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Geometric optimization of shapes on the basis of Bejan's Constructal theory☆

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Abstract

This paper documents the optimization of architecture in accordance with Bejan's Constructal theory. For illustration, we consider the optimization of a cavity that intrudes into a solid conducting wall, having internal heat generation and adiabatic conditions on the outer surfaces. The cavity is rectangular, with fixed volume and variable aspect ratio, and the solid is trapezoidal. The objective is to minimize the global thermal resistance between the volume of the entire system (cavity and solid) and the surroundings. The performance improves as the cavity becomes slender. The geometry is optimal when the cavity penetrates the conducting wall completely.

Keywords: Constructal theory; Hierarchical structures; Geometric optimization; Heat conduction; Cavity

1. Introduction

Constructal theory bases on a deterministic principle the occurrence of geometric form in flow systems [1,2]: nature and engineering are united in the search for optimized flow architecture. The same principle that in engineering is used for optimization subject to constraints can be used to predict the natural flow architectures that surround us.

Bejan's Constructal theory proved to be fully versatile and interdisciplinary. In Ref. [3], for example, it has been extended to economics: the principle of cost minimization in the transport of goods between a

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point and an area has been investigated in order to anticipate the dendritic pattern of transport routes that cover the area, and the shapes and numbers of the interstitial areas of the dendrite. Ref. [4] describes the path from the older method of entropy generation minimization to constructal design: the link between energy destruction and entropy generation, as the basis of the improvement of thermodynamic performance and the generation of flow configuration. Additional interdisciplinary applications are treated in Ref. [5].

In this paper, we return to the original engineering focus of Constructal theory, which is the optimization of architecture. We consider the constructal design of a rectangular cavity intruding into a conducting trapezoidal solid shown in Fig. 1. The external solid has uniform internal heat generation and adiabatic boundary conditions on the outer surfaces, while the cavity walls are isothermal. This problem can be associated to a large class of examples where augmentation and compactness (high density of heat transfer) are required, such as in the cooling packages of small-scale electronics [5–7].

We consider the optimization of the external shape of the cavity in the most fundamental sense, without application to a particular device or field, and rely on the constructal method: the external shape of the cavity is free to change subject to volume constraints, and in the pursuit of maximal global performance. The indicator of global performance is the overall thermal resistance between the volume of the entire system (cavity and solid) and the surroundings. For simplicity and clarity, we consider two-dimensional geometries where the overall volume is a trapezoidal body and the cavity volume has a rectangular shape. The trapezoidal body and the rectangular cavity have variable geometric aspect ratios.

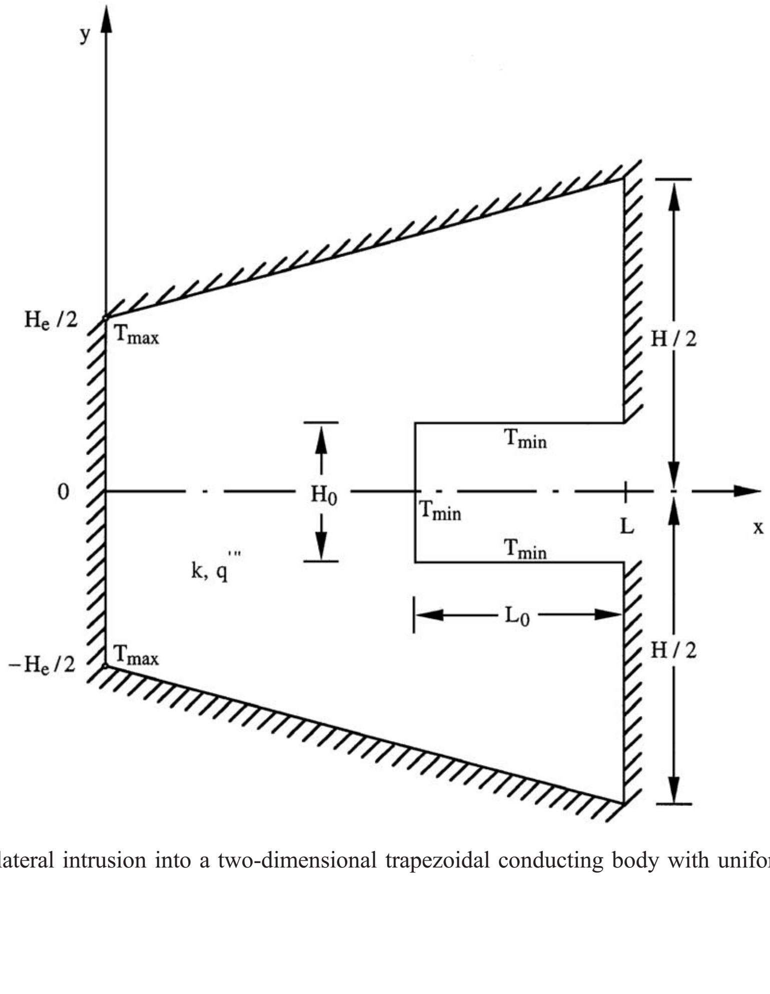

Fig. 1. Isothermal lateral intrusion into a two-dimensional trapezoidal conducting body with uniform heat generation.