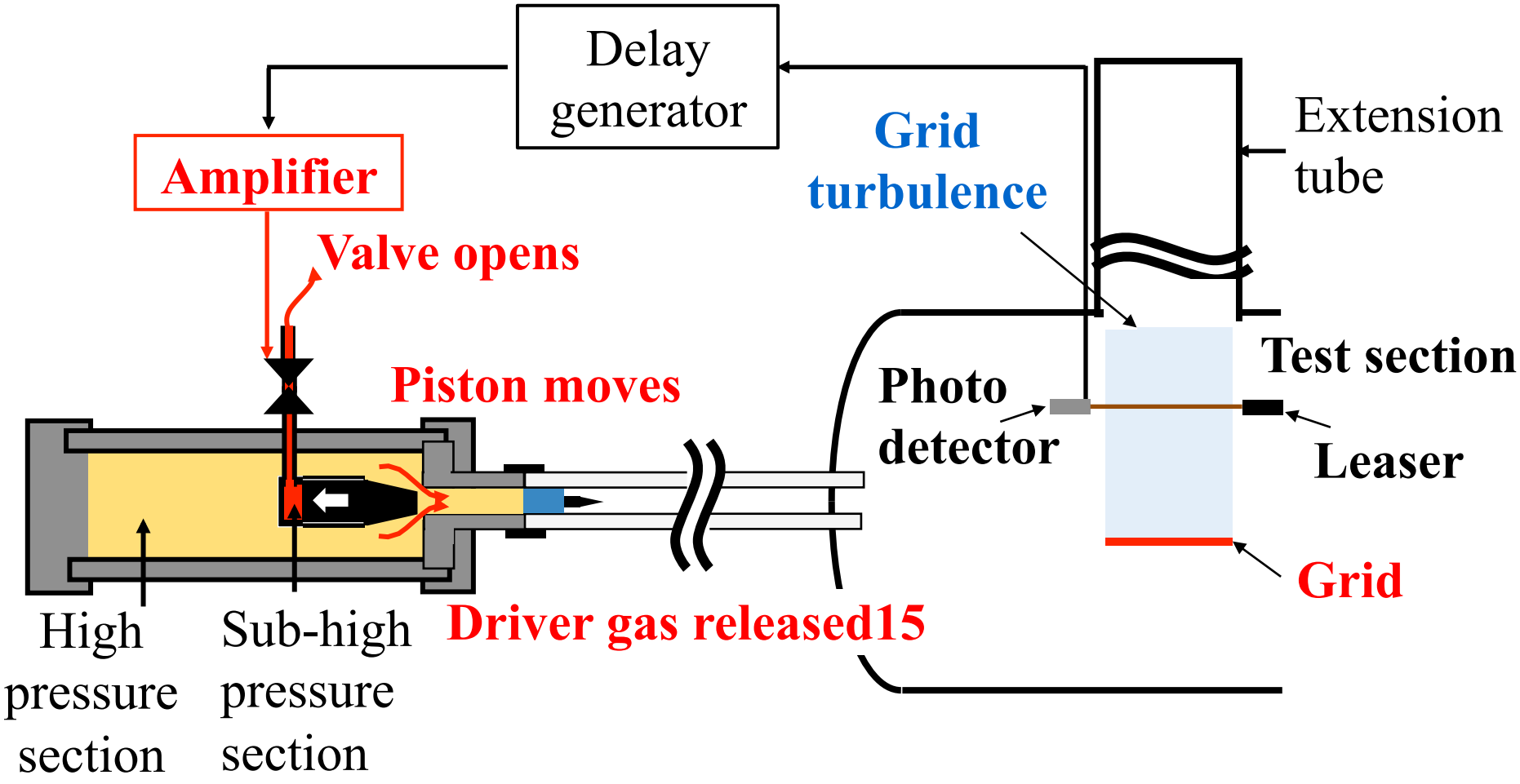
Synchronized Range Operation (1:Initial)



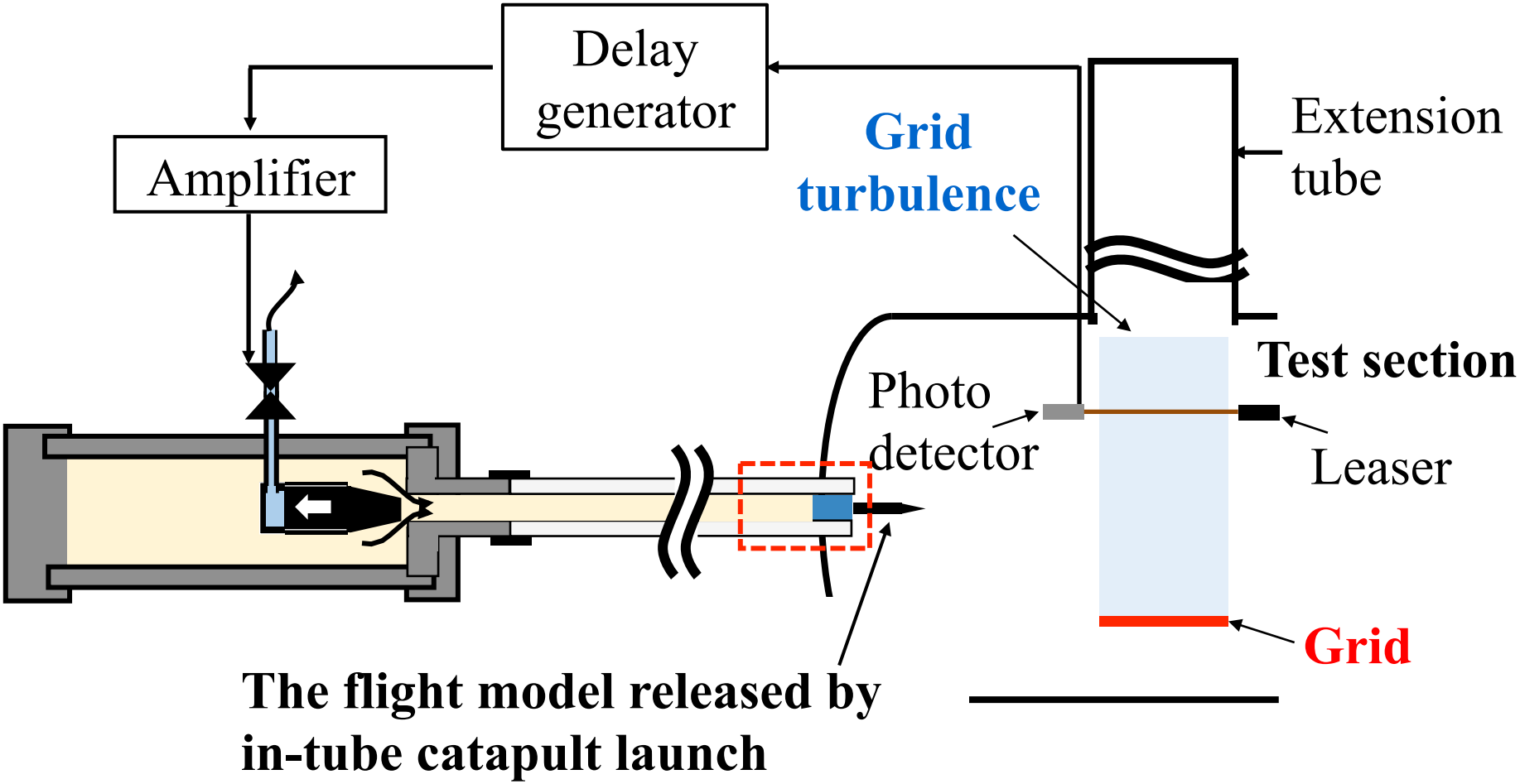
Synchronized Range Operation (2: valve open signal triggered)



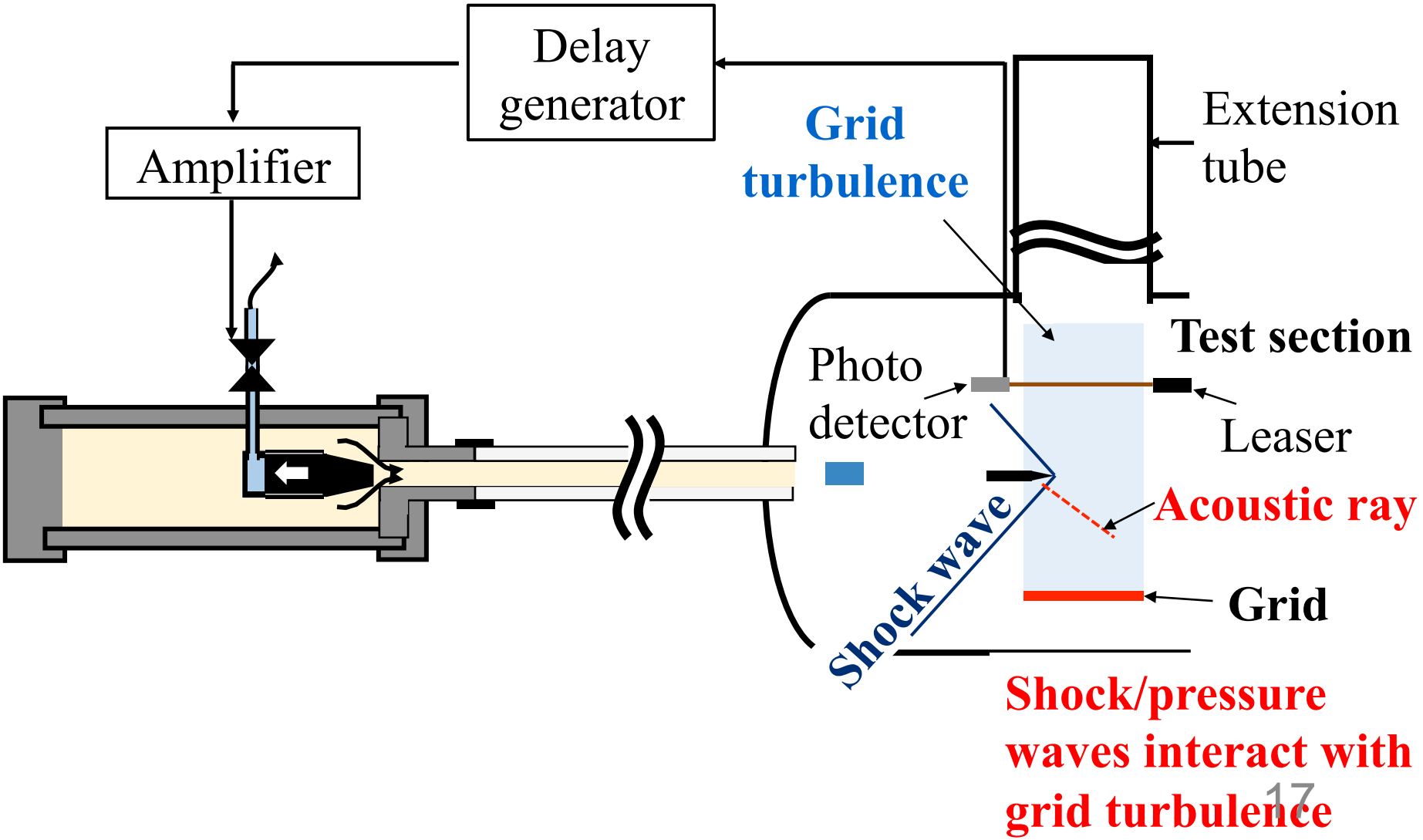
Synchronized Range Operation (3: Driver gas release)



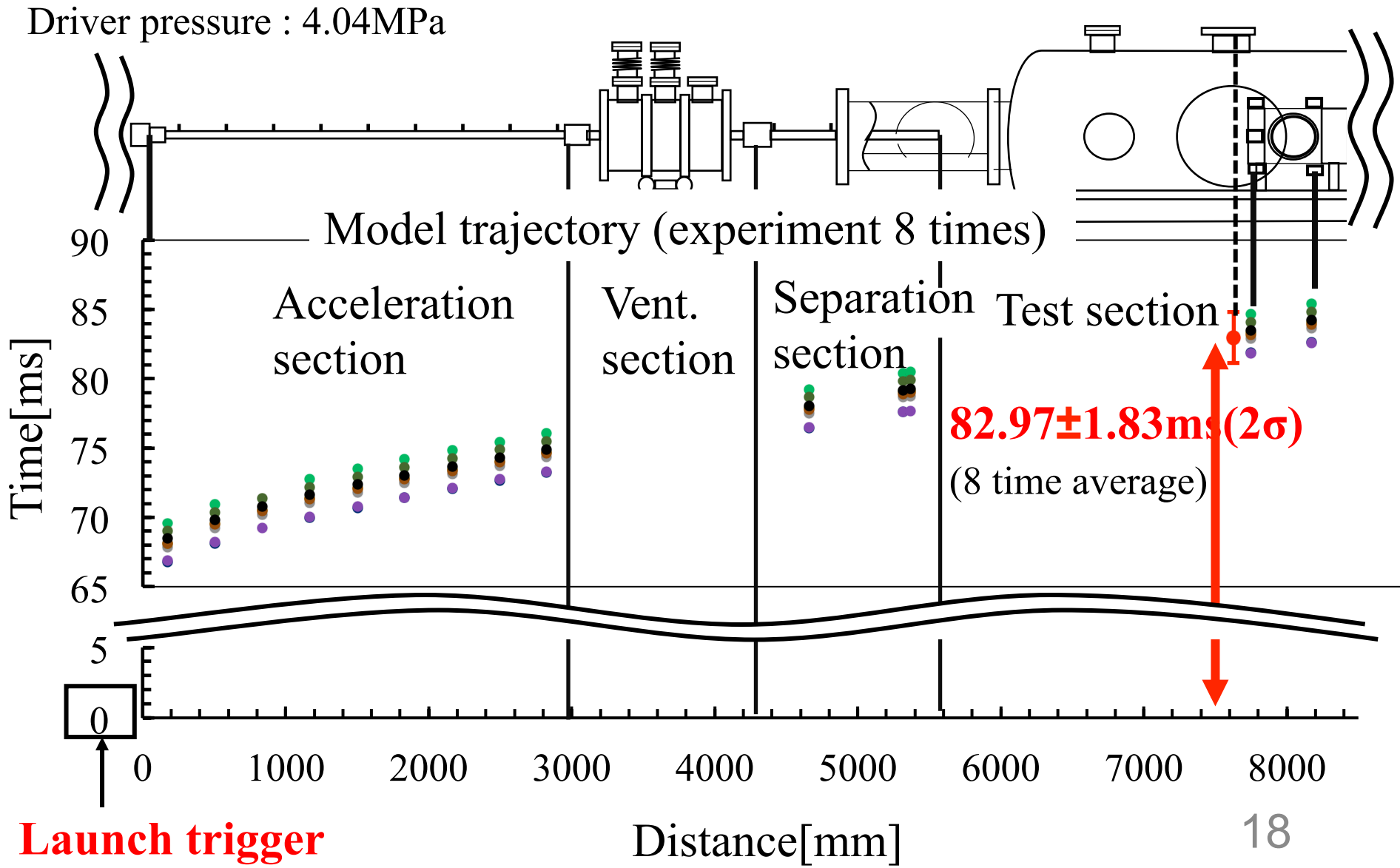
Synchronized Range Operation (4: launch from the muzzle)



Synchronized Range Operation (5: test time)

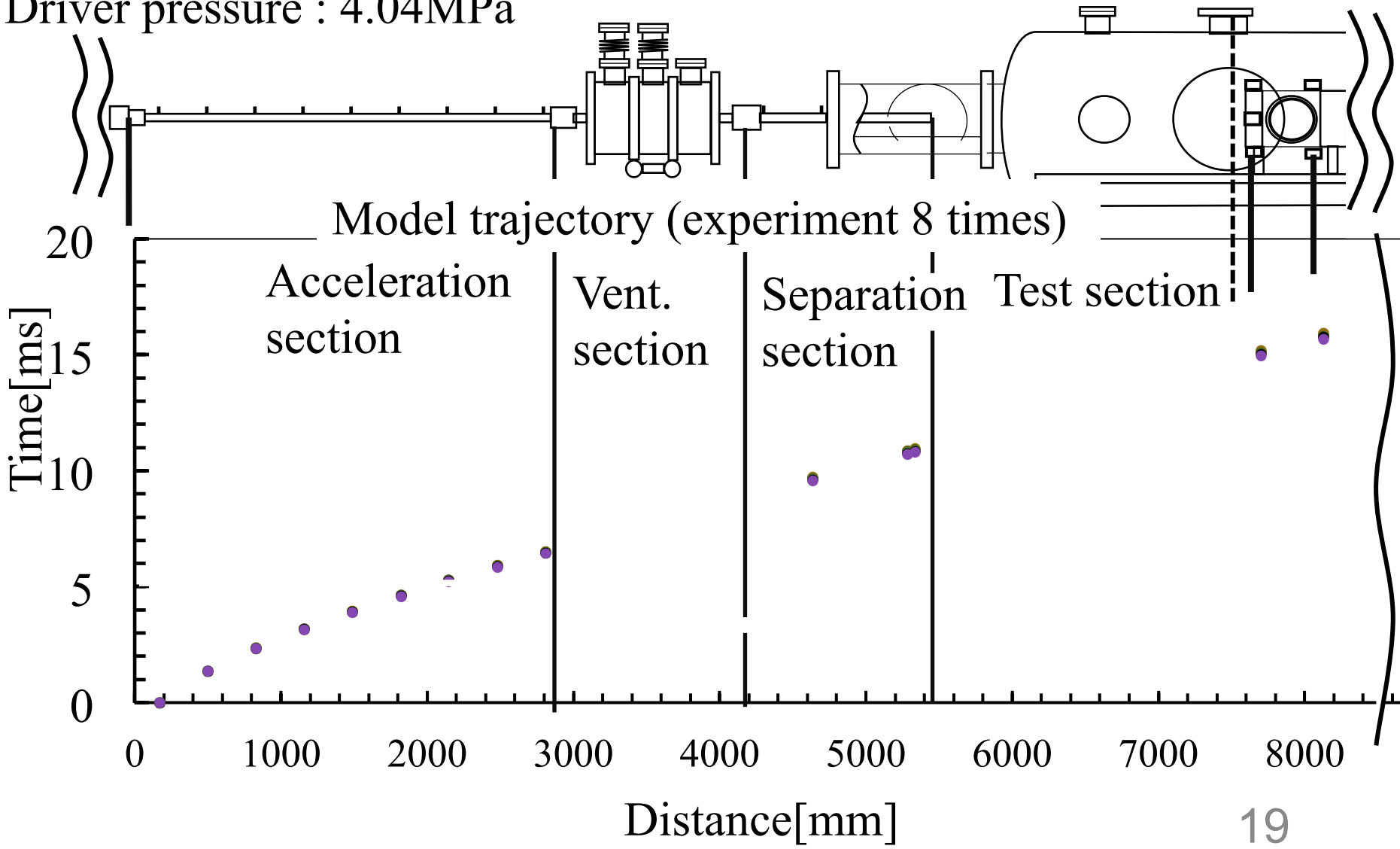


Reproducibility of Synchronization (for active control)

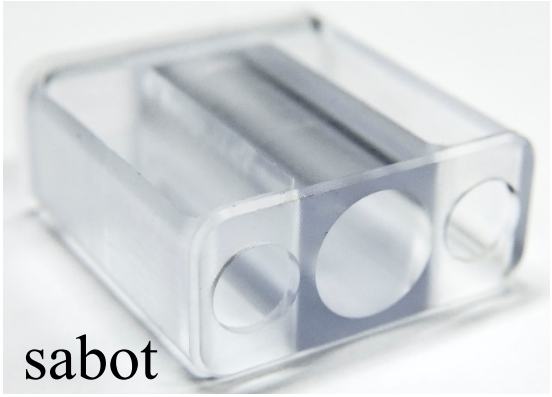


Reproducibility of Synchronization (from the first pressure transducer)

Driver pressure : 4.04MPa



Model and Sabot

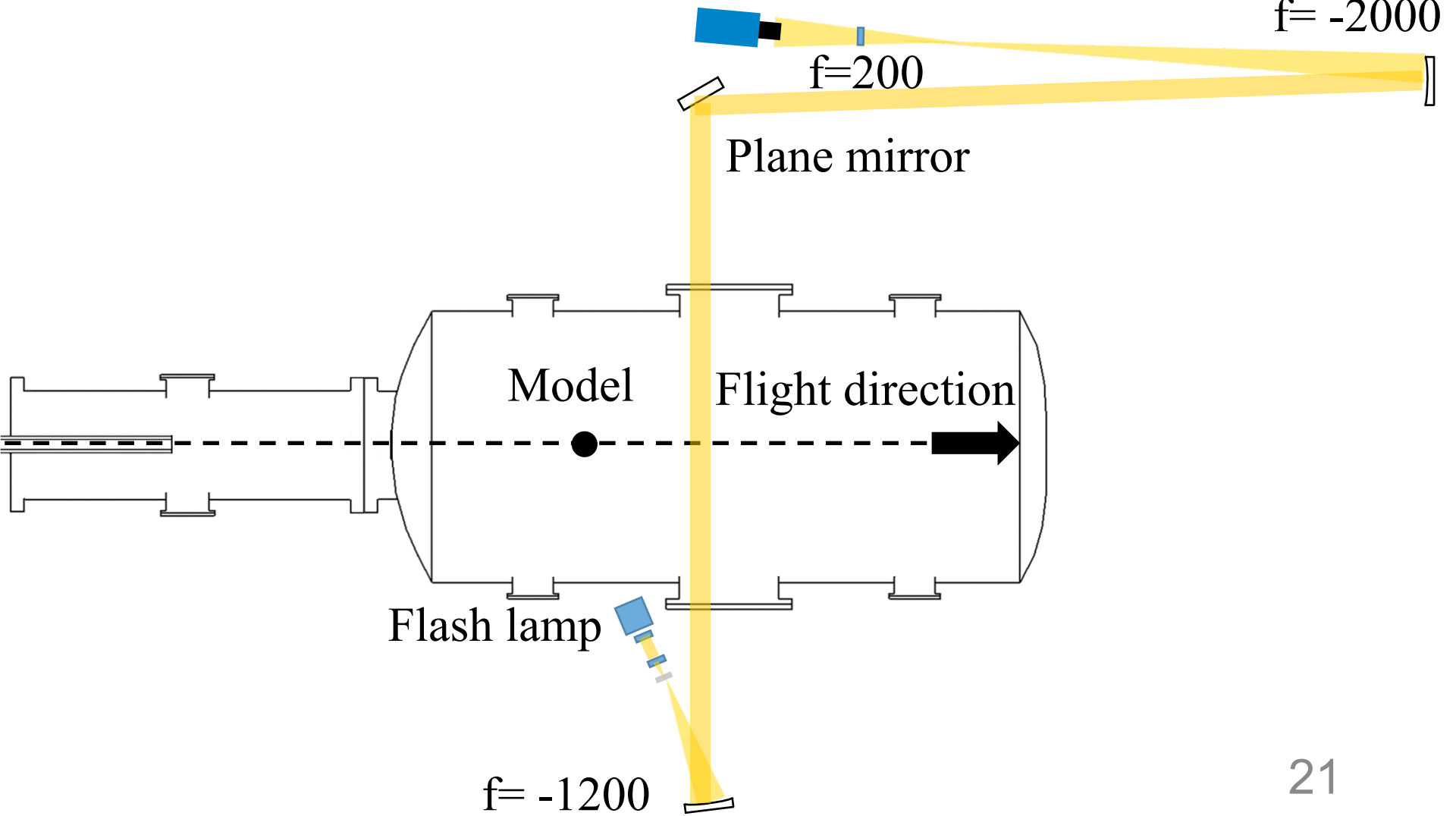


- Length: 45 mm
- Material :Polycarbonate
- Mass: 13.13±0.009g
- Support length: 40mm

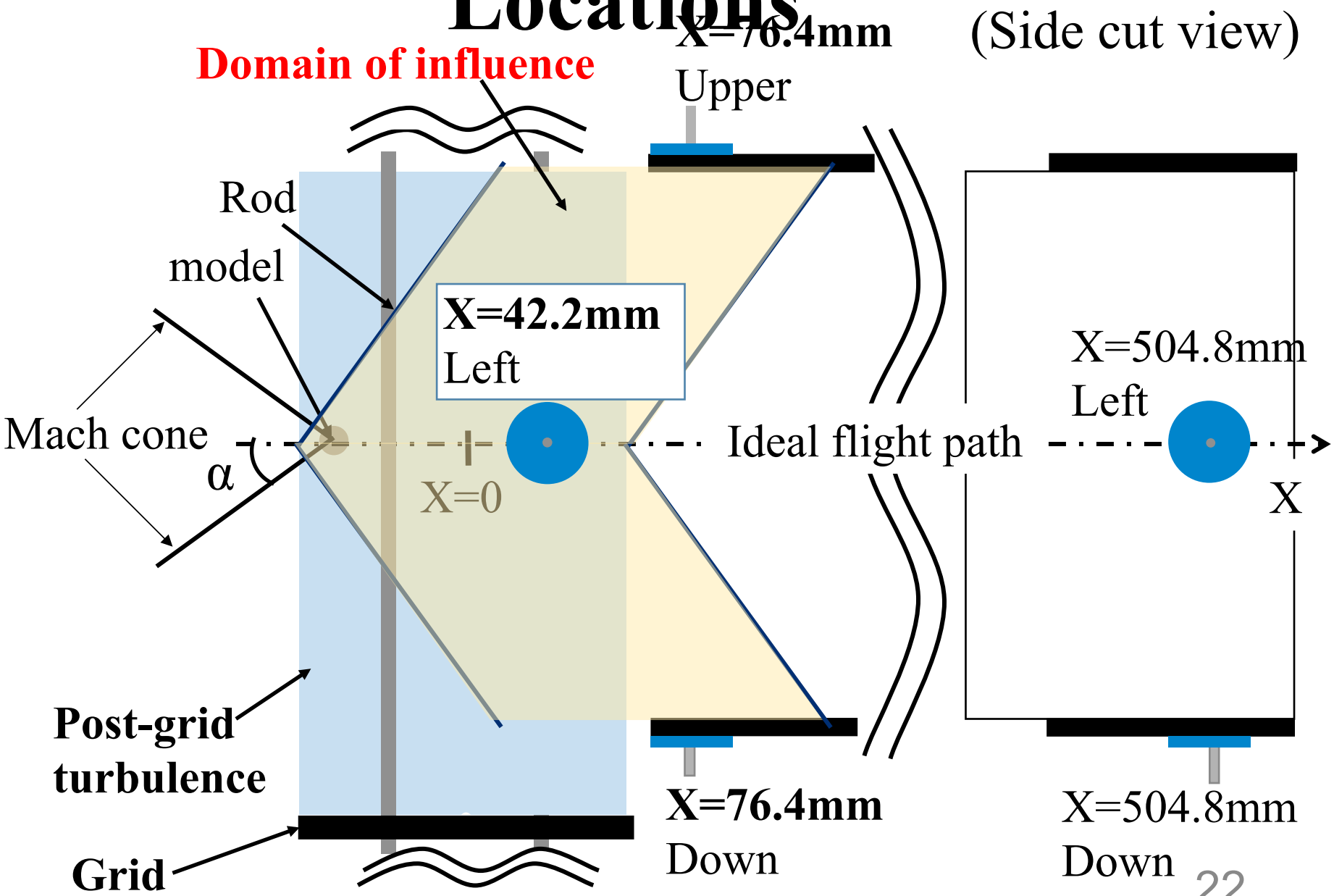
- Diameter: 15 mm
- Material: high carbon chromium bearing steel
- Mass:13.76±0.02

Schielen Visualization Setup

High speed camera for Schlieren visualization
Shimadzu, HPV-1

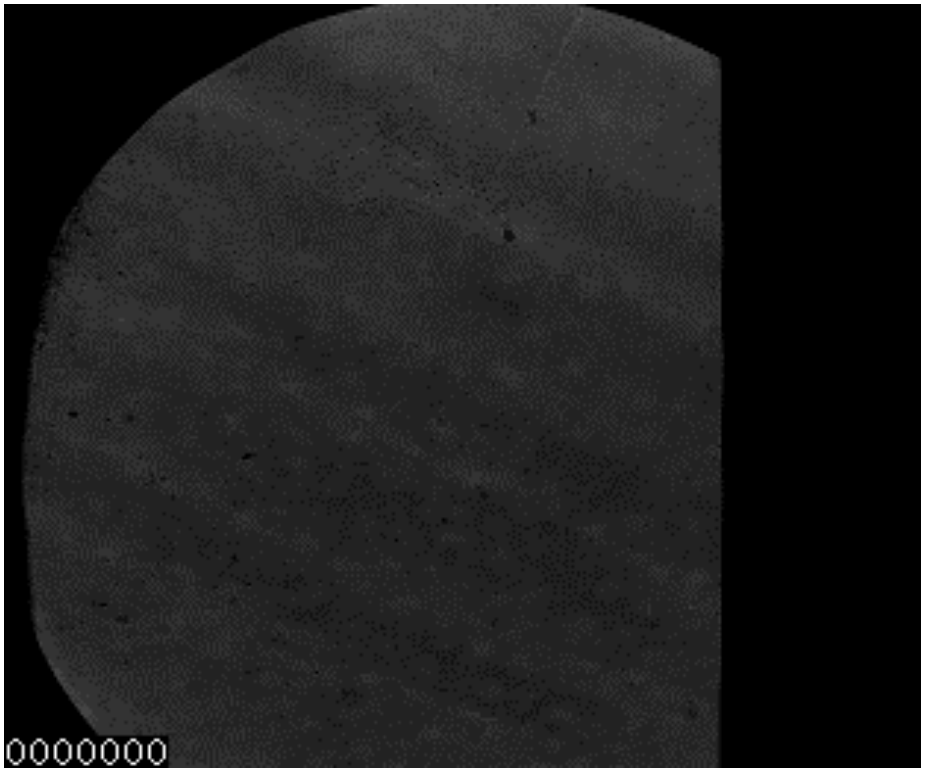


Pressure Transducer Locations



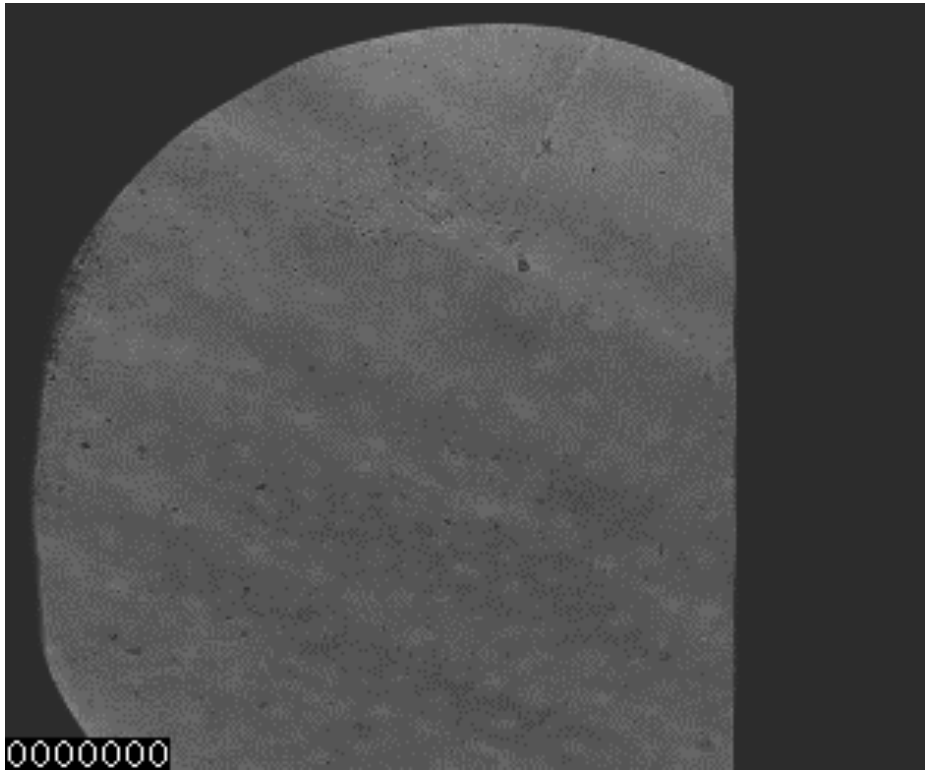
Schlieren Image

Without Grid drop



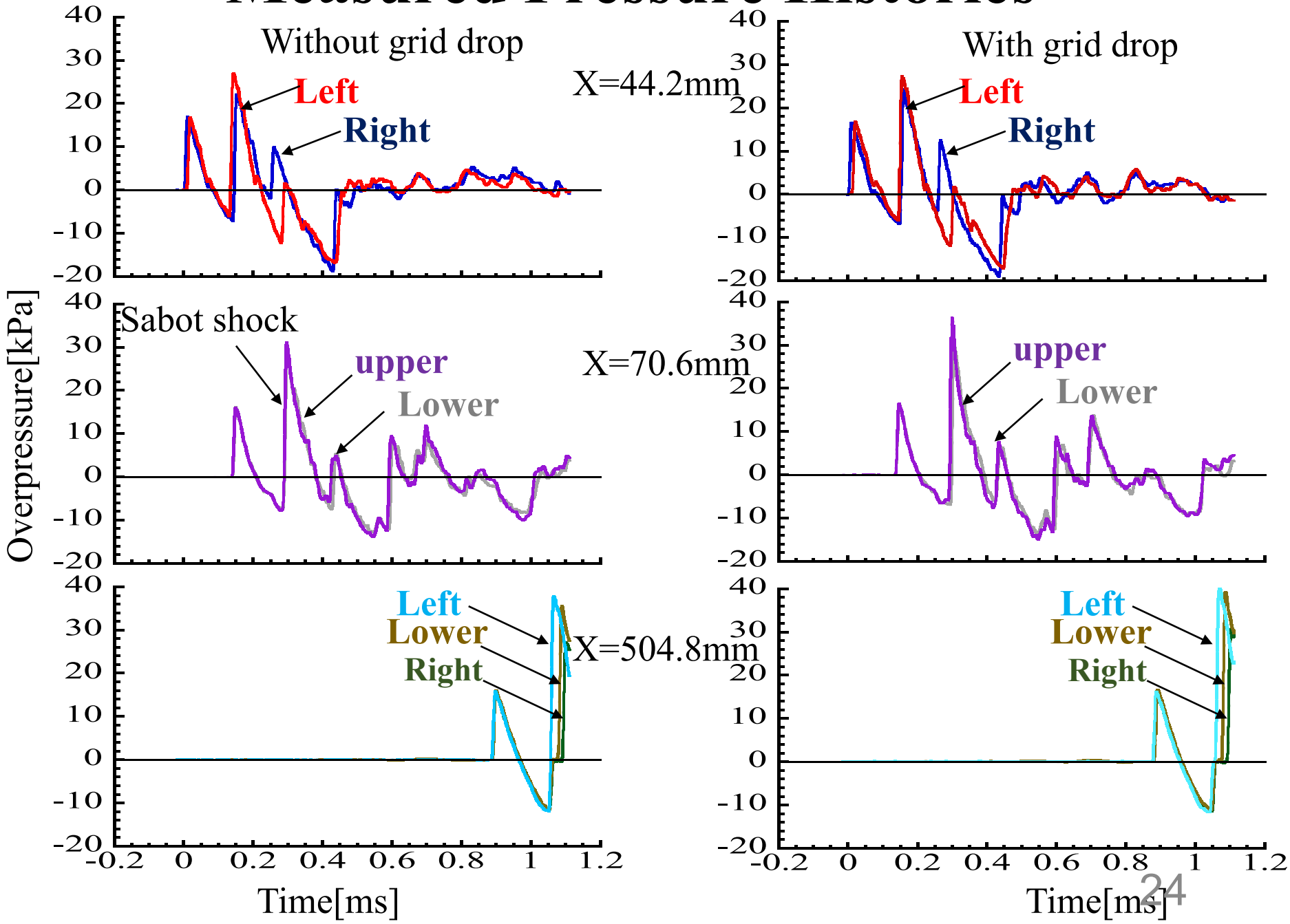
$M = 1.66$

With Grid drop



$M = 1.67$

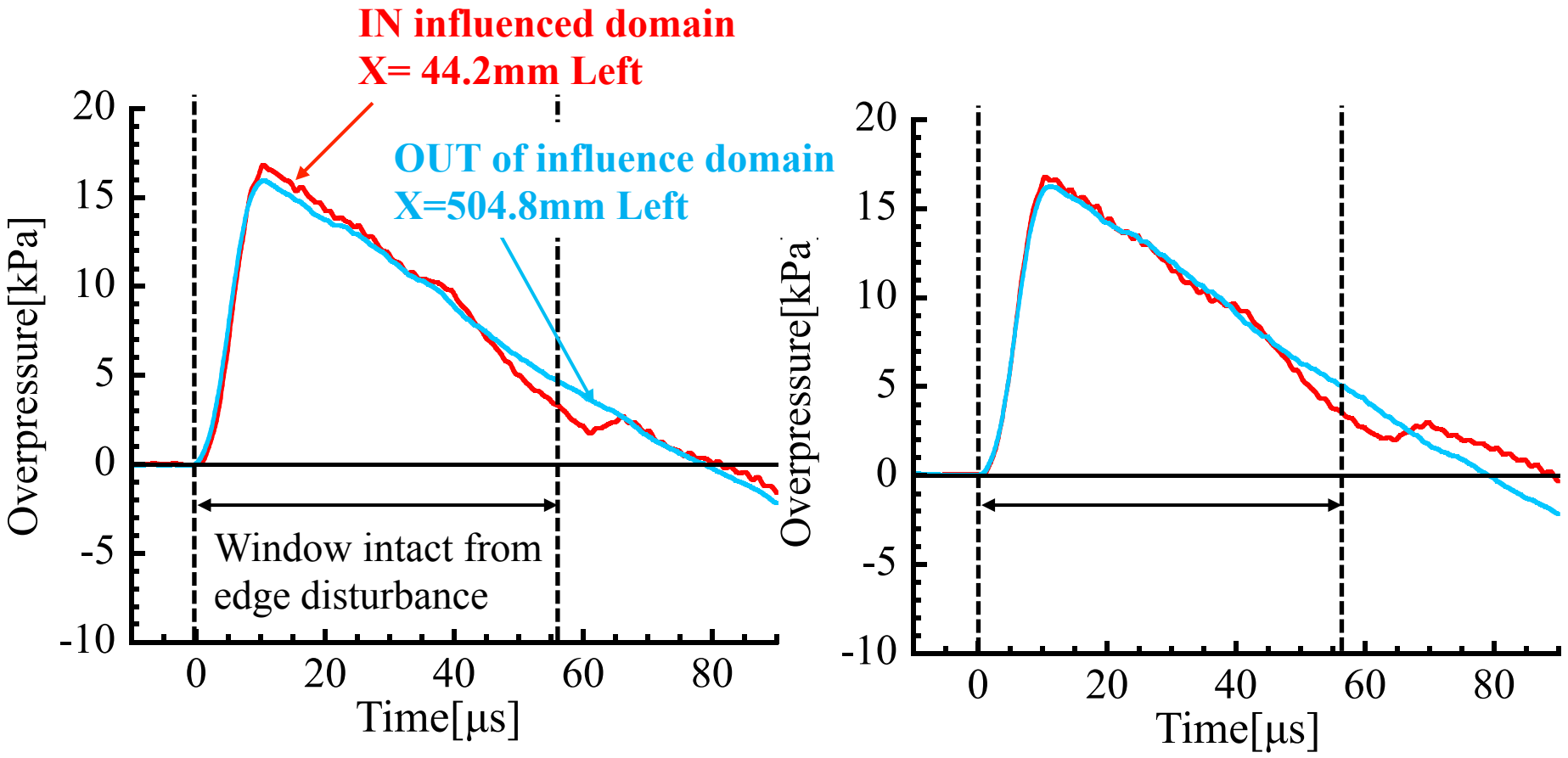
Measured Pressure Histories



Pressure Signature Comparison

Without grid turbulence

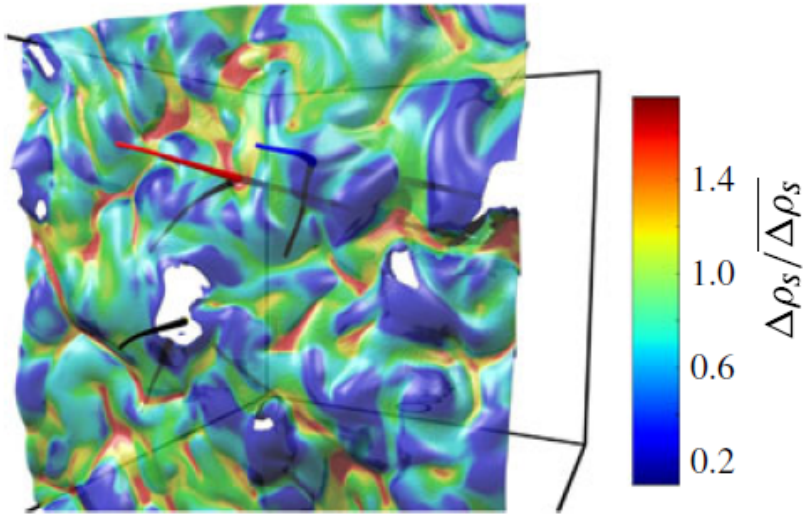
With grid turbulence



Mismatch between shock &turbulence

Larsson's criterion for "broken" shock wave

(Visualized by Direct Numerical Simulation)



: Shock Mach number

: Turbulent Mach number

: Reynolds number based on Taylor length scale

Proposed criterion:

$$M_t \gtrsim 0.6(M_s - 1)$$

$$M_t = \sqrt{R_{kk}}\,/c_u$$

M_t : Turbulence Mach number

M_s : Shock Mach number

c_u : Speed of sound at immediately upstream of the shock

$\sqrt{R_{kk}}$: Root mean square of the veloci of isotropic turbulence

This experiment

$$2.9\times10^{-4} \ll 6\times10^{-2}$$

$$M_t = 2.9\times10^{-4}$$

$$M_s = 1.1$$

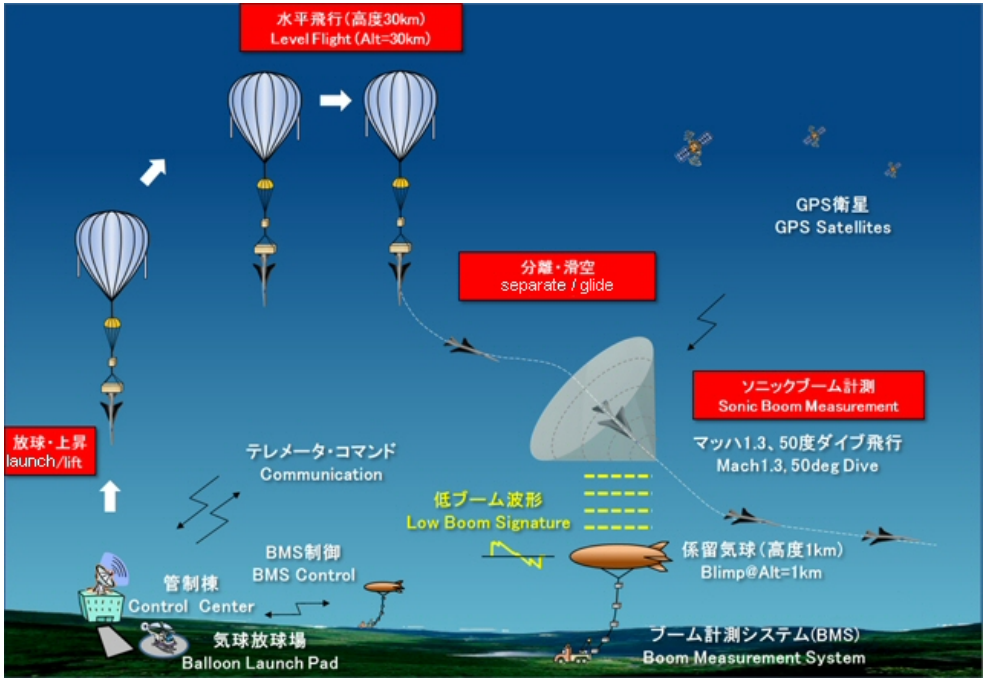
[1] Johan Larsson et al. "Reynolds- and Mach-number effects in canonical shock-turbulence interaction", *J.Fluid Mech.* **717**, 293-321 (2013)

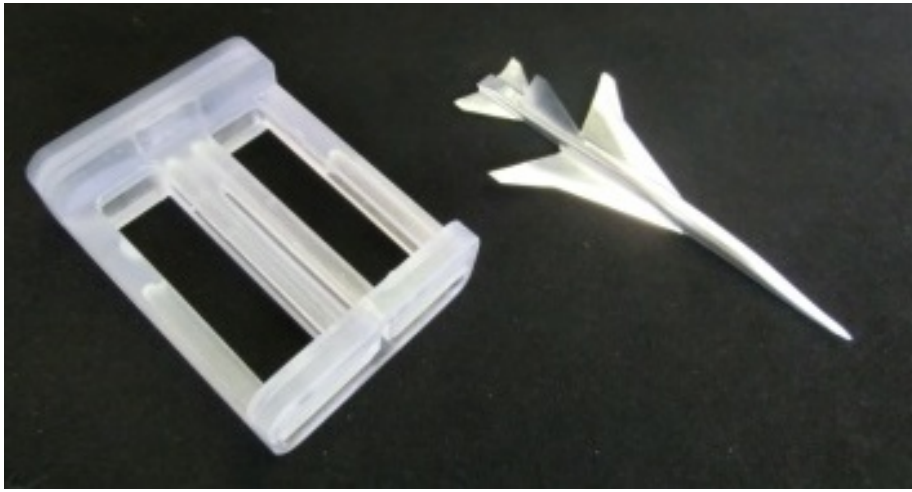
Near-field pressure profile over D-SEND#2 body

Laboratory free flight:D-SEND#2 model

D-SEND:
Drop test for **S**implified **E**valuation of **N**on-symmetrically **D**istributed sonic boom

Low boom signature during Mach 1.39 flight was measured at altitude=750m
D-SEND #2 field experiment at Esrange Space Center in Sweden,
was done in 24th July 2015.

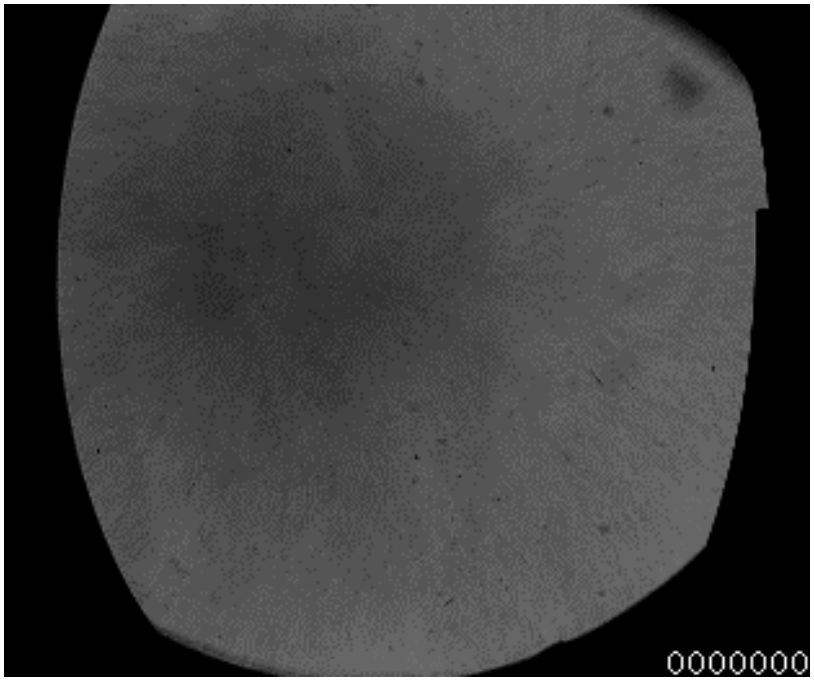




Model
length： 88.30mm
Span length： 40.02 mm

D-SEND#2 Schlieren Image

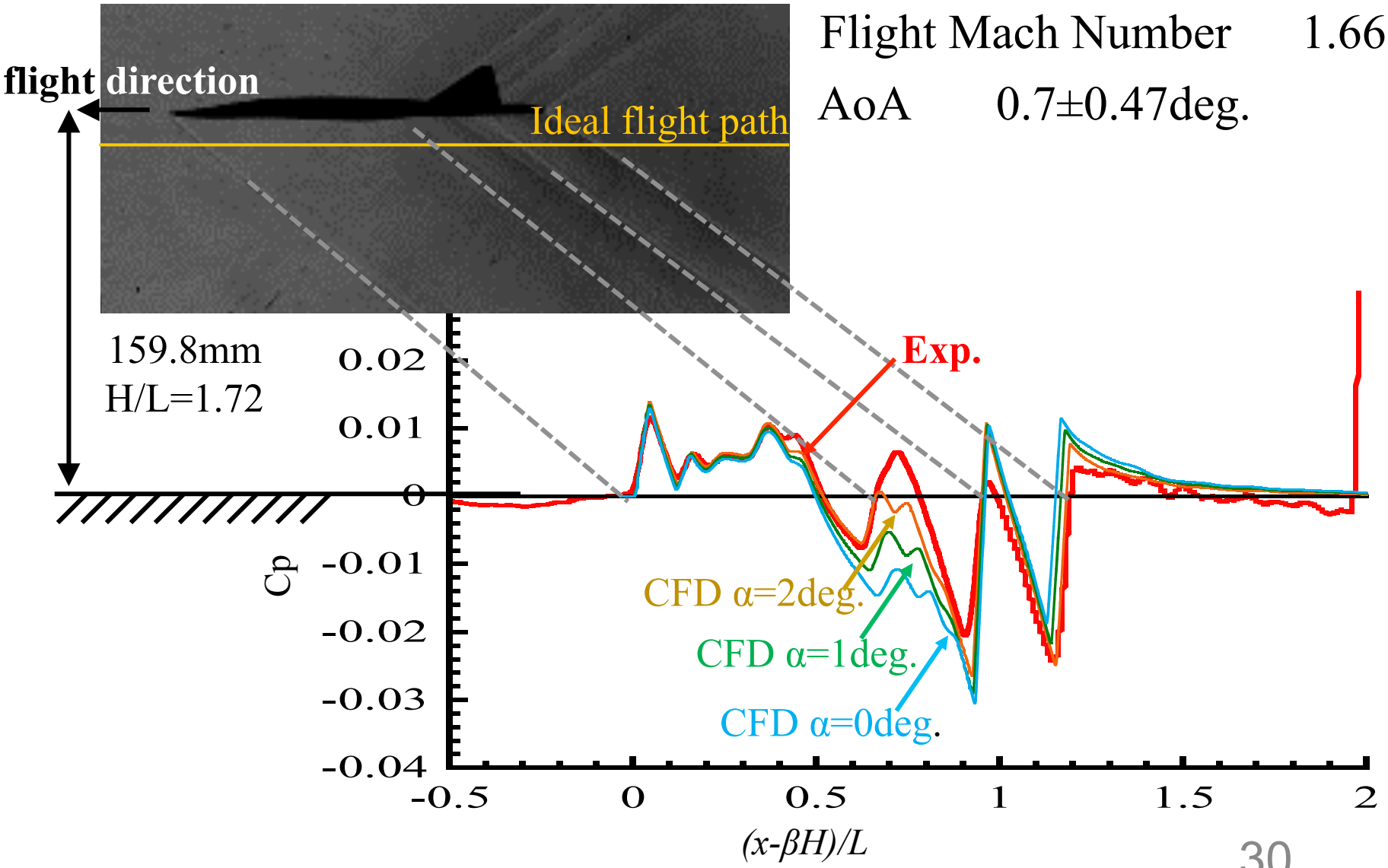
Side view



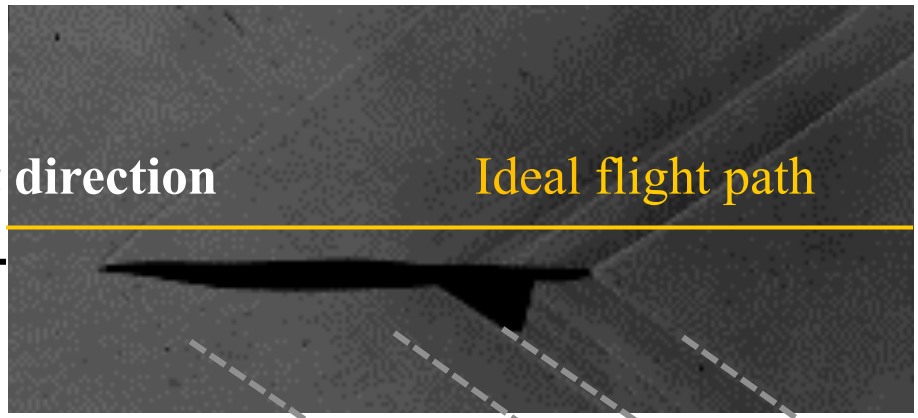
Top view

Flight Mach Number	1.66
AoA	0.7±0.47degree
Yaw angle	0.95±0.24degree

D-SEND #2 – Flight Path & AoA



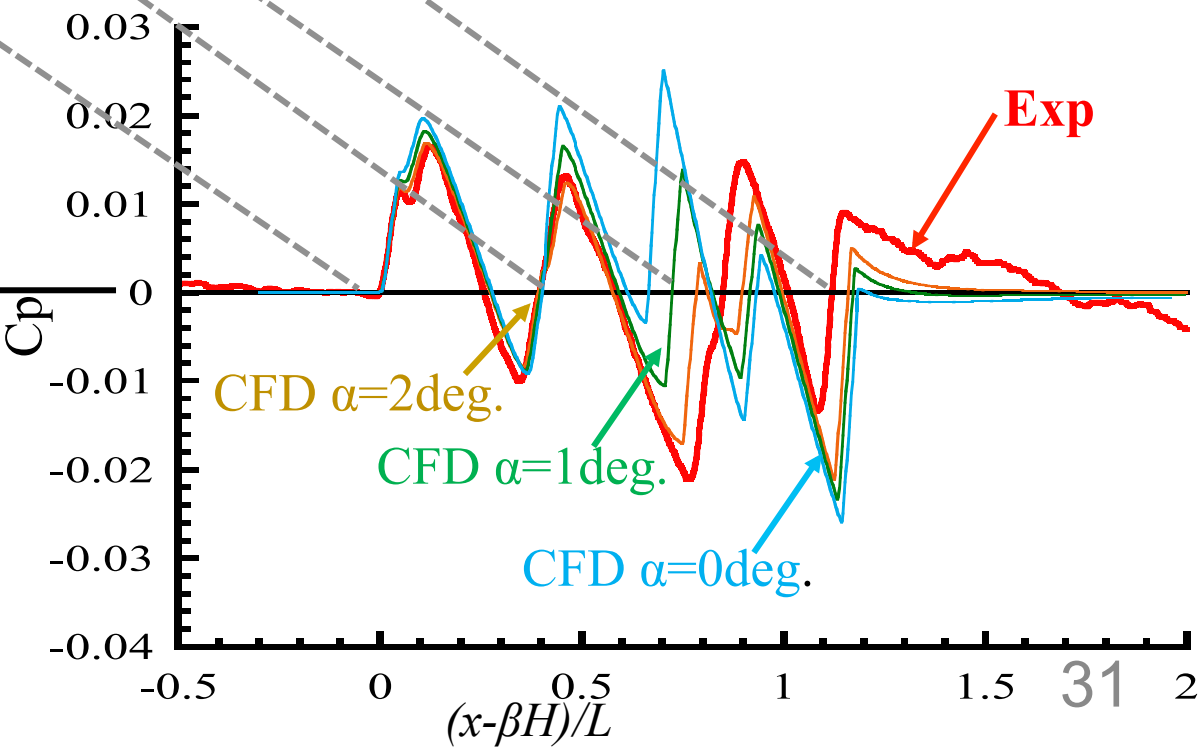
D-SEND #2 – Flight Path & AoA



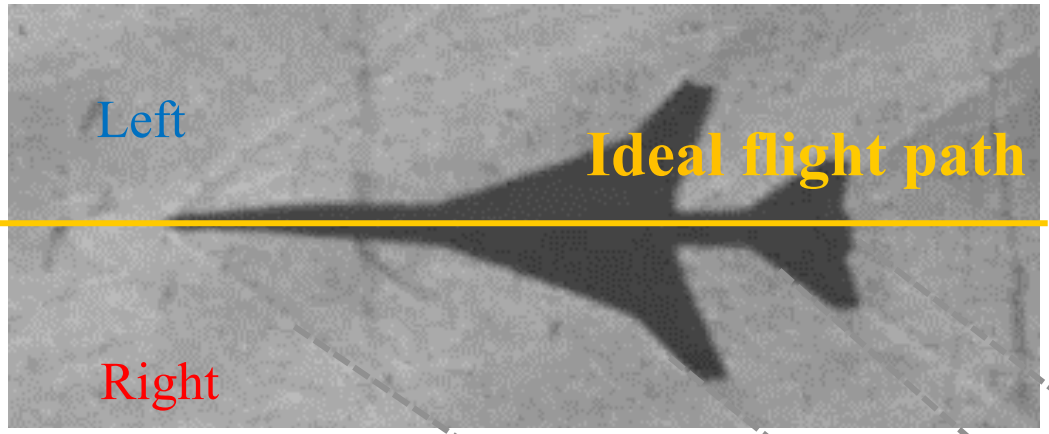
Flight Mach Number 1.66

AoA 0.7±0.47deg.

140.2mm
H/L=1.58



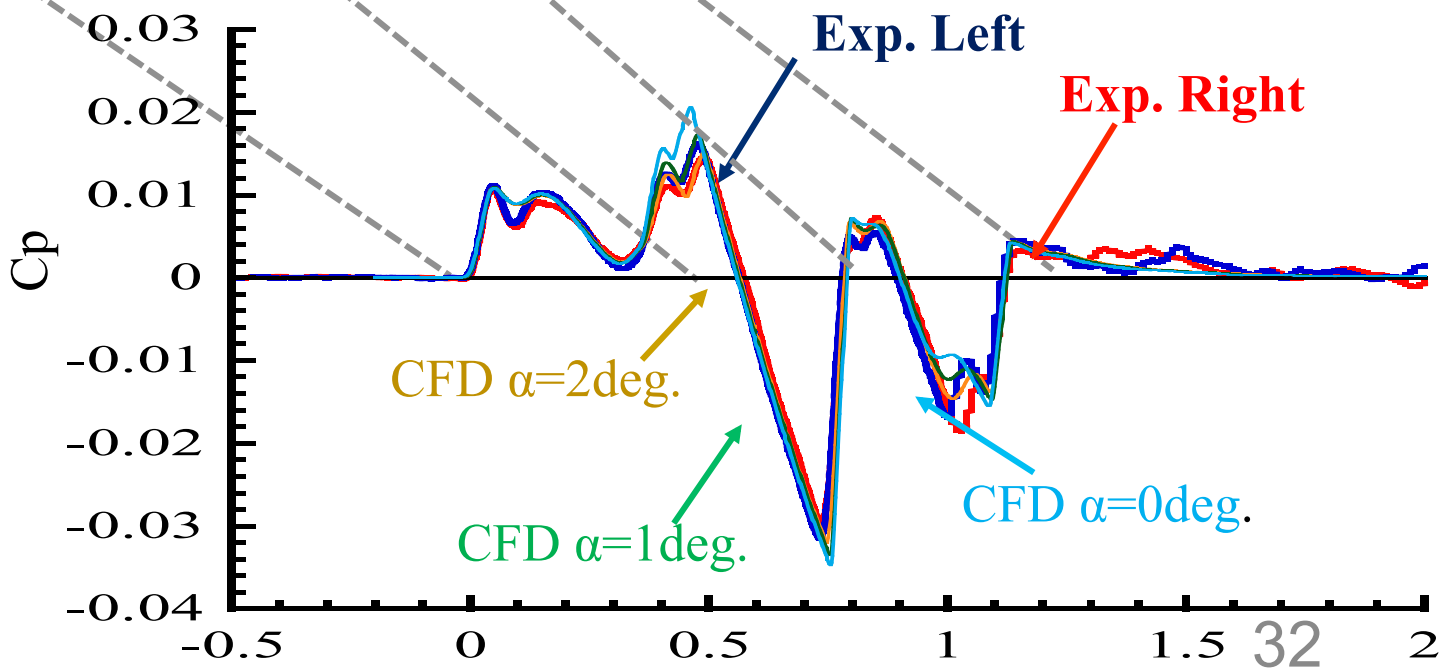
D-SEND #2 – Flight Path & Yaw Angle



Flight Mach Number 1.66

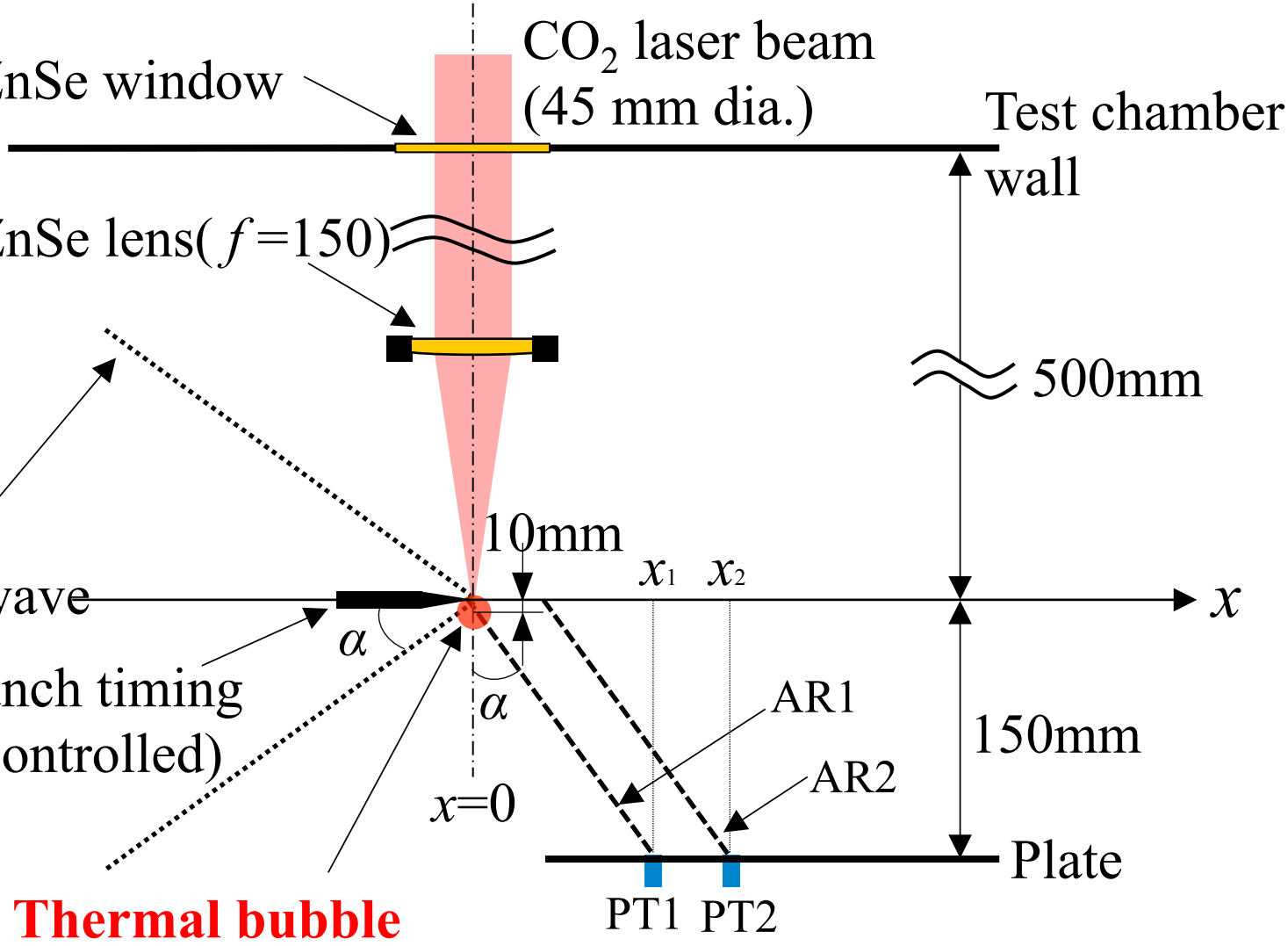
Yaw angle 0.95±0.24deg.

Roll -11.6～+11.6deg.



Sonic boom moderation using a laser-induced thermal bubble

Deposition of Laser Pulse Energy to Generate a Thermal Bubble



Thermal bubble Schlieren Image

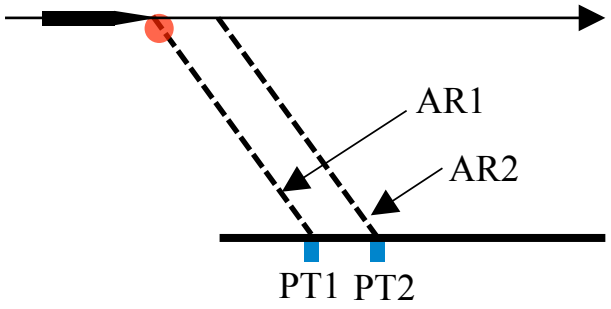
w/ energy deposition

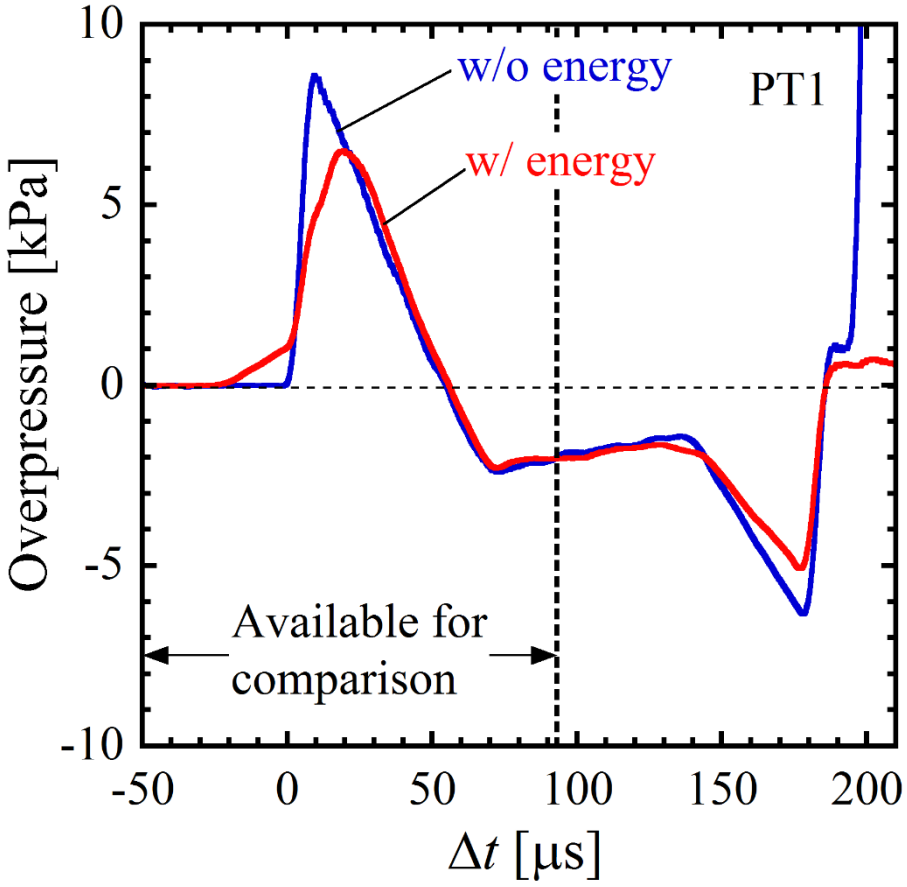
Flight Mach number : 1.68
A.o.A. : 1.6 deg.
Laser energy : 4.19 J
Test section pressure : 68 kPa

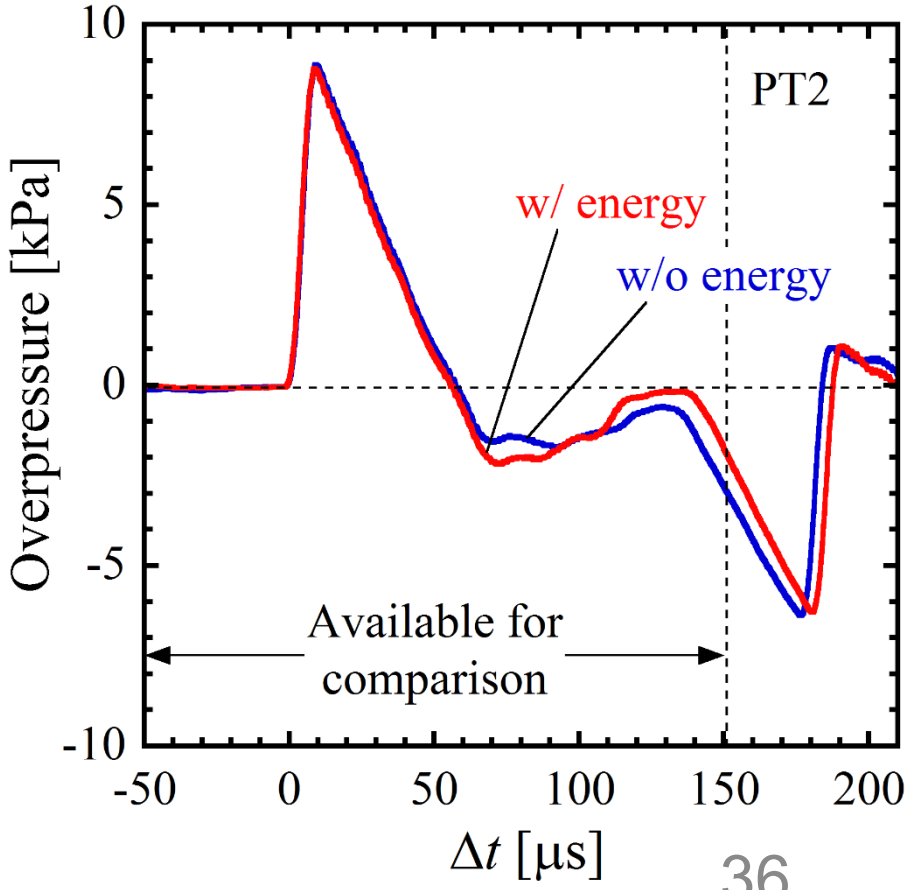
w/o energy deposition

Flight Mach number : 1.70
A.o.A. : 3.1 deg.
Laser energy : 0 J
Test section pressure : 68 kPa

Pressure Modulation by Thermal Bubble







Summary

- We have developed an **actively-controlled aeroballistic range** useful for shock interaction study.
- Interaction between grid turbulence and a Mach 1.7 sphere did not yield significant pressure modulation. The mismatch between the shock strength and the turbulence **intensity** is expected to be a primary reason.
- Near-field pressure profile over a **D-SEND#2** model was successfully obtained.
- **Moderation of sonic boom using a thermal bubble** was demonstrated.