

Thin Electronic Casing Cooling CFD–CHT Simulation: OpenFOAM Validation Study

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Abstract. This report documents an OpenFOAM conjugate heat-transfer (CHT) validation of forced airflow and package heating in the Hatakeyama thin electronic casing benchmark, used as a production baseline for the tensorECool template. Steady multi-region flow and heat transfer are solved with chtMultiRegionSimpleFoam and RAS kOmegaSST for three inlet locations ($X_{in} = 100, 130, 150$ mm). Geometry, volumetric heat load (2.6 W), and PIV stations follow Hatakeyama et al. Validation focuses on streamwise velocity line profiles $U_y(x)$ at $Z = 7$ mm against digitised experimental markers. Package temperature rise and solid/fluid temperature fields are presented to illustrate the thermal distribution; quantitative temperature error against experiment is not discussed because the published thermal data are insufficient for a robust point-wise assessment in this recreation.

1. INTRODUCTION

Air-cooled thin casings for electronics couple a side inlet with a heated PBGA/PCB stack, outlet chimneys, and acrylic side walls. The Hatakeyama test bench [1] provides a compact, well-documented geometry with PIV streamwise-velocity profiles at five streamwise stations and a measured package temperature rise for three inlet positions.

Validating an OpenFOAM CHT template for this case is important because it forms a foundational element of tensorCFD [2], an open-source initiative by PT Tensor aimed at delivering production-ready, industry-grade simulation templates. The validated setup is intended as a core engine for tensorECool. Verifying velocity line profiles against experiment, together with a consistent multi-region mesh and thermal field, supports a reliable baseline for electronics cooling CFD development.

2. NUMERICAL METHODS

2.1 Solver and Turbulence Model

Steady conjugate heat transfer was solved with chtMultiRegionSimpleFoam (OpenFOAM v2512). Air is treated with Boussinesq buoyancy; turbulence is RAS kOmegaSST. Wall treatment uses continuous wall functions on the fluid side; coupled fluid–solid interfaces use compressible::turbulentTemperatureCoupledBaffleMixed. Air properties: $\rho_0 = 1.2$ kg/m³, $\mu = 1.8 \times 10^{-5}$ Pa·s, $Pr = 0.7$, $T_0 = 300$ K. PCB conductivity is anisotropic $\kappa = (2, 2, 0.35)$ W/m/K; PBGA mold $k = 1$ W/m/K with volumetric heat $Q = 2.6$ W in the package.

Numerical method: bounded linearUpwind for U and h , upwind for k and ω , cell-limited gradients, classic SIMPLE, GAMG for p_{rgh} , under-relaxation $p_{rgh} = 0.3$, $U = 0.3$, $h = 0.75$, $k, \omega = 0.3$. Cases were run to 4,000 SIMPLE iterations with field writes every 100 iterations.

2.2 Geometry and Boundary Conditions

Geometry follows Hatakeyama et al. [1]: outer acrylic shell 200 x 257 x 30 mm; inner cavity 120 x 235 x 10 mm. Side inlet duct 20 x 10 mm with uniform $V_{in} = 2.82$ m/s ($Q_{in} = 5.64 \times 10^{-4}$ m³/s). Three identical top outlets, each 22 mm wide in x , with chimney protrusion 22 mm in $+y$ and Z -slot 2.5 mm wall + 5 mm opening + 2.5 mm wall. L-shaped islands separate the outlets (5 mm fingers). PCB 110 x 110 x 1.2 mm and PBGA 45 x 45 x 2.5 mm are centred at (0.100, 0.100) m. The $+X$ outer

face (side_posX) is slip; the left polystyrene dummy remains. Inlet location Xin shifts the 20 mm duct: Xin = 100, 130, 150 mm.

2.3 Mesh Generation

A structured hex mesh is generated with blockMesh (1 mm in-plane), z-slabs aligned with PCB (1.2 mm), PBGA top (3.7 mm), and outlet planes at 2.5 / 7.5 mm, then dummy solids removed with topoSet/subsetMesh and regions split for fluid / PCB / PBGA. Fluid cell counts are about 715k (Xin100/130) and 756k (Xin150); PCB $\approx$ 48k cells; PBGA $\approx$ 12k cells.

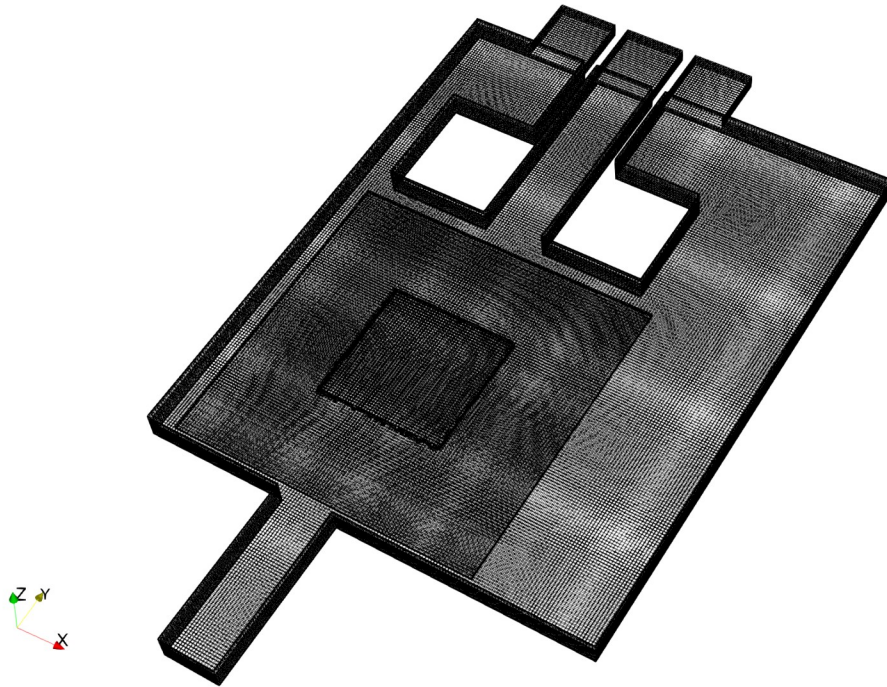


FIGURE 1. Structured multi-region mesh of the Hatakeyama thin casing: full domain view.

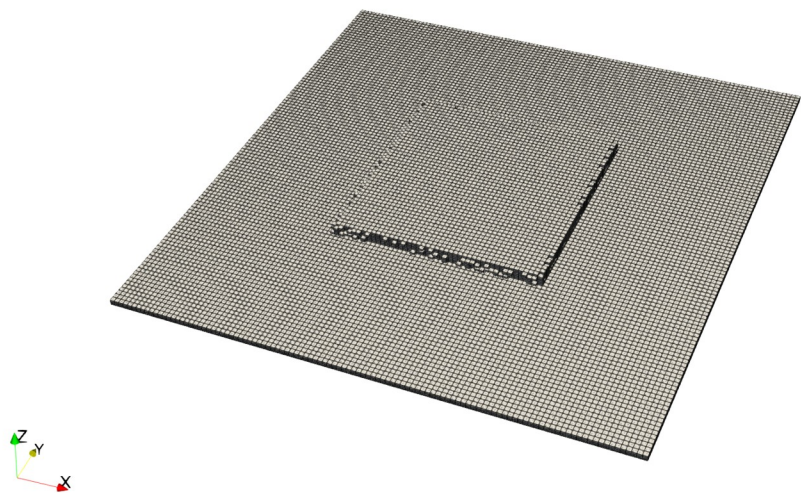


FIGURE 2. PCB and PBGA solid regions within the cavity mesh.

TABLE 1. Baseline numerical setup (Xin100)

Item	Setting
OpenFOAM	v2512 (opencfd/openfoam-run)
Solver	chtMultiRegionSimpleFoam (steady, Boussinesq air)
Turbulence	RAS kOmegaSST
Inlet Vin / T0	2.82 m/s / 300 K (uniform)
Heat load	2.6 W (PBGA volumetric)
PCB kappa	(2, 2, 0.35) W/m/K
Fluid cells (Xin100)	≈ 715,000
End time (iterations)	4,000

3. VELOCITY DISTRIBUTION VALIDATION

Validation compares OpenFOAM streamwise velocity $U_y(x)$ at $Z = 7$ mm with digitised PIV markers from Hatakeyama Fig. 6 [1] at $Y = 60, 80, 100, 120, 140$ mm ($X = 40\text{--}160$ mm). Profiles are reported for all three inlet locations after 4,000 iterations.

TABLE 2. Velocity profile RMSE vs digitised PIV (m/s); CFD interpolated onto experiment X

Y [mm]	Xin100	Xin130	Xin150
60	0.311	0.319	0.600
80	0.357	0.287	0.527
100	0.422	0.383	0.438
120	0.417	0.431	0.391
140	0.435	0.412	0.376

3.1 Xin = 100 mm

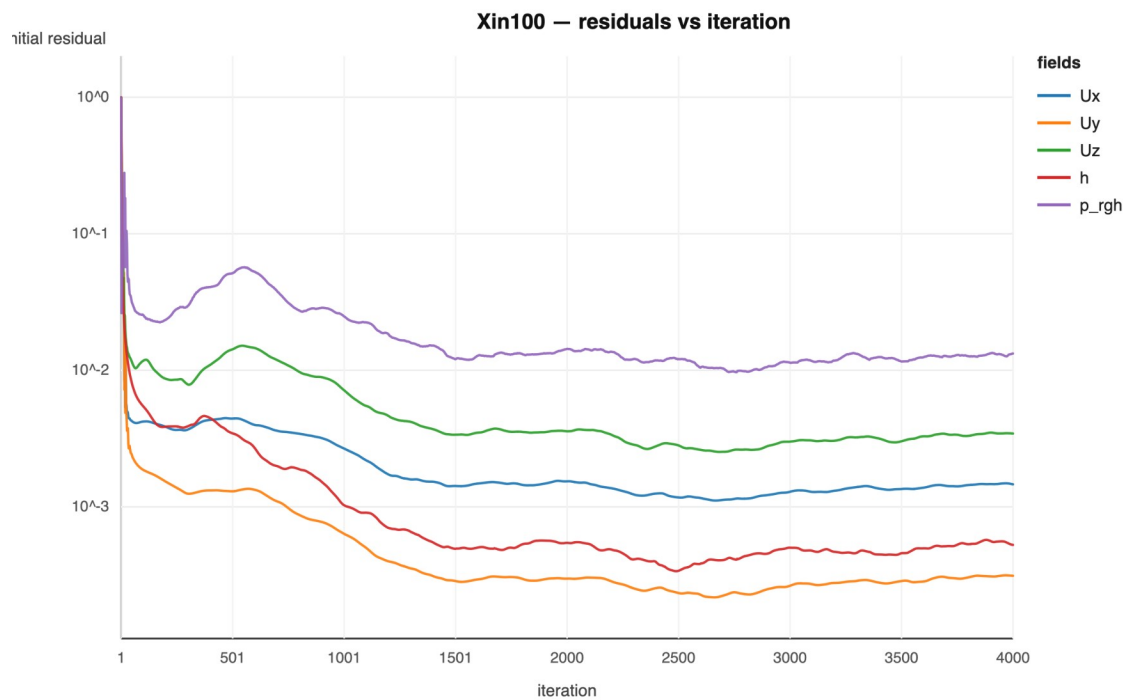


FIGURE 3. Residual history (Xin100).

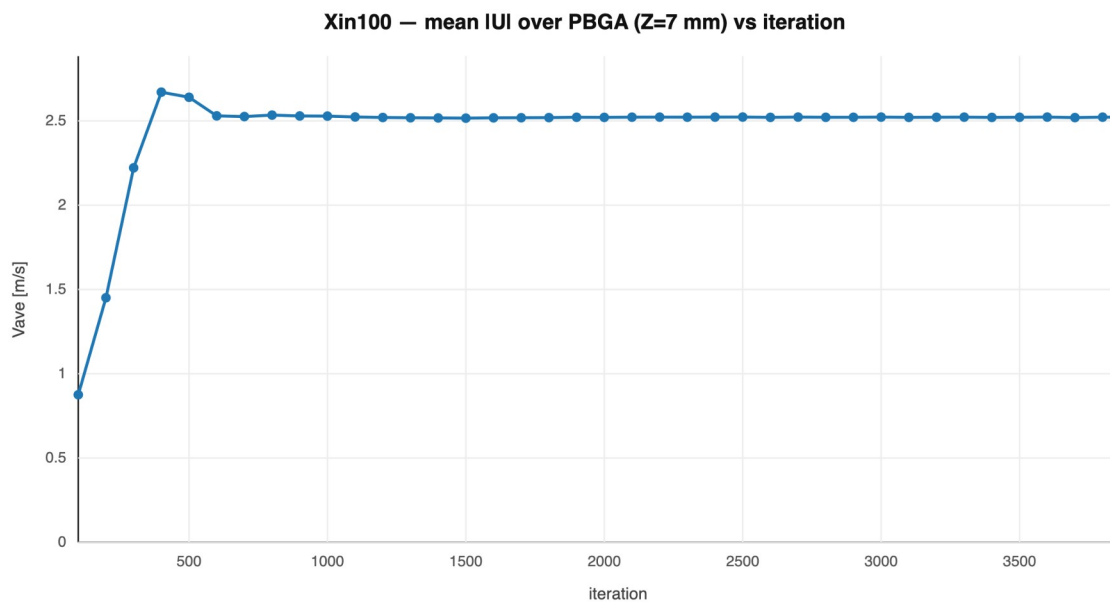


FIGURE 4. Domain-average velocity history (Xin100).

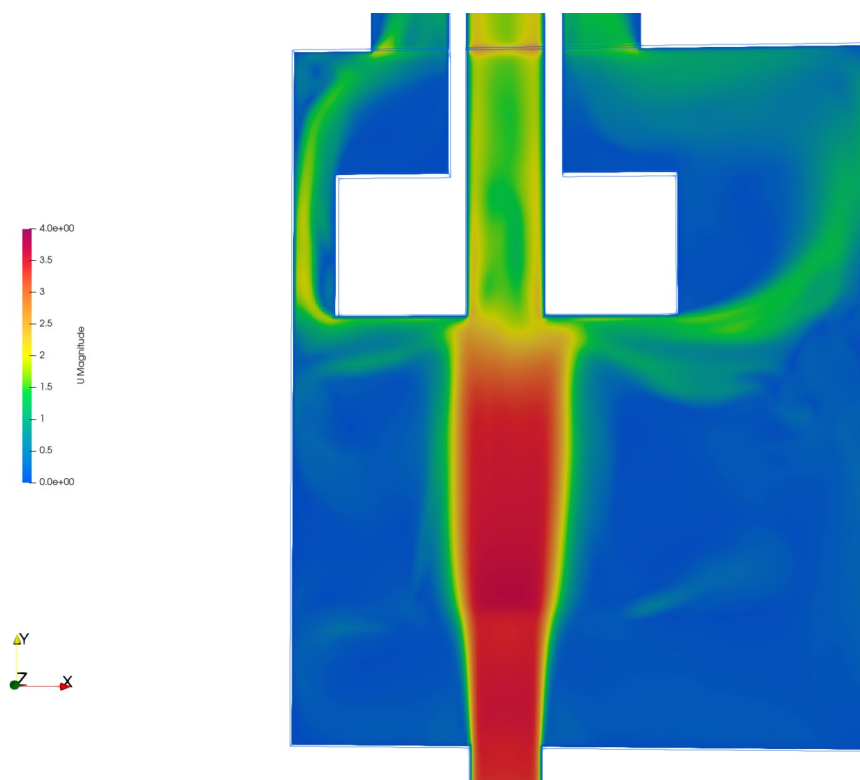


FIGURE 5. Mid-plane velocity magnitude (Xin100): side inlet, package wake, and chimney outflow.

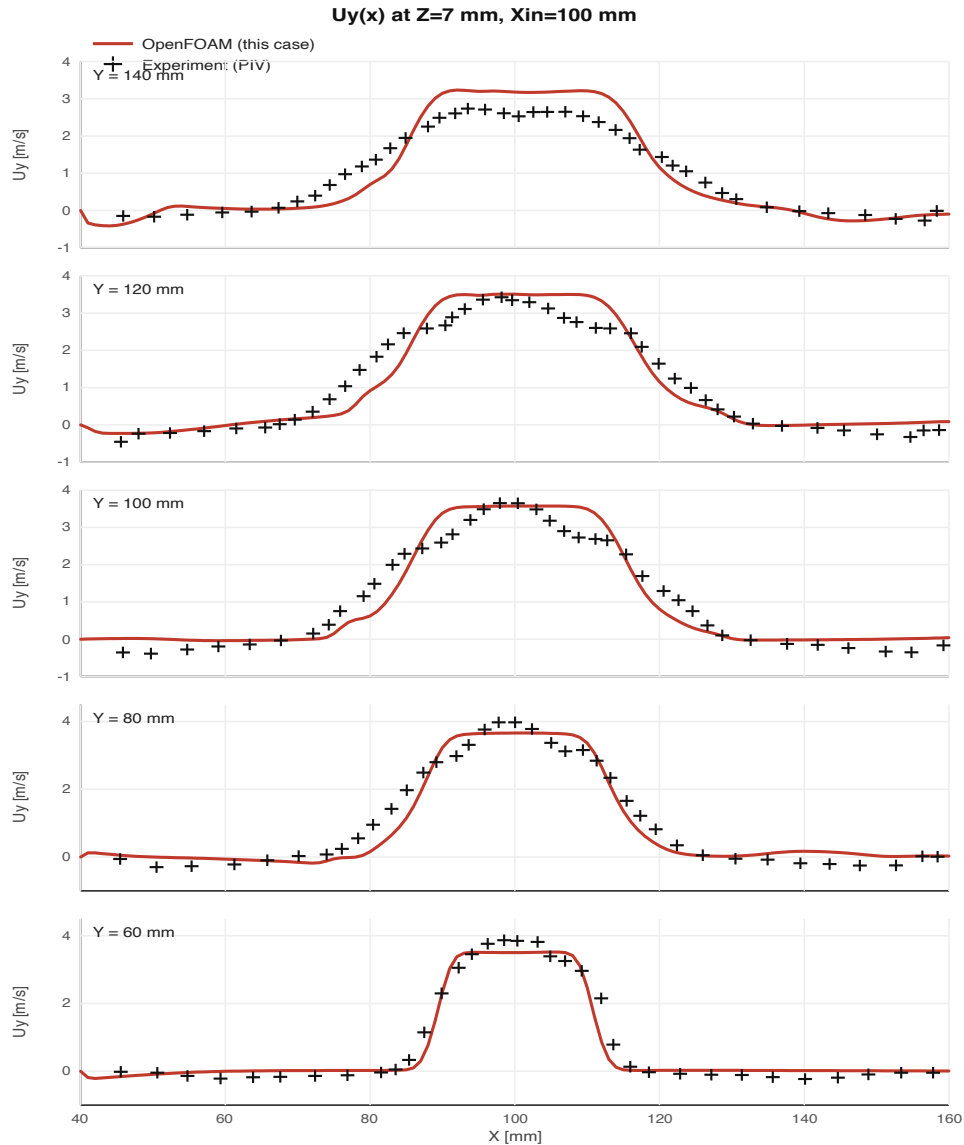


FIGURE 6. Streamwise $U_y(x)$ at $Z = 7$ mm ($X_{in}=100$): OpenFOAM versus digitised PIV [1]. Stations $Y = 140$ (top) to $Y = 60$ mm (bottom).

Mid-plane velocity fields show the side inlet jet, acceleration over the package, and outflow toward the three chimney slots. Stacked $U_y(x)$ profiles recover the experimental jet core and side recirculation at $Y = 60$ – 100 mm. Downstream stations ($Y = 120$ – 140 mm) remain slightly peaky relative to PIV—consistent with under-predicted lateral mixing in the package wake under steady RANS—but the overall jet–wake–outlet topology matches the experiment.

3.2 $X_{in} = 130$ mm

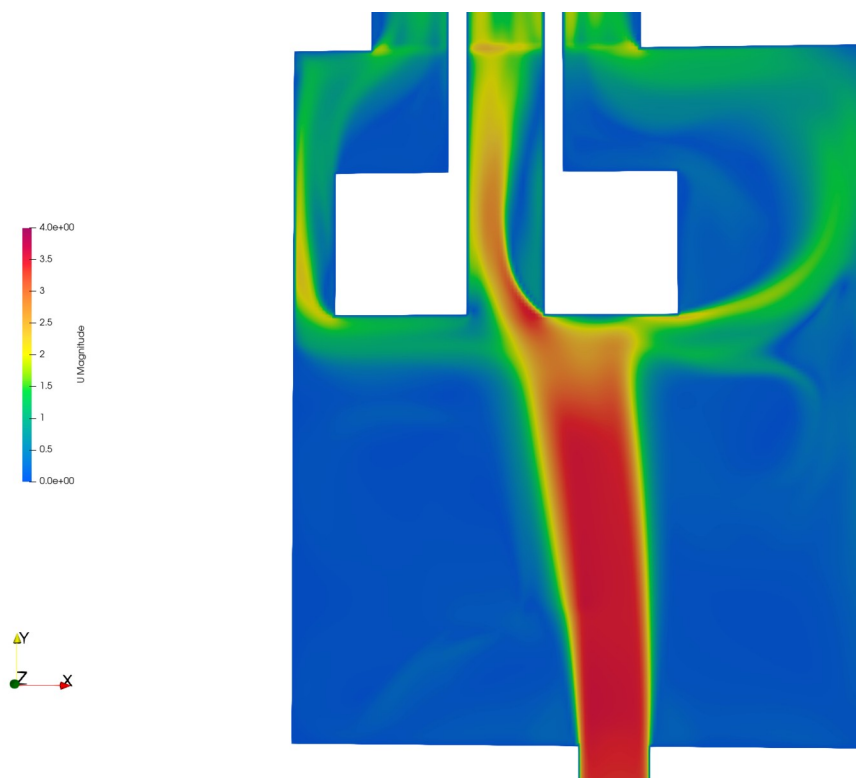


FIGURE 7. Mid-plane velocity magnitude (Xin130).

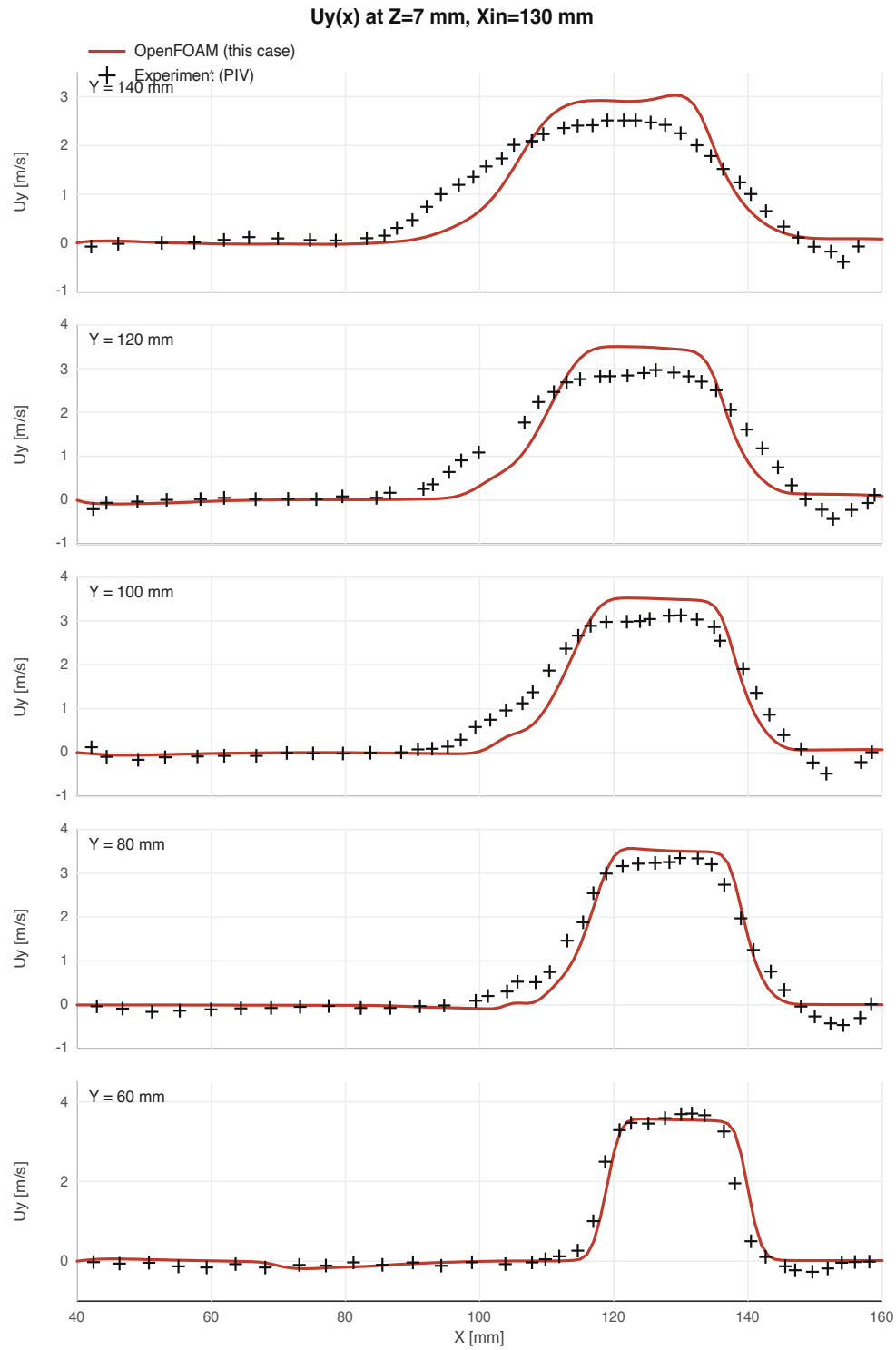


FIGURE 8. Streamwise $U_y(x)$ at $Z = 7$ mm ($X_{in}=130$): OpenFOAM versus digitised PIV [1].

Shifting the inlet to $X_{in} = 130$ mm moves the high-speed core and changes how the jet interacts with the package and L-islands. Profile overlays capture the streamwise evolution of U_y with RMSE values of similar magnitude to X_{in100} at mid and far stations (Table 2).

3.3 $X_{in} = 150$ mm

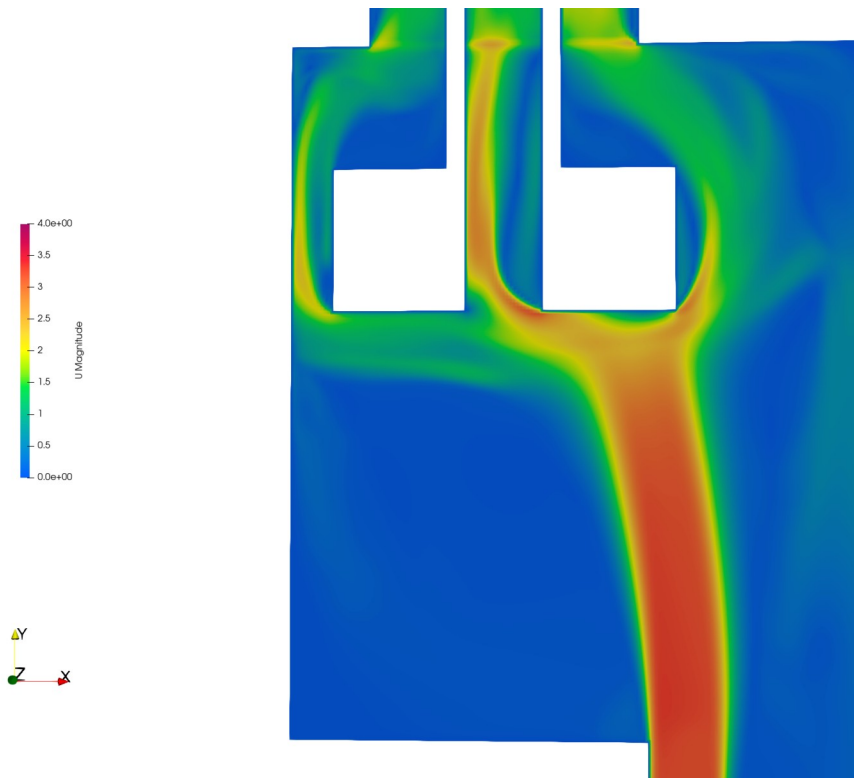


FIGURE 9. Mid-plane velocity magnitude (X_{in150}).

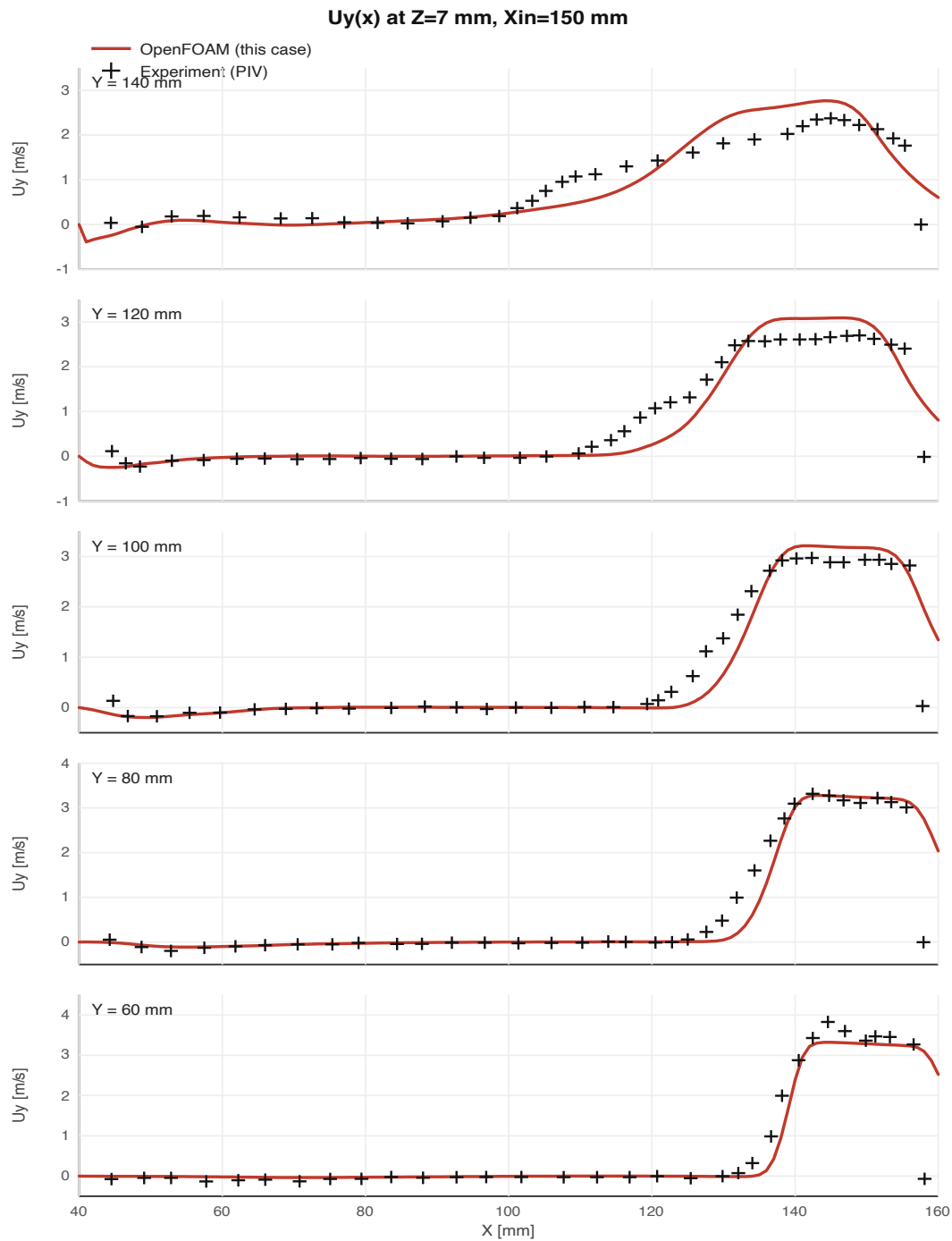


FIGURE 10. Streamwise $U_y(x)$ at $Z = 7$ mm ($X_{in}150$): OpenFOAM versus digitised PIV [1].

At $X_{in} = 150$ mm the duct sits closer to the +X wall. Near-inlet stations show larger local RMSE where the sampled line cuts a steeper spanwise gradient; mid and far stations remain comparable to the other X_{in} cases.

4. TEMPERATURE DISTRIBUTION

Conjugate heat transfer produces a hot PBGA package, lateral conduction into the anisotropic PCB, and convective cooling by the air jet. Mid-plane fluid temperature and solid temperature fields for Xin100/130/150 illustrate the thermal plume and the response to inlet location: farther inlet positions reduce local cooling over the package and raise package temperatures.

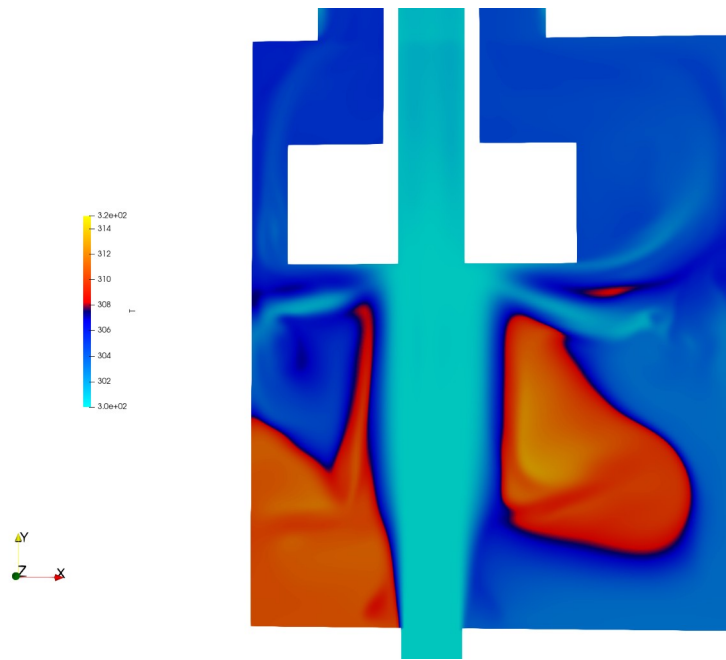


FIGURE 11. Mid-plane fluid temperature (Xin100).

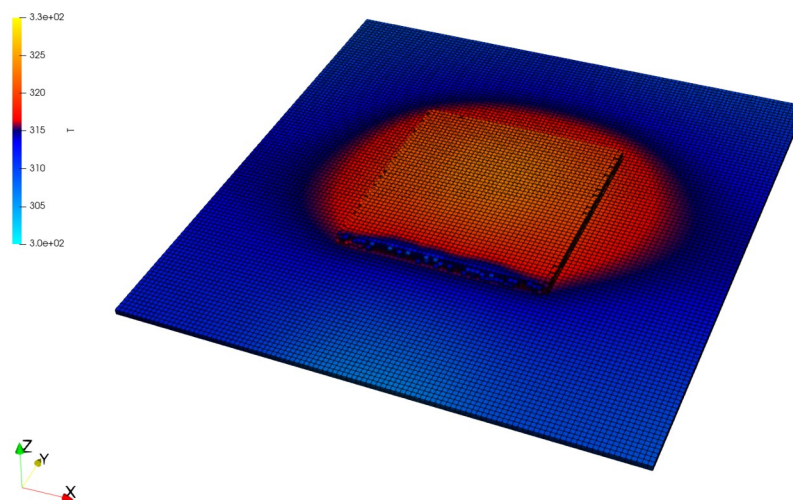


FIGURE 12. PCB / PBGA solid temperature (Xin100).



FIGURE 13. Package temperature-rise history $\Delta T = T_{PBGA,avg} - T_{inlet}$ (Xin100).

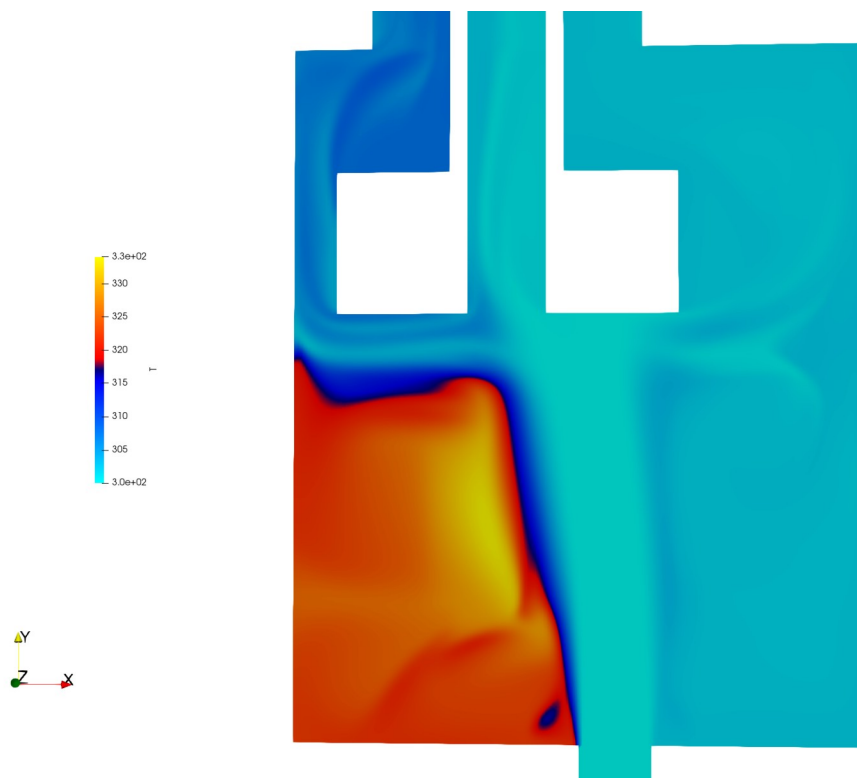


FIGURE 14. Mid-plane fluid temperature (Xin130).

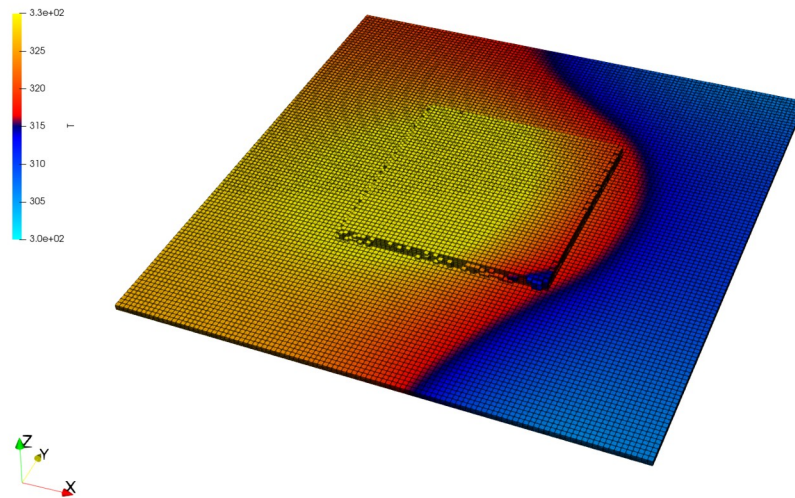


FIGURE 15. PCB / PBGA solid temperature (Xin130).

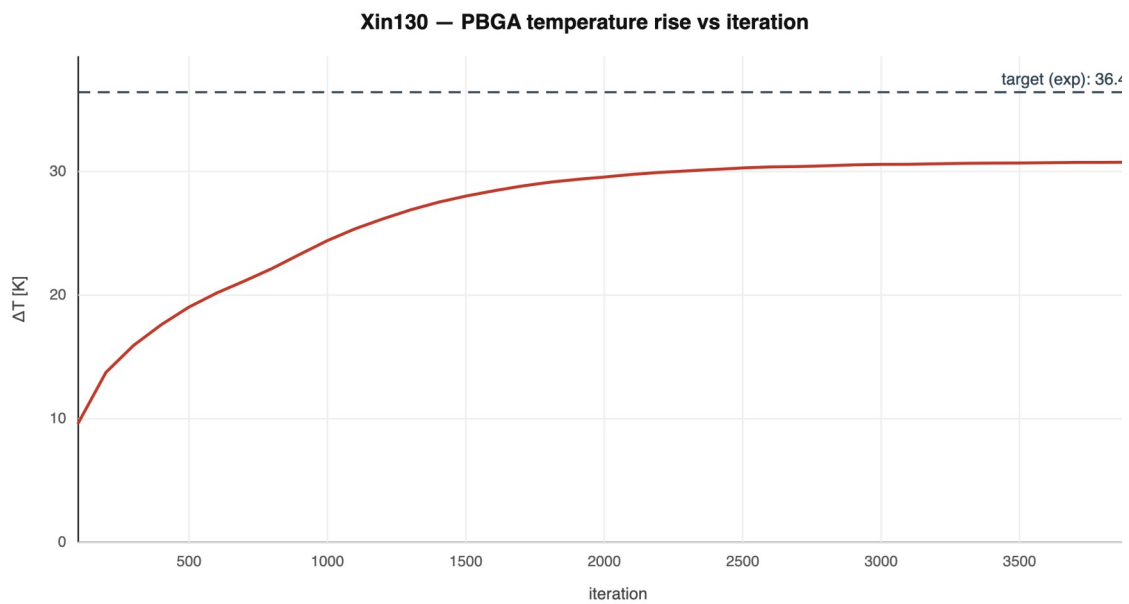


FIGURE 16. Package temperature-rise history (Xin130).

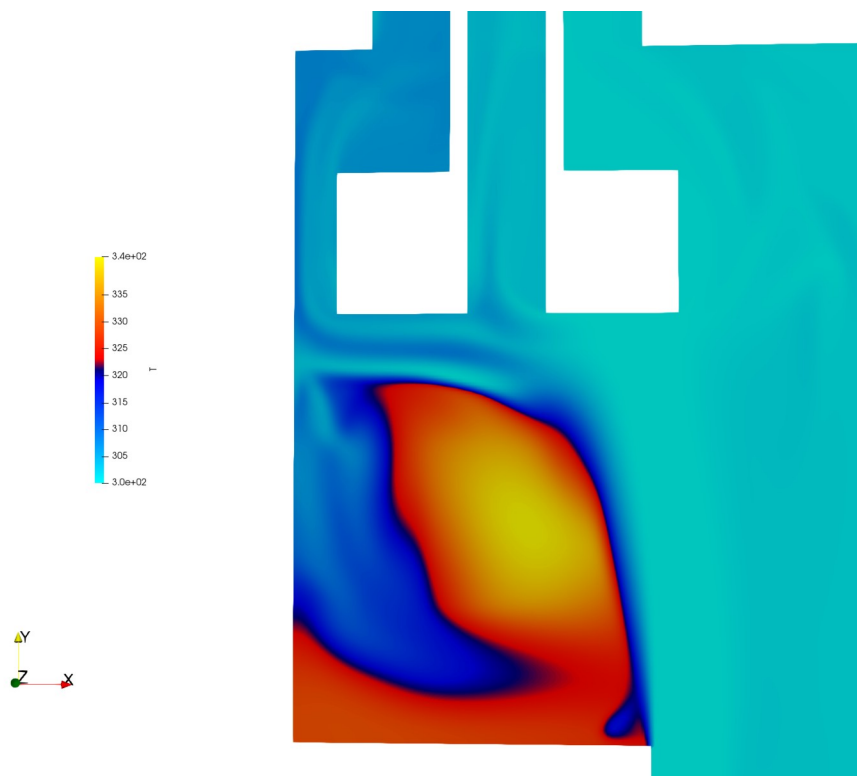


FIGURE 17. Mid-plane fluid temperature (Xin150).

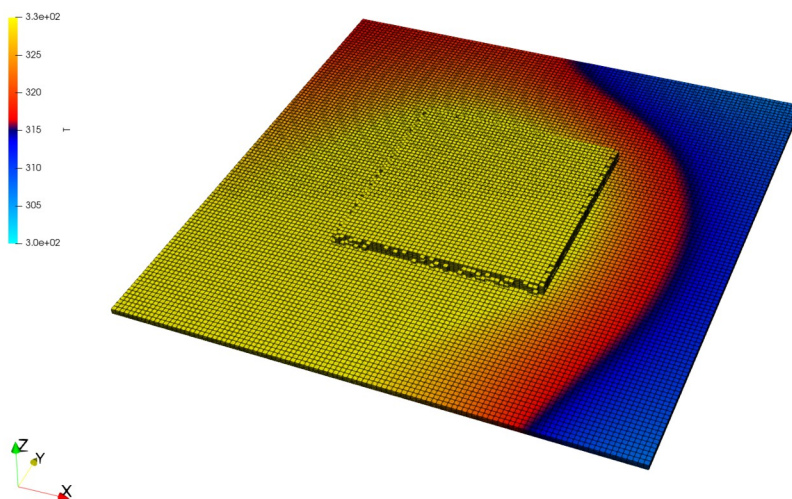


FIGURE 18. PCB / PBGA solid temperature (Xin150).

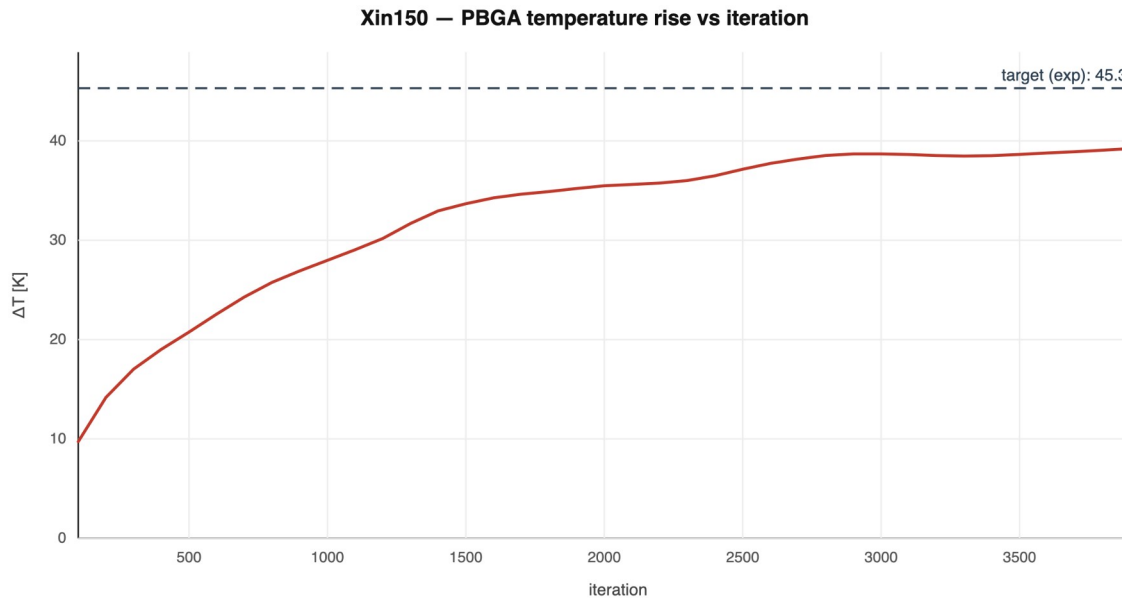


FIGURE 19. Package temperature-rise history (Xin150).

Package temperature rise is defined as $\Delta T = T_{\text{PBGA,avg}} - T_{\text{inlet}}$. Histories of ΔT confirm that the thermal field settles over several thousand SIMPLE iterations for each Xin case. A detailed quantitative temperature-error discussion against the published package rise is omitted here because the experimental thermal information available from the paper is not sufficient for a robust, spatially resolved validation comparable to the PIV velocity dataset.

5. CONCLUSIONS

This study established and validated an OpenFOAM v2512 CHT workflow for the Hatakeyama thin electronic casing against digitised PIV streamwise-velocity profiles at five stations for $X_{\text{in}} = 100, 130, \text{ and } 150 \text{ mm}$ [1]. With kOmegaSST, uniform inlet, Fig. 2–aligned outlets (22 mm openings, 5 mm fingers, 5 mm Z-slot), and anisotropic PCB conductivity, the CFD recovers the essential jet, wake, and chimney-driven velocity structure. Remaining differences are mainly under-spreading of the wake at $Y = 120\text{--}140 \text{ mm}$, typical of steady RANS mixing. Temperature fields and ΔT histories document a consistent conjugate thermal response; temperature error metrics are not emphasised pending richer experimental thermal data. The three-inlet suite provides a practical production baseline for the tensorElectronicCooling template.

ACKNOWLEDGEMENT

Thanks to PT Tensor for sponsoring this validation study and for advancing the CFD community through the tensorCFD initiative [2]. This work reflects their aim of keeping high-fidelity engineering templates accessible, practical, and production-ready.

In the spirit of open-source collaboration, the tensorECool case structure, mesh dictionaries, and post-processing tools are developed under PT Tensor’s OpenFOAM template programme you can access in this GitHub: <https://github.com/pt-tensor/tensorECool.git>.

REFERENCES

1. Hatakeyama, T., Ishizuka, M., Kibushi, R., & Nakagawa, S. (2012). A test bench for validation of CFD analysis for air flow in thin electronic casing model. *Journal of Physics: Conference Series*, 395, 012024. DOI: 10.1088/1742-6596/395/1/012024.
2. PT Tensor. OpenFOAM case templates / tensorCFD. <https://en.pt-tensor.com/openfoam-case-templates/>