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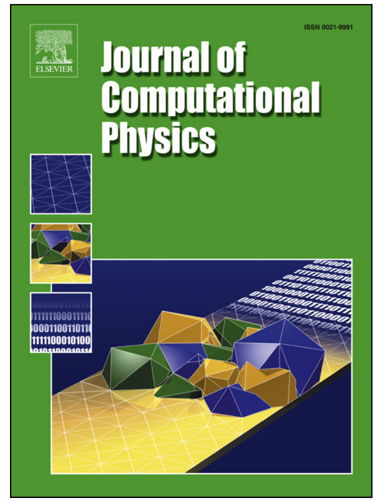


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PII: S0021-9991(17)30032-3
DOI: http://dx.doi.org/10.1016/j.jcp.2017.01.022
Reference: YJCPH 7084

To appear in: *Journal of Computational Physics*

Received date: 20 July 2016
Revised date: 7 January 2017
Accepted date: 13 January 2017

Please cite this article in press as: X. Pan et al., Fully decoupled monolithic projection method for natural convection problems, *J. Comput. Phys.* (2017), http://dx.doi.org/10.1016/j.jcp.2017.01.022

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# Fully decoupled monolithic projection method for natural convection problems

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**Abstract**

To solve time-dependent natural convection problems, we propose a fully decoupled monolithic projection method. The proposed method applies the Crank–Nicolson scheme in time and the second-order central finite difference in space. To obtain a non-iterative monolithic method from the fully discretized nonlinear system, we first adopt linearizations of the nonlinear convection terms and the general buoyancy term with incurring second-order errors in time. Approximate block lower-upper decompositions, along with an approximate factorization technique, are additionally employed to a global linearly coupled system, which leads to several decoupled subsystems, i.e., a fully decoupled monolithic procedure. We establish global error estimates to verify the second-order temporal accuracy of the proposed method for velocity, pressure, and temperature in terms of a discrete $l^2$-norm. Moreover, according to the energy evolution, the proposed method is proved to be stable if the time step is less than or equal to a constant. In addition, we provide numerical simulations of two-dimensional Rayleigh–Bénard convection and periodic forced flow. The results demonstrate that the proposed method significantly mitigates the time step limitation, reduces the computational cost because only one Poisson equation is required to be solved, and preserves the second-order temporal accuracy for velocity, pressure, and temperature. Finally, the proposed method reasonably predicts a three-dimensional Rayleigh–Bénard convection for different Rayleigh numbers.

*Keywords:* Projection method; Monolithic approach; Second-order temporal accuracy; Numerical stability; Natural convection; Rayleigh–Bénard convection

## 1. Introduction

Natural convection occurs in many engineering applications and in natural science, such as the collection of solar energy, processor cooling device, energy-efficient design of buildings and rooms, and mantle convection. In these applications, natural convection performs a pivotal role in the transport of energy and detailed information on fluid motion, and the temperature and fluid distributions are necessary for the fundamental understanding and design of safe

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