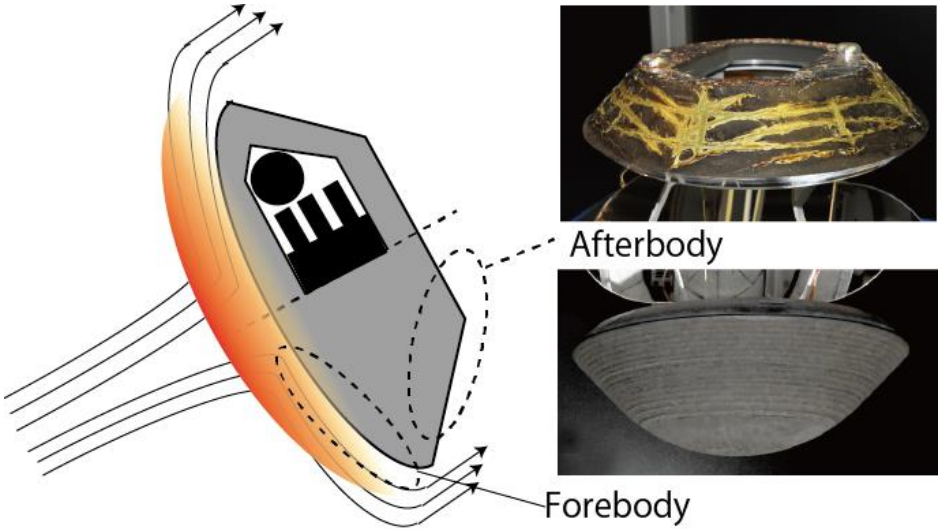
Design and characteristics of the suborbital expansion tube HEK-X for afterbody heating of sample return capsule

Kohei Shimamura

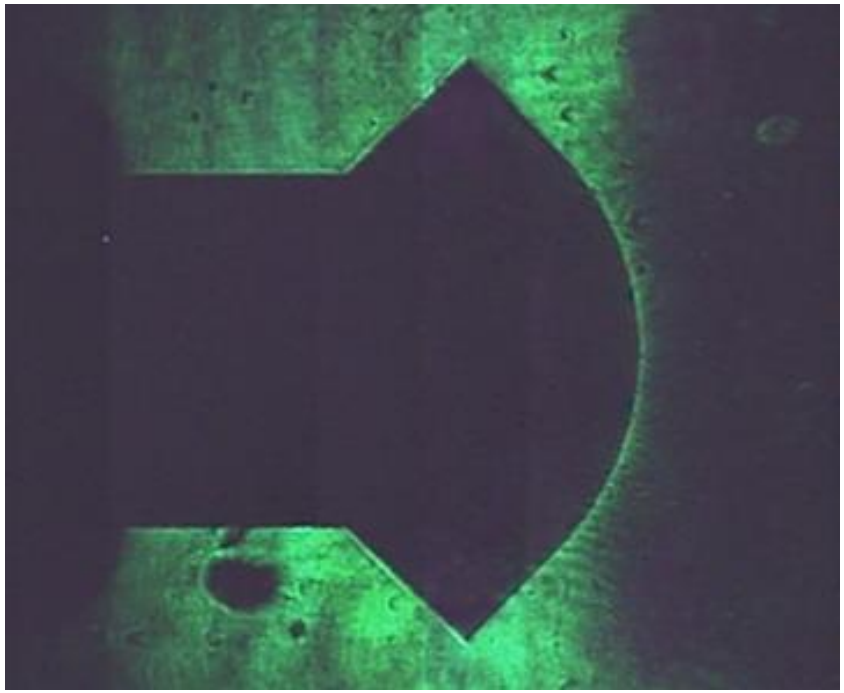
University of Tsukuba

Department of Engineering Mechanics & Energy

Evaluation of afterbody heating of sample return capsule in the ground facilities



Afterbody heating was estimated at 1/100 of stagnation heating (15 MW/m^2)

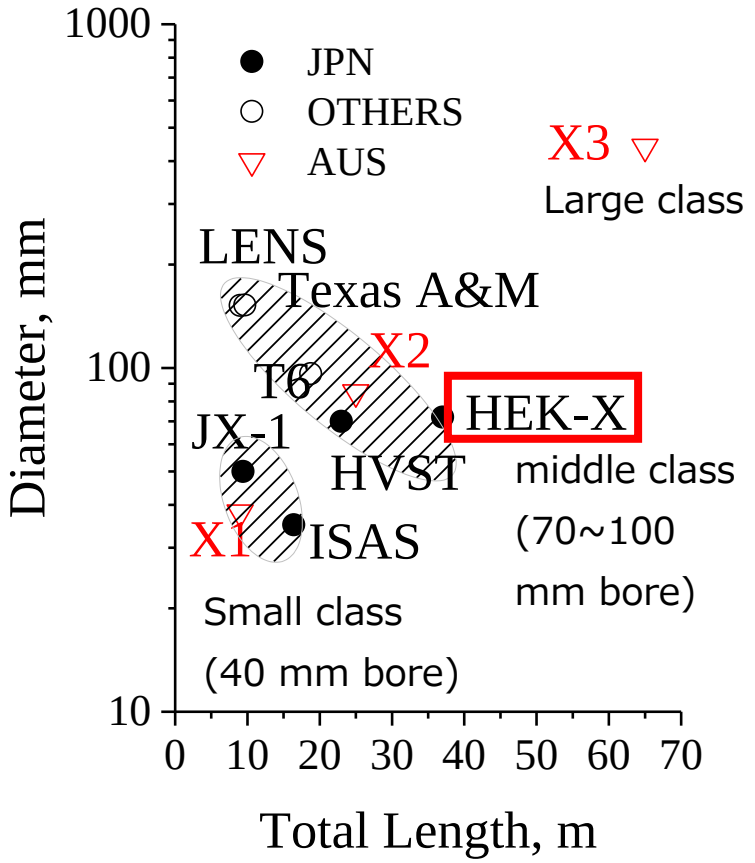


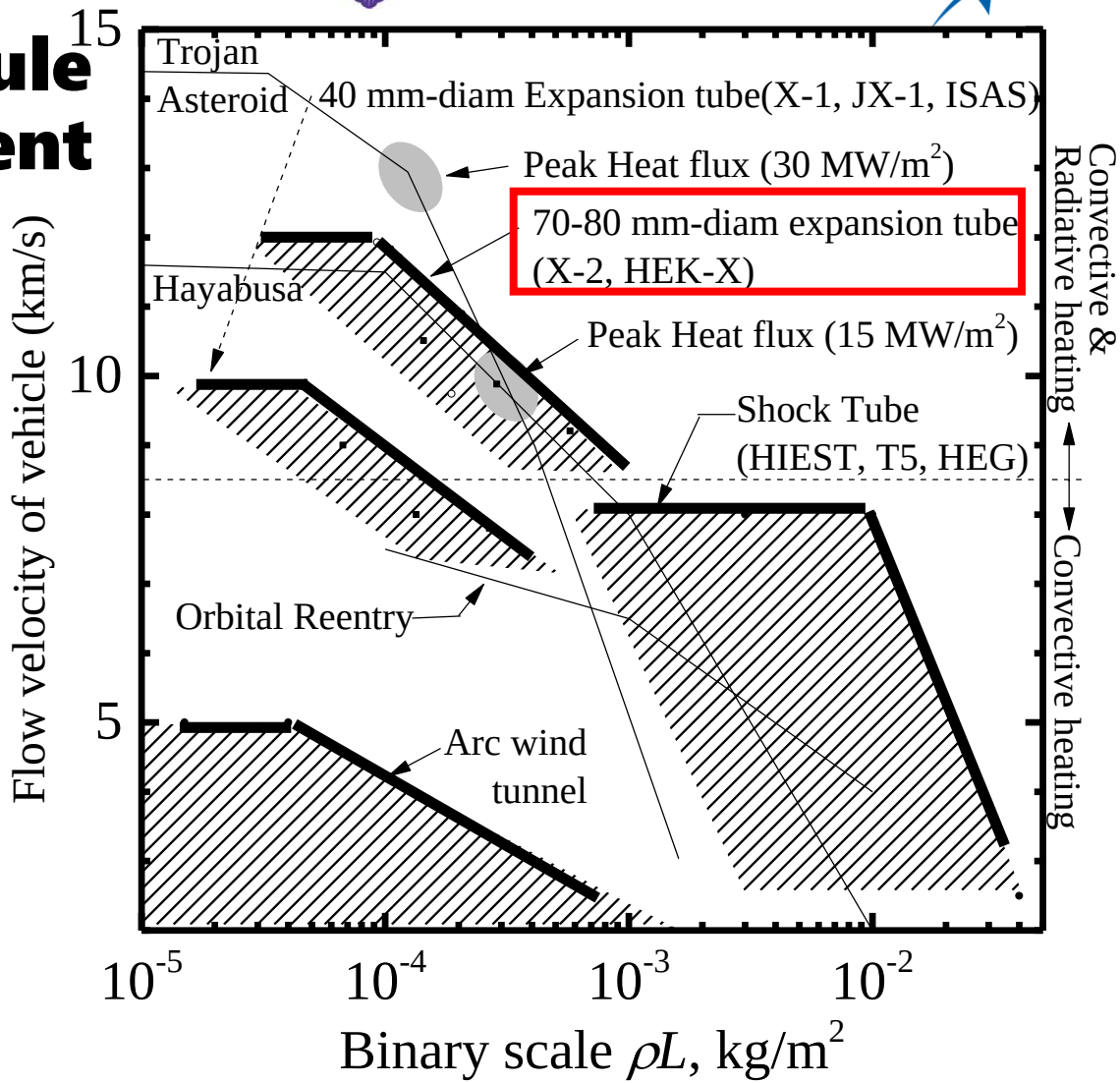
Forebody heating visualization

In this talk: High-speed imaging for test time evaluation of HEKX

Highspeed visualization method is proposed to obtain arrival of SW, CS, and EX-tail or head, and determine the test time of expansion tube.
Time history of density change is obtained by visualization of wedge (oblique SW) and hemispherical shape probe(Shock-standoff distance).

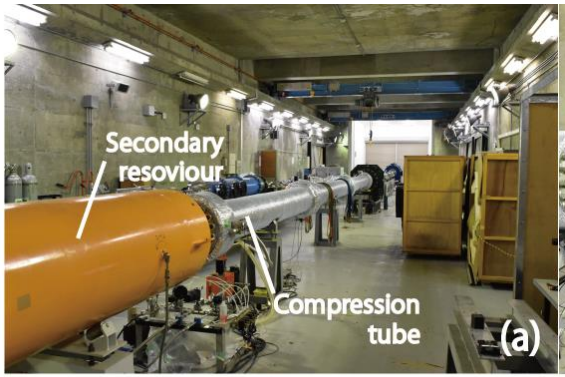
Post hayabusa capsule heat flux measurement

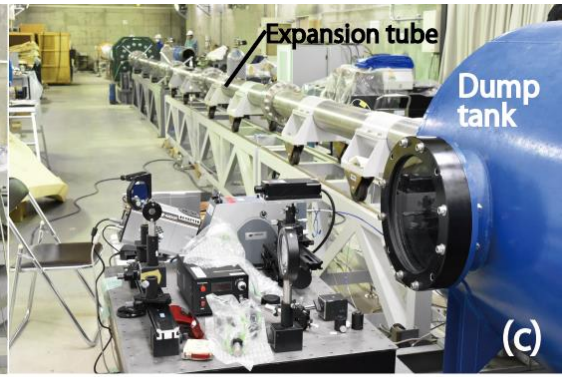


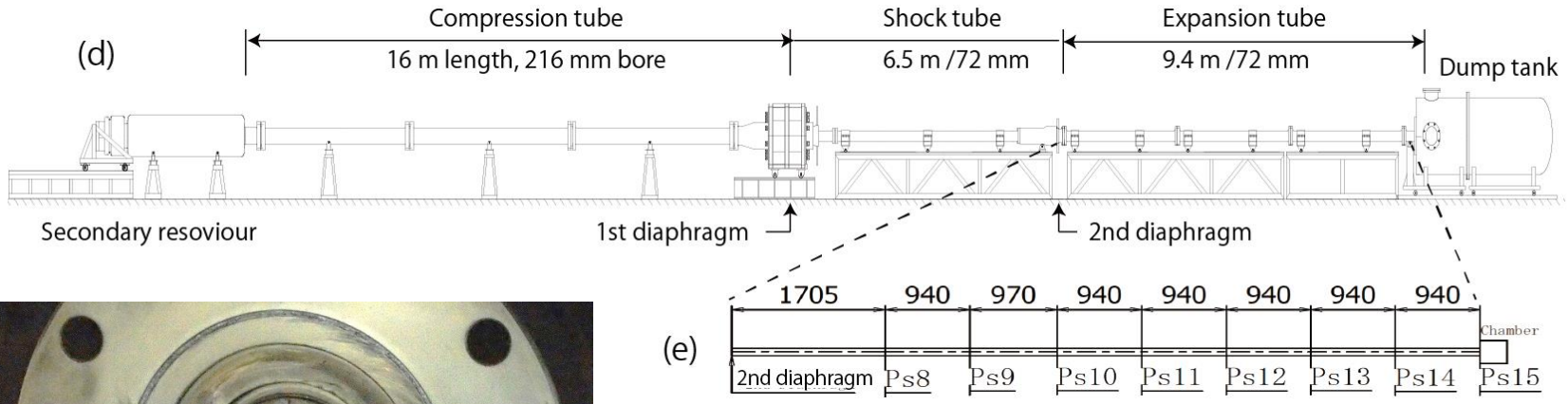


- ✓ Radiation heating is important topic in the deep space exploration mission.
- ✓ HEK-X is possible to cover the maximum heat flux of HAYABUSA reentry condition. Total length of HEK-X is the longest in the middle class of expansion tube.

Free-piston driven expansion tube HEK-X
34 m, 72 mm bore (JAXA Kakuda, since 2015)







Test section

Specifications

	HEK-X	X2(UQ)
✓ Piston Mass, kg	**15.7**	10.5
✓ Compression tube length[m]/bore[mm]	**16/210**	3.8/257
✓ Shock tube length[m]/bore[mm]	**6.5/72**	3.4/85
✓ Expansion tube length[m]/bore[mm]	**9.4/72**	5.2/85
✓ Nozzle length [m] / bore [mm]	**-**	1.4/208

- Thermocouples and pitot

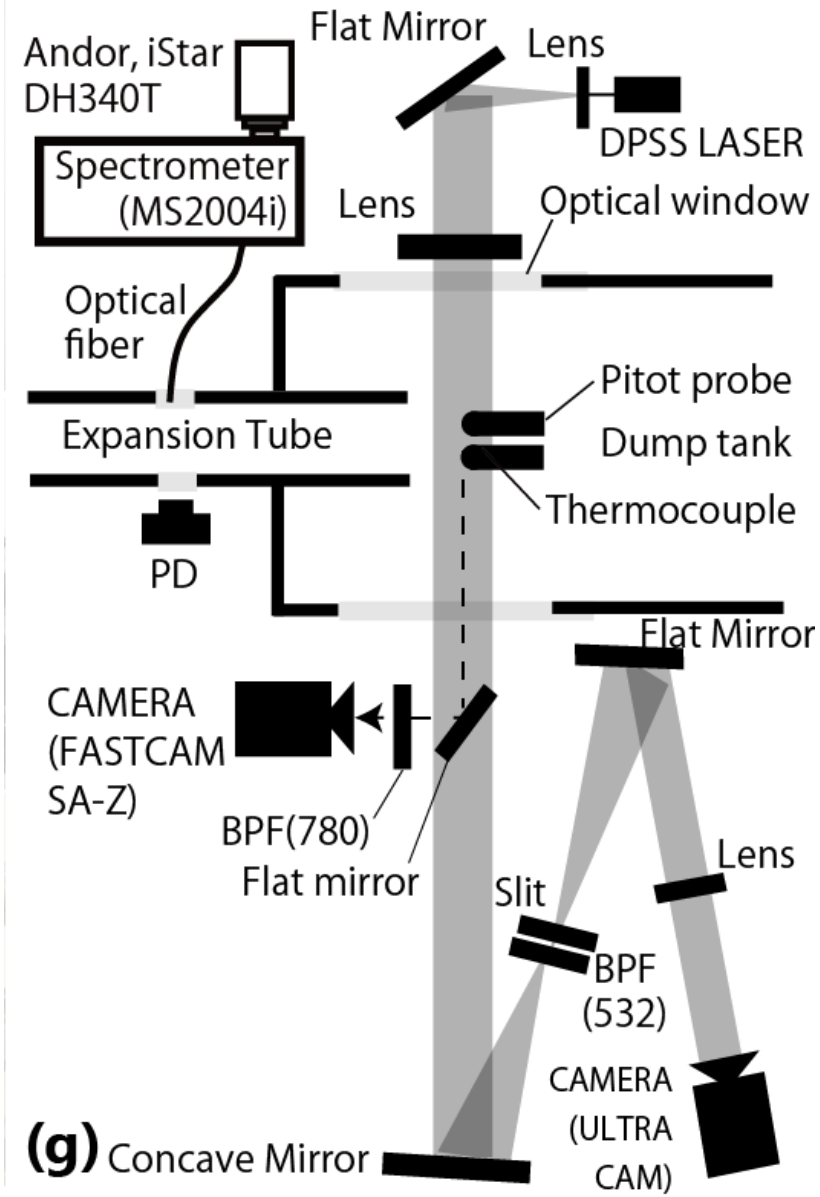
E-type coaxial thermocouples (Φ2.3mm)
PCB(114B28) sensor with cover
15 degree wedge probe
Two probes and wedge were set at 15 mm distance from the end of expansion tube.

- Laser Schlieren for 15 deg wedge

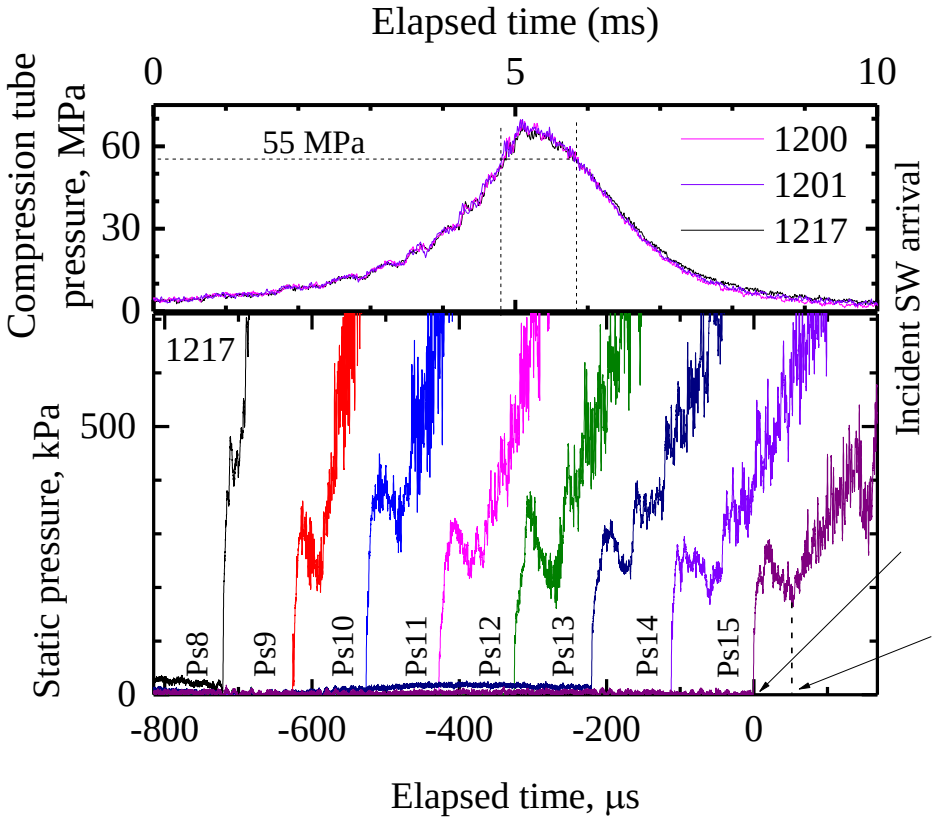
Light source：1W 532nm DPSS Laser
Camera：ULTRA CAM(NAC)
FPS1MHz kHz, Exposure time 0.1 us 120 frames available

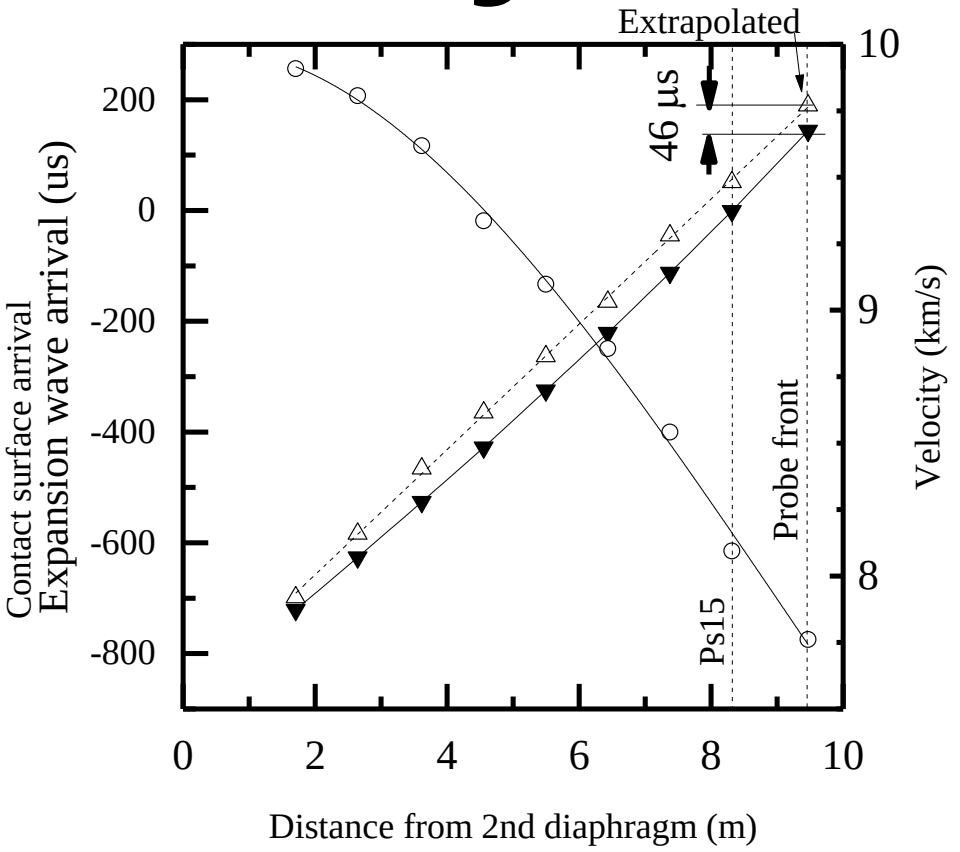
- Self-emission w/780nmBPF

Filter: Ø1" Bandpass Filter, CWL = 780 ± 2 nm, FWHM = 10 ± 2 nm (Thorlabs)
camera：FASTCAM SA-Z
FPS700 kHz, Exposure time 0.25 us
10 k frames are available



Rupture pressure history, static pressure histories and x-t diagram

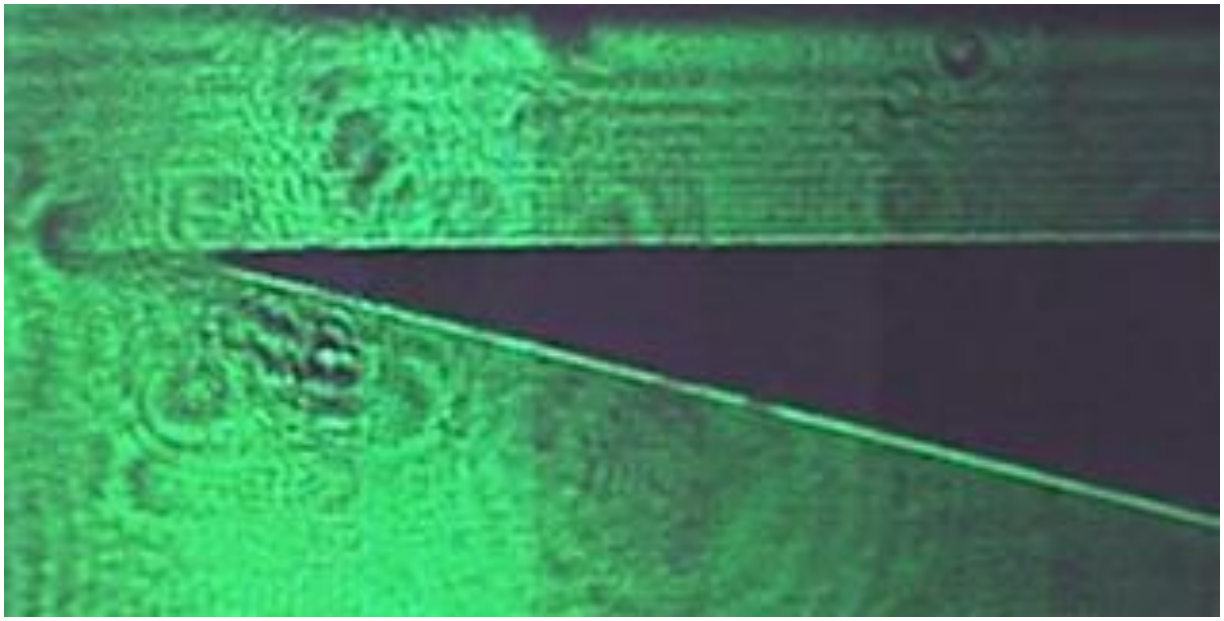


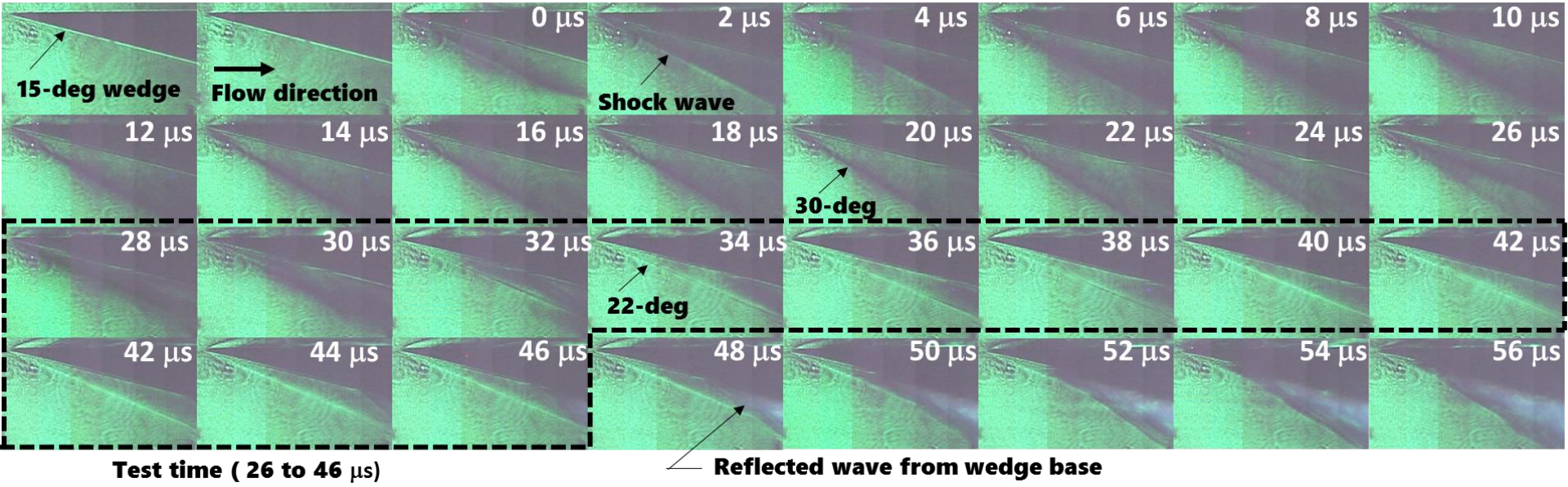


Rupture pressure was hold at 55 Mpa (~1ms) with over drive operation.
SW and Ex-wave arrivals are obtained from each static pressure history.
Displacement of SW and Ex-wave, and SW velocity are obtained on the x-t diagram.
At the test section, SW-Ex wave duration is estimated as 46 us.

Schlieren images

Shot # 1217
Probe shape:
15 deg wedge
Camera condition:
FPS: 0.5 M
Exposure: 100 ns

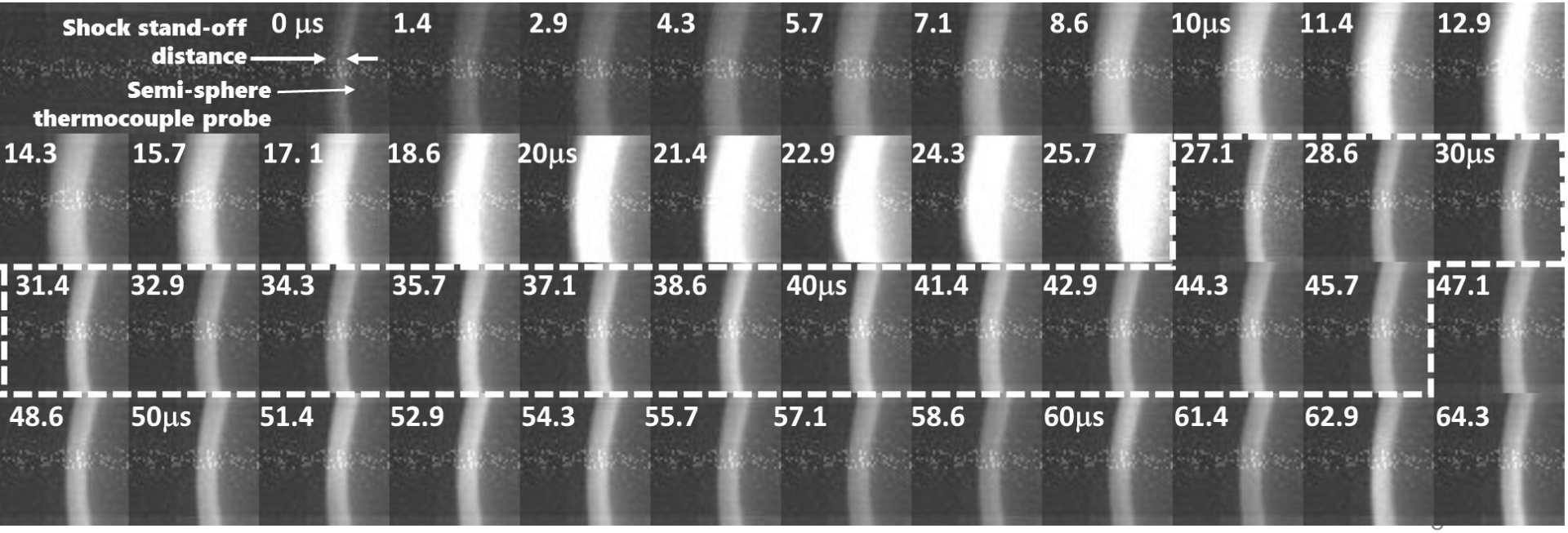


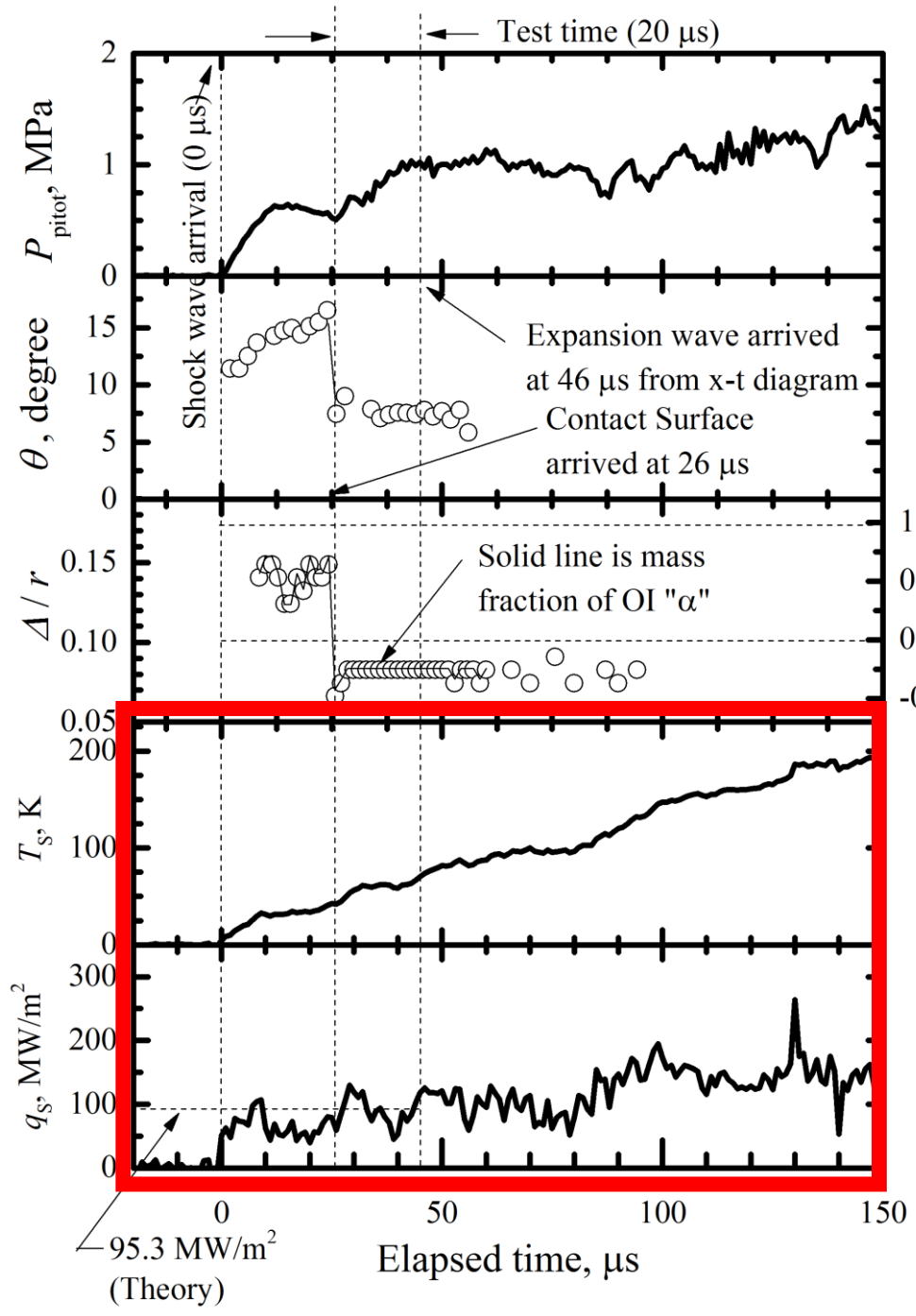


Reflected wave was observed because expansion wave arrived and density increased.

Self emission images

Shot # 1217
Probe shape:
Spherical (D = 20 mm)
E-type thermocouples
Camera condition:
FPS: 0.7 M
Exposure: 100 ns





University of Tsukuba JAXA

TEST TIME CALCULATION

The discontinuity contact surface is observed in the pitot history, SW angle, shock standoff distance at 26 us. Test time = 46 – 26 = 20 us

STAGNATION HEAT FLUX

Stagnation heat flux In the test time was 100 MW/m^2.

Theoretical formula (Tauber-Sutton) can be compared with the experimental result,

$$q_{conv} = 1.35 \times 10^{-10} \sqrt{\frac{\rho_\infty}{R_n}} U_\infty^{3.04} \left(1 - \frac{h_w}{H_0}\right)$$

Theoretical heat flux was 95.3 MW/m^2 which is good agreement with the experimental results.

Test time evaluation in the other conditions

	1218	1217	1215
Reservoir	5.77(MPa)	5.77(MPa)	5.77(MPa)
Compression	92.4(kPa)	92.4(kPa)	92.4(kPa)
Test gas	7(kPa)	10	14
Acceleration gas	61(Pa)	93	197
Test time (theory)	129.5us	163us	195us
Test time (exp)	15us	20us	40us
SW velocity (theory)	11.00km/s	10.12 km/s	9.23km/s
Sw velocity (exp)	**8.2 km/s**	**7.6 km/s**	**6.9 km/s**
Heat Flux (test time) MW/m^2	**70**	**100**	**300**

Because Paull-Staker theory do not consider the viscosity effects, the SW velocity and test time of experiments is different from that of theoretical results.
To obtain the suborbital condition (>8 km/s), we need to increase the reservoir pressure (under construction).

Conclusions

- ✓ The Schlieren visualization and self-emission image were used to simultaneously identify the test time of the expansion wave tube with the pressure / thermal probe measurement.

- ✓ Contact surface behind the shock wave was visualized. SW and Ex-wave arrivals are obtained from each static pressure history. Displacement of SW and Ex-wave, and SW velocity are obtained on the x-t diagram. At the test section, SW-Ex wave duration is estimated as 46 us for shot #1217. We could calculate the test time with the static pressure history.

- ✓ Because Paull-Staker theory do not consider the viscosity effects, the SW velocity and test time of experiments is different from that of theoretical results. To obtain the suborbital condition (>8 km/s), we need to increase the reservoir pressure (under construction).