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Aerothermal characterization of additively manufactured compact heat exchanger modules by Infrared Thermography

by A. Lecardonnel*, H. Cleris*, D. Laboureur*

* *von Karman Institute for fluid Dynamics, Sint-Genesius-Rhode, Belgium*

Abstract

This paper studies multiple elementary additive manufactured modules that differed by their cross-section, fin arrangement, fin shape, or material. The aerothermal performances were experimentally characterized with compressed air flowing into the structure at ambient temperature. The heat was provided by an electrical resistance placed on top of each module. Pressure taps, thermocouples and infrared camera were used to monitor the pressure losses and heat exchanged across the sample. The resulting Colburn and Fanning factors were compared for all the modules. For both materials, the same two geometries reached greater aerothermal performances than the reference off-set strip geometry.

1. Additively manufactured elementary modules

Several geometries, varying the cross section fin arrangement, fin shape, or material were tested. Its external dimensions are 52 mm×120 mm and with height ranging from 6.5 to 17 mm, and the fins occupy an effective length equal to 100 mm. The external wall thickness is 1 mm. An example of elementary channel is shown in figure 1. The materials chosen were AS7G06 (aerospace aluminium alloy with low weight, high resistance to corrosion and excellent heat and electricity conduction) and Inconel 718 (IN718) (aerospace nickel-based super-alloy with good resistance to oxidation, corrosion and high strength in temperature ranges from cryogenic up to around 1000 K). A Laser Powder-Bed Fusion machine AddUp FormUp™ 350 was used to print the samples. The build volume of the printer is 350 mm x 350 mm x 350 mm equipped by a roller layering system. Fine powders with grain size in the range of 5 – 25 μm were selected for the AS7G06 and IN718 materials. A specific set of process–parameters was developed in order to print a very fine walls (0.6 mm) and improve the surface roughness. The parts were used net-shape, without surface finishing. To characterize the modules roughness, the R_a (arithmetic mean deviation) was measured with surface roughness meter MITUTOYO Surftest SJ 201P. The measured R_a varied from 6 to 27 μm, depending on the sample.

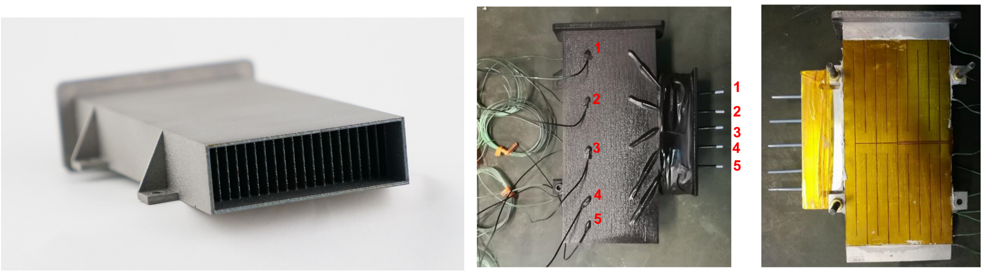

Fig. 1. *Left: Off-set strip fin elementary module, Right: Module instrumentation*

2. Aerothermal characterization of the elementary modules

The elementary modules were connected to the compressed air system with a metallic rectangular pipe and a bronze porous plate to ensure a fully developed flow at the inlet of the module. A 0.2 mm copper heating plate was glued on the top side of the sample, as shown in figure 1 to provide 130 W by Joule effect to the air flowing inside the sample. The plate was fixed on the module using a very high conductivity paste OMEGA TM 201, to reduce a possible effect of the contact resistance. Three rotameters in parallel were allowing to regulate the mass-flow within a range from 0 to 20 g/s. The pressure drop along the sample was monitored using a row of five pressure taps with a 0.4 mm diameter located on one side of the channel, as shown in figure 1 middle. The pressure difference between each pressure tap was measured using a pressure transducer. The inlet and outlet air temperatures were measured respectively by four and nine type-K thermocouples. Thermocouples were also positioned to measure the evolution of the temperature inside the channel, and on the top wall of the sample, as shown in figure 1. Insulation has been adopted to cover the element on the sides and the top wall to make negligible any effect of heat dispersion by both radiation and natural convection with the ambient. To study the temperature distribution over the module bottom surface (painted with a high emissivity paint), a Flir A655sc IR camera (calibrated with emissivity correction) is used as a non-intrusive measurement technique , which was shown to be efficient for complex fluid flow configurations [1].

3. Comparison of the modules aerothermal properties

Due to the variety of internal structure shapes, the hydraulic diameter was defined as the ratio between the total fluid volume and the total exchange area. Given the asymmetrically heated modules, the convective heat transfer coefficient was determined according to the definition of Karwa [2] that uses inlet and outlet temperatures as well the top wall temperature measured by thermocouples, as the bottom wall temperature from the IR, as shown in figure 2 left. The coefficients were then non-dimensionnalized in Nusselt number and Colburn factors. The comparison between all samples followed the analysis of Stimpson [3]. The friction factor augmentation of a sample compared to the reference offset strip fin geometry was plotted against the Nusselt number augmentation of a sample compared to the same reference geometry. The comparison of all Aluminum samples is provided in figure 2 right and show that some of the tested new geometries are outperforming the offset strip reference geometry.

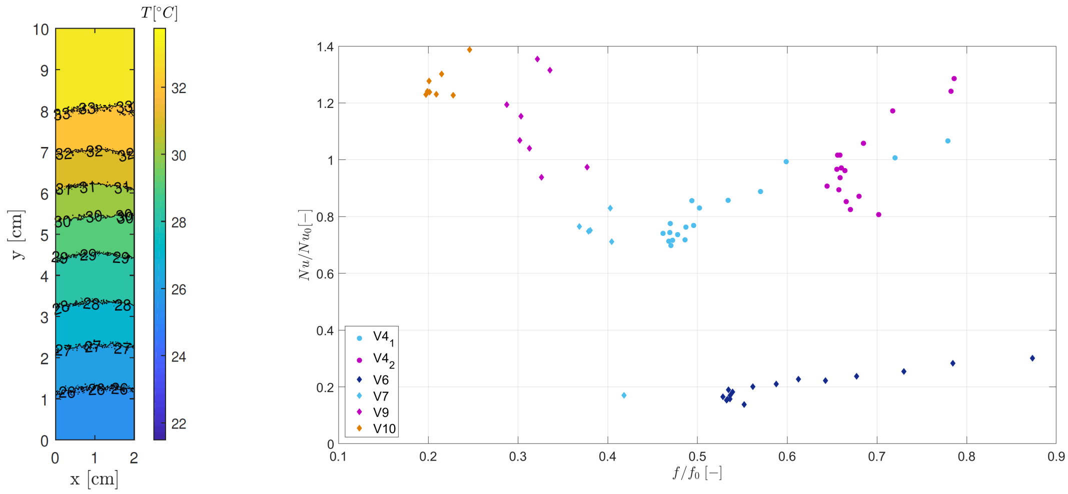

Fig. 2. *Left: Temperature contours from IR camera of off-set strip fin aluminium module with 10 g/s, Right: Heat transfer augmentation vs. friction factor augmentation of aluminium samples*

The final paper will also detail the aeraulic performances of the different samples, mostly through the evolution of the fanning factor with Reynolds, which showed an influence of the internal structure design on the transition Reynolds number. The fully turbulent Fanning was estimated and used to fit a equivalent roughness from the Colebrook method. This equivalent roughness increases linearly with the measured roughness, similarly to other samples from additive manufacturing measured in literature [3].

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References

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