Heat flux measurements of Hayabusa capsule in 6-9 km/s Earth reentry using expansion tube

T. Kondo[1], Y. Fujiwara[2], K. Shimamura[1], H. Tanno[3], K. Yamada[4], Y. Nagata[4]
[1]University of Tsukuba, Japan; [2]Wseda University; [3]ISAS/JAXA; [4]JAXA KSPC

INTRODUCTION

- Expansion tube is of interest because it can simulate the reentry condition of a sample return capsule.
- But it is difficult to measure the pressure or temperature of the flow made by an expansion tube because of the short test flow period which is only microseconds order.
- In this research, a heat flux measuring system has been developed using a new small amplifier circuit.
- We measured heat flux around the 1:10 model of the Hayabusa sample return capsule model in 6-9 km/s various flow with HEK-X expansion tube (JAXA KSPC).

HEK-X EXPANSION TUBE

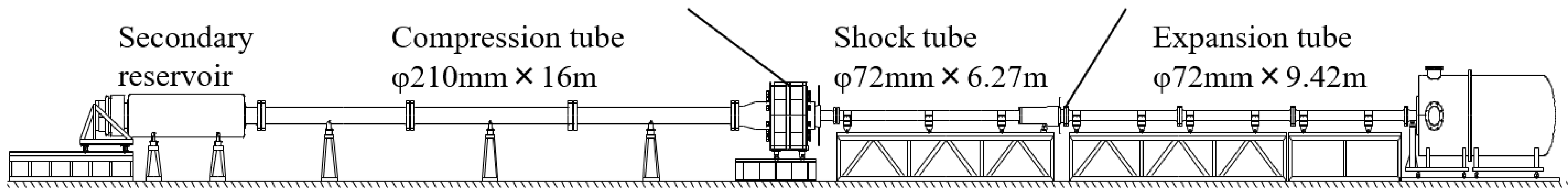


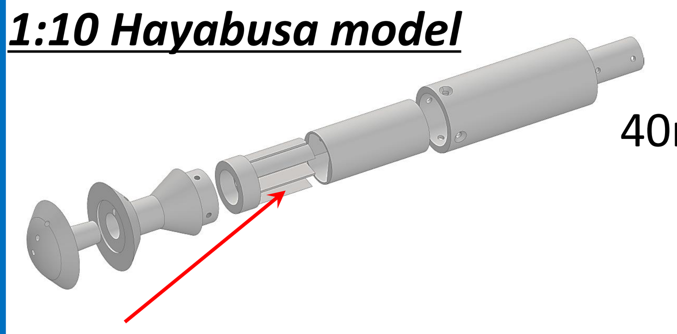
Table of shot condition

	#1262	#1267	#1269	#1217	#1219	#1226	#1227
2nd diaphragm thickness[μm]	50	16	16	50	50	50	50
Secondary reservoir [MPa]	5.57	5.57	5.57	5.57	5.57	6.50	6.50
Compression tube (He) [kPa]	94.2	94.2	94.2	94.2	94.2	94.2	94.2
Shock tube (Air) [kPa]	10	10	10	10	7	10	10
Expansion tube (Air) [Pa]	100	40	47	93	49	90	75
Shock speed [km/s]	6.69	8.77	9.03	8.18	8.06	7.32	7.91
Model	SRC	SRC	SRC	Sphere	Sphere	Sphere	Sphere

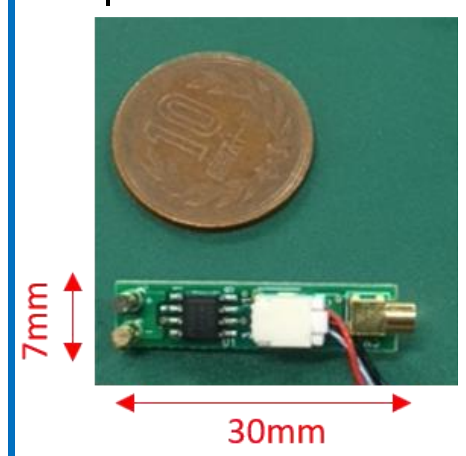
- #1262 was conducted by Fujiwara et al.(2020) using Hayabusa model and #1217-1227 were conducted by Shimamura et al.(2018) using spherical model in HEK-X.
- Using thinner lumirror film for the second diaphragm and setting the initial pressure of the expansion tube lower, #1267 and #1269 had been conducted in nearly 9km/s flow.

MEASURING SYSTEM

1:10 Hayabusa model

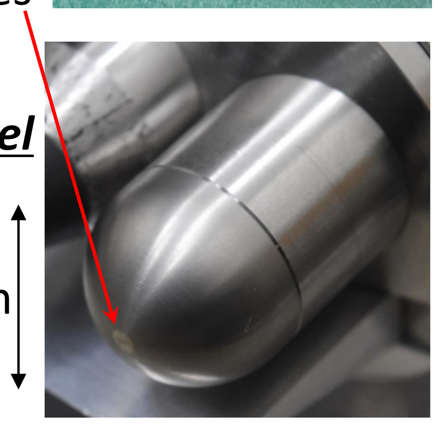


Amplifier



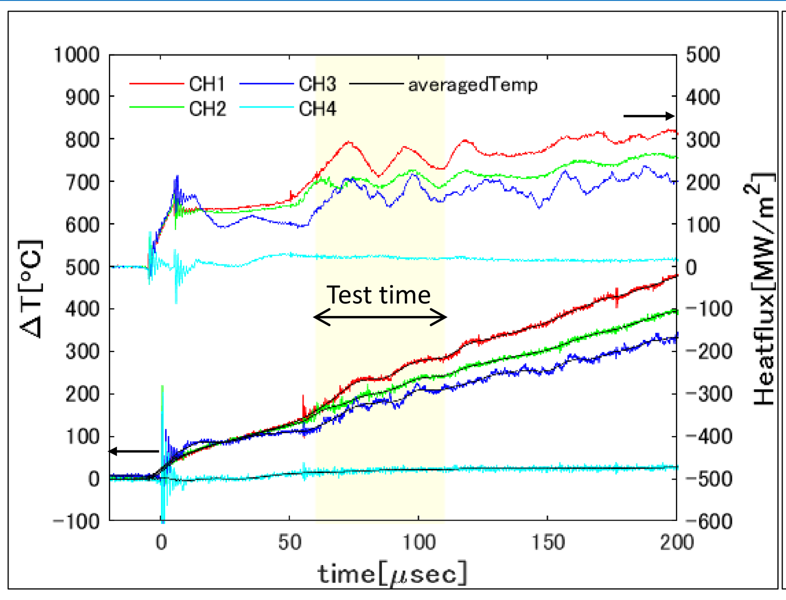
E-type coaxial thermocouples

Sphere model

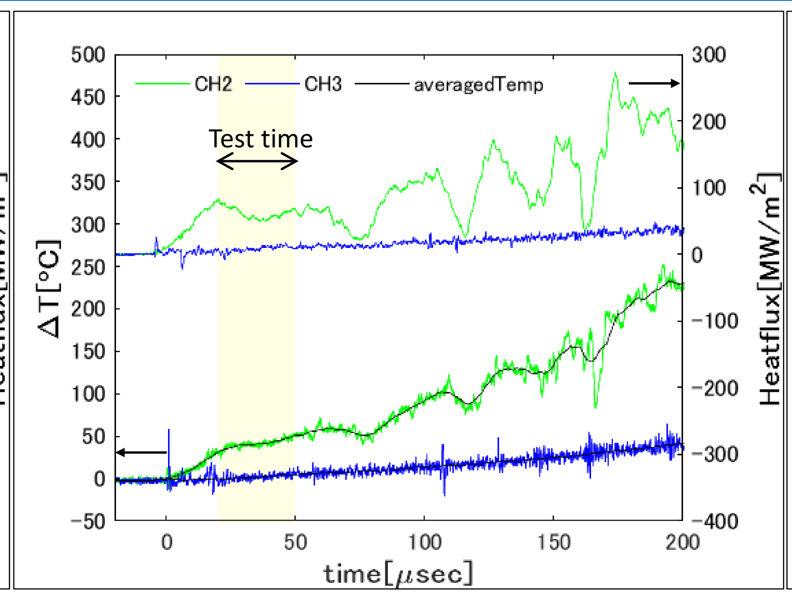


- Coaxial tapered E-type thermocouples are known to have response times of typically 1 μs and it is enough responsiveness for this measurement because the test time of HEK-X is 10 μs order.
- The amplifier gain had been set as 28dB in to have 10 MHz responsiveness.

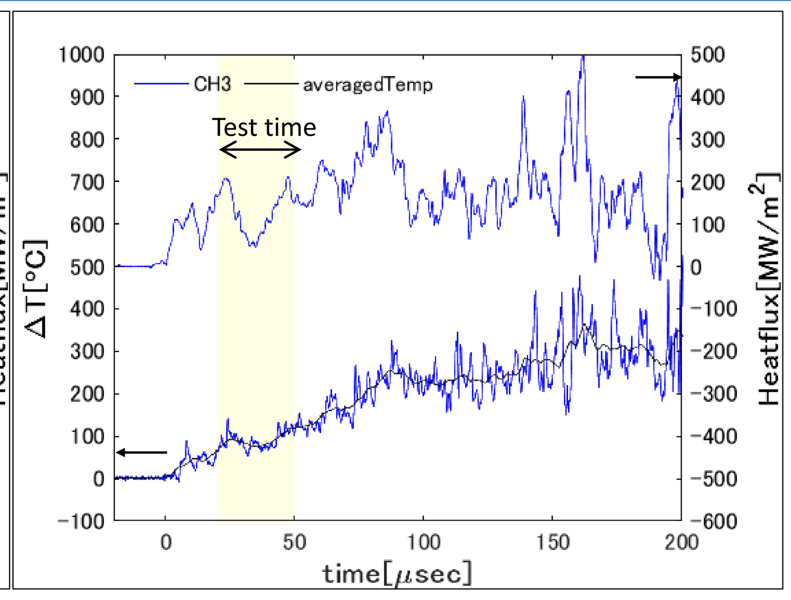
RESULTS OF MEASURING



#1262



#1267



#1269

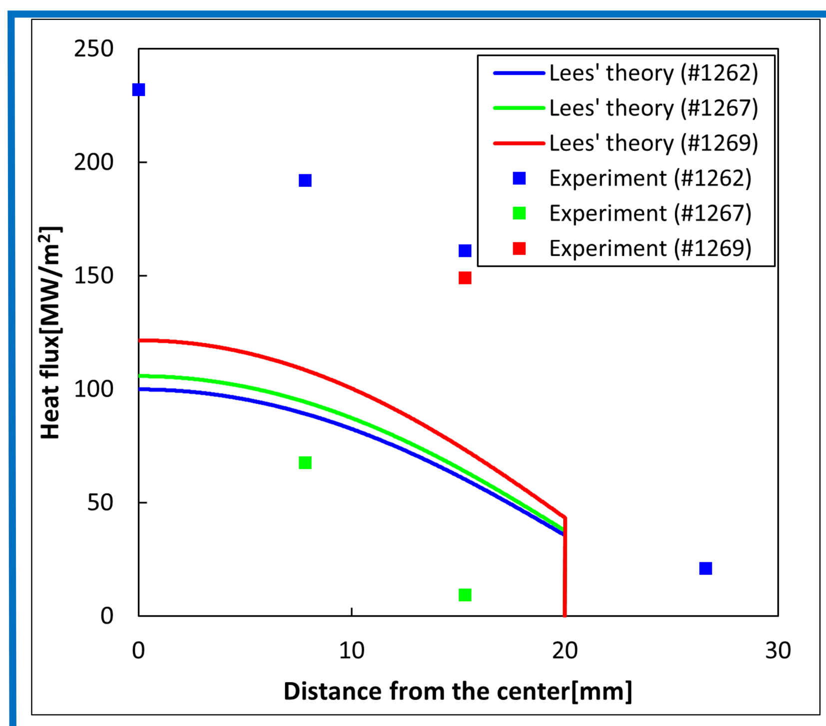
- Heat flux has been calculated from equation (1) derived from a 1-dimensional heat equation.

$$q(t_n) = 2\sqrt{\frac{\rho c k}{\pi}} \sum_{i=1}^{n} \frac{T(t_i) - T(t_{i-1})}{\sqrt{t_n - t_i} + \sqrt{t_n - t_{i-1}}} \quad (1)$$

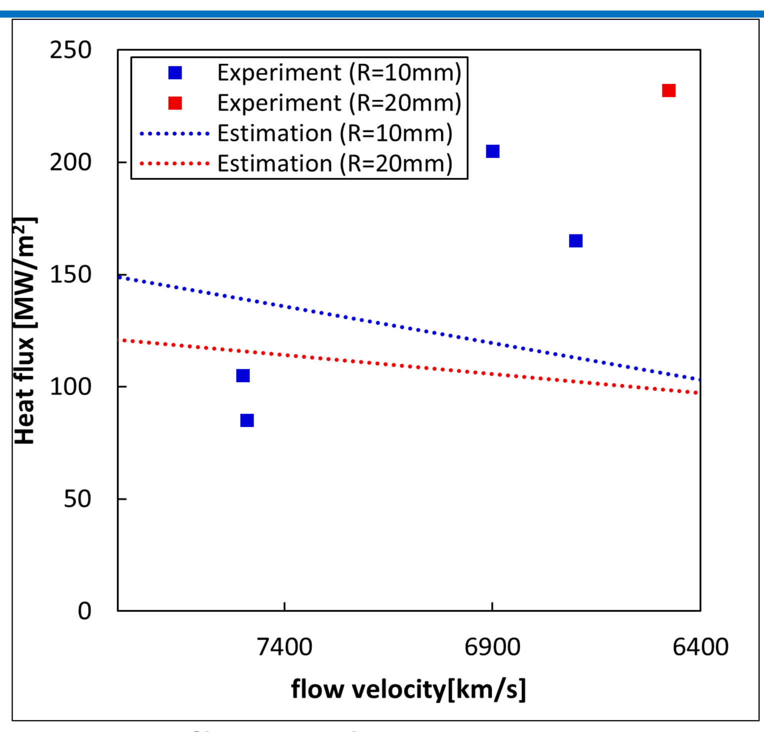
where $\sqrt{\rho c k} = 8918.6[Ws^{\frac{1}{2}}/m^2 K]$ (which is the physical property value of metals constituting E-type thermocouple), T is the measured temperature and t_n is the time at which heat flux is being determined.

- Each measuring point on forebody was named CH1, CH2 and CH3 from the stagnation point, and the measuring point on the afterbody was named CH4.
- There are not temperature data of four all points for #1267 and #1269.

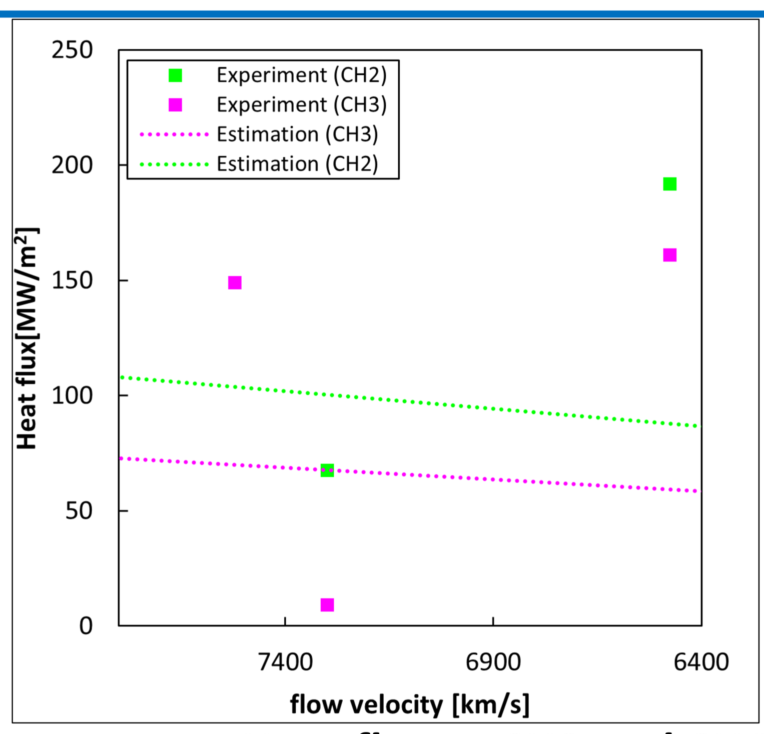
COMPARISON WITH LEES' THEORY



Heat flux around the SRC model



Heat flux at the stagnation point (#1217-1227, #1262)



Heat flux at CH3 and CH4 (#1262, #1267, #1269)

- Heat flux data were plotted against flow velocity.
- Stagnation point data and CH2 data show the same trend as experiment data is in good agreement when the flow velocity is higher, but for CH3, there is no such trend.
- The cause of the error between the experimental and theoretical values has not been clarified and needs to be verified in the future.

- Plots are experiment data of #1262, #1267 ,and #1269. The solid line is the theoretical value of heat flux calculated by Tauber's empirical formula(1991) and Lees' theory (1956).
- For #1267 and #1269, the shock speed was almost the same, but heat flux was different.
- For #1262, the heat flux is almost twice as much as the theoretical value, but the distribution of heat flux agrees approximately with that of the theoretical value.

CONCLUSION

✓ Measured heat flux in 6km/s flow looks in good agreement with the distribution of theoretical value, but each value is almost twice as much as that from theory.

✓ There is a trend that experiment data match the theoretical values in higher flow velocity.

✓ For causes of the difference between experimental and theoretical value of heat flux, these can be thought,
・The simple theory of thermal equilibrium assumption used in the process of calculating the theoretical value of heat flux may not be sufficiently accurate.
・The flow got into the model may affect the noise of temperature data.

✓ More experiments and improvement of the model are needed to measure heat flux using HEK-X in higher velocity flow.

18th International Planetary Probe Workshop
June 17th, 2021, online