Hypersonic boundary-layer transition measurement using Focused Laser Differential Interferometry

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Introduction

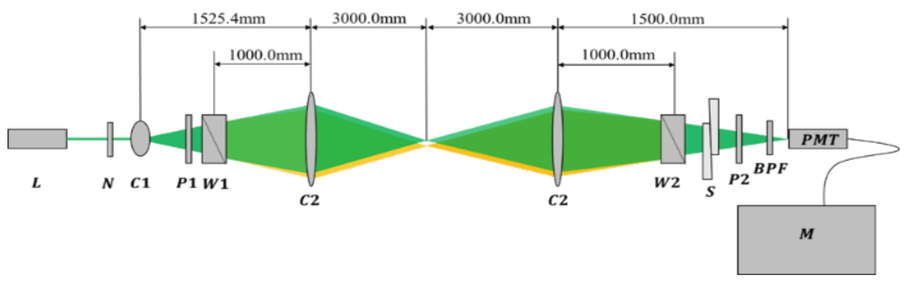
✓The boundary layer changes from laminar flow to turbulent flow, and the surface heating rate and surface friction of the object increase several times, which is a factor in increasing the capacity of the thermal protection system of hypersonic aircraft.

✓Boundary layer transition occurs when an unstable mode called 2nd-Mode grows.

✓In Japan, 2nd-Mode waves have recently been measured in the free-piston high-enthalpy shock wave tunnel JAXA-HIEST at Kakuda Space Center using PCB sensors mounted on a 7-degree half-width cone model, and the 2nd-Mode was detected at 200 kHz to 400 kHz at a position about 500 mm downstream from the nose tip of the mold.

✓In this study, we applied Focused Laser Differential Interferometry (FLDI), which is non-contact optical system to measure the 2nd-Mode in HIEST and conduct a comparison with PCB sensors measurements.

Focused Laser Differential Interferometry



✓FLDI is an optical system experimental device that separates lasers into two lasers on several hundred μm and applies refraction and interference of light.

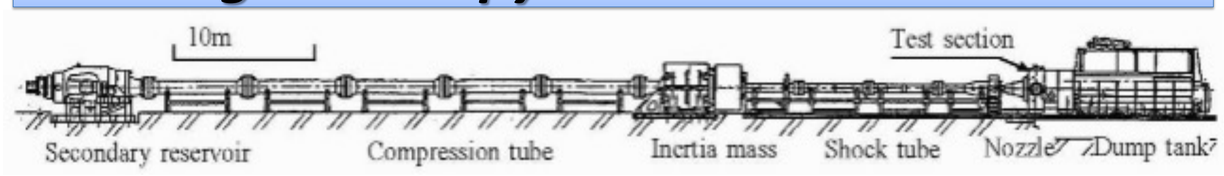
✓FLDI has a high temporal resolution, spatial resolution, non-contact characteristics.

✓FLDI can detect the phase difference between two lasers separated from the detected voltage change and measure the density difference through a conversion formula.

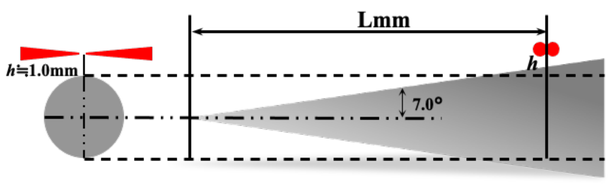
$$\Delta\rho = \frac{\lambda}{2\pi KL}\left(\frac{V}{V_0} - 1\right) \quad (1)$$

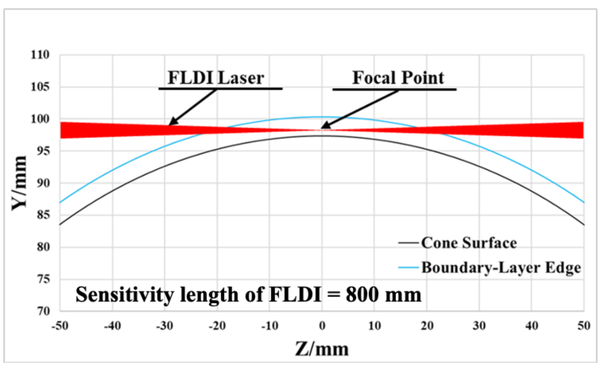
✓By frequency analysis of this density fluctuation, it is possible to detect the spectral characteristics of the dominant density fluctuation within the test time.

High-enthalpy shock tunnel HIEST



Shot.No	Stagnation conditions			Free flow conditions			Re [*10^6/m]	FLDI position L [mm]
	Temperature [K]	Pressure [MPa]	Enthalpy [MJ/kg]	Density [kg/m^3]	Velocity [m/s]	Mach no.		
2965	3177	28.50	3.831	0.02793	2656	7.622	4.099	799.0
2968	3172	27.48	3.825	0.02784	2654	7.621	4.087	749.0
2970	3092	28.73	3.720	0.02988	2618	7.648	4.445	699.0
2971	3139	27.48	3.782	0.02814	2639	7.632	4.153	-





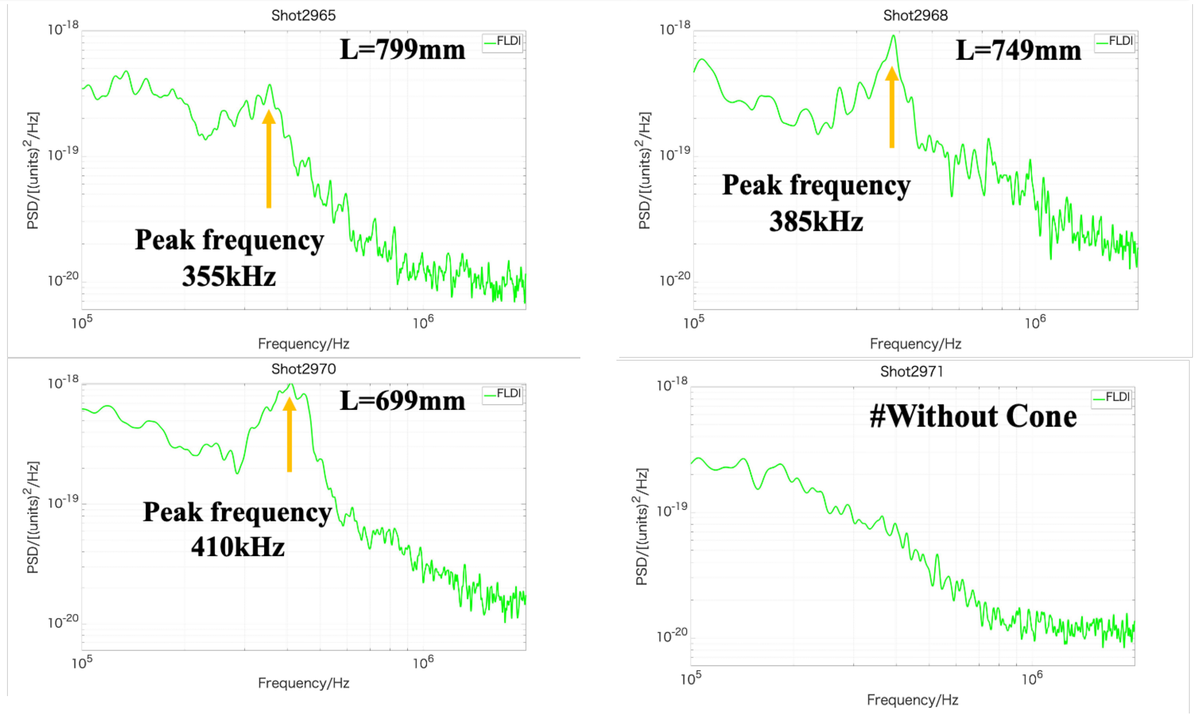
✓High-speed pressure transducers are mounted on the upper surface of the model.

✓the FLDI laser was passed at three positions of 699 mm, 749 mm and 799 mm from the tip of the model nozzle.

✓CH.8 and CH.9 of the PCB sensors were located at 699 mm from the nose tip.

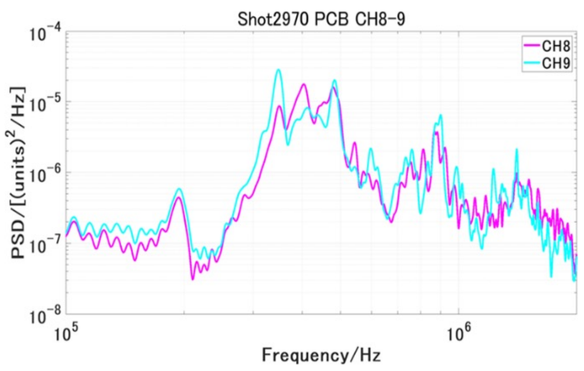
✓Shot 2971 was the shot without the model.

Results of FLDI



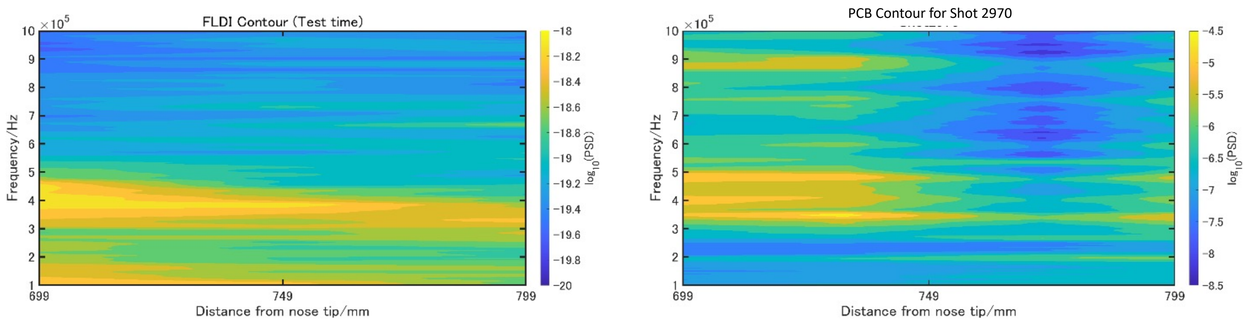
✓4 power spcectral density showed high amplitudes in the frequency range around 300 kHz to 500 kHz which seemed to be the 2nd mode.

Comparison with PCB sensors



✓Same as FLDI, the spectrum showed that high amplitudes in the frequency range around 300 kHz to 500 kHz.

✓it is difficult to identify the peak frequency of the PCB sensors, because FLDI detected the peak frequency more significantly than the PCB sensors, and the PCB sensors detected a sharp peak frequency over a wider band .



✓From both of contours, the relatively strong signals were observed in 300 kHz to 500 kHz.

✓In the FLDI plot, the frequency of this strong signal was reduced as increased the distance from the cone tip.

✓This trend is predicted by the stability analysis, and shows the good agreement with the analytical predictions calculated by Ide et al.

Conclusion

✓The 2nd-Mode was measured with Focused Laser Differential Interferometry in high-enthalpy shock tunnel HIEST.

✓The spectrum of FLDI and PCB showed high amplitudes in the frequency range around 300 kHz to 500 kHz which seemed to be the 2nd mode.

✓The peak frequency was decreased as increased the distance from the nose tip, and this trend is predicted by the theoretical stability analysis.

✓To improve the accuracy using FLDI in the future, it is necessary to reexamine so that the sensitivity region of FLDI fits within the boundary layer and acquire the spatial distribution of the transition using multiple FLDIs.

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