This Week's Citation Classic

Eckert E R G & Carlson W O. Natural convection in an air layer enclosed between two vertical plates with different temperatures.
Int. J. Heat Mass Transfer 2:106-20, 1961.
[Heat Transfer Laboratory, University of Minnesota, Minneapolis, MN]

Natural convection heat transfer was studied in an air space enclosed between two isothermal vertical plates and two adiabatic horizontal plates. Buoyancy caused by a temperature difference between the vertical plates generates natural convection currents in the air filling the enclosure. Interferometry is used to obtain the temperature field and local heat transfer. [The *SCI*® indicates that this paper has been cited in over 110 publications since 1961, making it the 2nd most-cited paper ever published in this journal.]

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"When I came to the US in 1945, I designed and built, together with R.M. Drake, Jr., and E. Soehngen, a Zehnder-Mach interferometer with a size (200 mm mirrors) which made it useful for the study of convective heat transfer situations. The instrument served as a model for a number of interferometers built at various universities in the US and I also had another one constructed when I moved in 1952 to the University of Minnesota and started the Heat Transfer Laboratory.

"The paper cited above was one of the first detailed studies of a natural convection situation using such an instrument. It considered an air space enclosed between two vertical plates of different temperatures and two adiabatic horizontal plates. A crisis occurred during the experiments when one of the glass windows installed in the remaining two vertical walls of the enclosure broke. These windows (150 mm in diameter and 25 mm thick) had to transmit one of the light beams of the interferometer and had to be of high optical quality. Their replacement by an optical company would have caused considerable delay. Fortunately, it was found that thin glass plates (approximately 2 mm thick) could serve the purpose and that such plates of sufficient optical quality could be selected from a stock of normal optical glass plates. With this discovery, the experiments could proceed. It turned out that thin plates even have the advantage of creating less distortion of the light path by thermal stresses. The local optical refraction coefficient of the air could be calculated from the interferograms and the temperature field could be deduced from those. Local heat transfer coefficients were calculated from the temperature gradients at the surfaces of the enclosure.

"It was found that heat transfer occurred by conduction only in the major portion of the air space at low Rayleigh numbers. Convection currents deformed the temperature field at increasing Rayleigh numbers finally creating boundary layers along the vertical walls within which the mean temperature drop was concentrated. Observation of the interference fringes demonstrated that the temperature field was completely stationary at low Rayleigh numbers but that fluctuations occurred at first in the core of the air space and later also penetrating into the boundary layers at large Rayleigh numbers. This made it possible to calculate stability limits for steady flow in the enclosure.

"I was puzzled when I learned that this particular paper has been referenced with special frequency. It may have served as a guide for other convection studies using the interferometer. Heat transfer in a rectangular enclosure is also a practical problem with a number of engineering applications. Accordingly, experiments had determined the overall heat transfer before the publication of this paper. However, little understanding of the physical processes occurring could be derived from these investigations. G.K. Batchelor[1] had, therefore, to base an analysis of the problem published in 1954 on an assumed model of the flow field which was not verified by our experiments. The development of electronic computers in more recent years made it possible to calculate the temperature and velocity field in natural convection by finite difference procedures and a rectangular enclosure is convenient for such calculation because the domain is finite. It offers itself, therefore, as a test case for comparison with experimental findings. Recent work in the field is reported in *Advances in Heat Transfer*."[2]

1. **Batchelor G K.** Heat transfer by free convection across a closed cavity between vertical boundaries at different temperatures. *Quart. Appl. Math.* **12**:209-33, 1954.
2. **Ostrach S.** Natural convection in enclosures. (Hartnett J P & Irvine T F, eds.) *Advances in heat transfer.* New York: Academic Press, 1972. Vol. 8. p. 161-227.