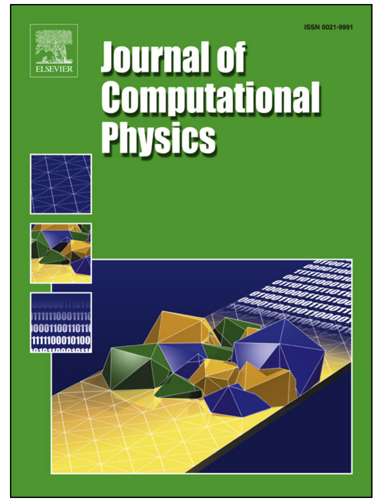
Accepted Manuscript



A positivity-preserving, implicit defect-correction multigrid method for turbulent combustion

M. Wasserman, Y. Mor-Yossef, J.B. Greenberg

PII: S0021-9991(16)30037-7
DOI: http://dx.doi.org/10.1016/j.jcp.2016.04.005
Reference: YJCPH 6532

To appear in: *Journal of Computational Physics*

Received date: 4 May 2015
Revised date: 22 December 2015
Accepted date: 2 April 2016

Please cite this article in press as: M. Wasserman et al., A positivity-preserving, implicit defect-correction multigrid method for turbulent combustion, *J. Comput. Phys.* (2016), http://dx.doi.org/10.1016/j.jcp.2016.04.005

A Positivity-Preserving, Implicit Defect-Correction Multigrid Method for Turbulent Combustion

M. Wasserman[a,b,1,*], Y. Mor-Yossef[a,b,2], J. B. Greenberg[a,3]

[a]*Faculty of Aerospace Engineering, Technion, Israel Institute of Technology, Haifa 32000, Israel*
[b]*Israeli CFD Center, Caesarea Industrial Park 38900, Israel*

Abstract

A novel, robust multigrid method for the simulation of turbulent and chemically reacting flows is developed. A survey of previous attempts at implementing multigrid for the problems at hand indicated extensive use of artificial stabilization to overcome numerical instability arising from non-linearity of turbulence and chemistry model source-terms, small-scale physics of combustion, and loss of positivity. These issues are addressed in the current work. The highly stiff Reynolds-averaged Navier-Stokes (RANS) equations, coupled with turbulence and finite-rate chemical kinetics models, are integrated in time using the unconditionally positive-convergent (UPC) implicit method. The scheme is successfully extended in this work for use with chemical kinetics models, in a fully-coupled multigrid (FC-MG) framework.

To tackle the degraded performance of multigrid methods for chemically reacting flows, two major modifications are introduced with respect to the basic, Full Approximation Storage (FAS) approach. First, a novel prolongation operator that is based on logarithmic variables is proposed to prevent loss of positivity due to coarse-grid corrections. Together with the extended UPC implicit scheme, the positivity-preserving prolongation operator guarantees unconditional positivity of turbulence quantities and species mass fractions throughout the multigrid cycle. Second, to improve the coarse-grid-correction obtained in localized regions of high chemical activity, a modified defect correction procedure is devised, and successfully applied for the first time to simulate turbulent, combusting flows.

The proposed modifications to the standard multigrid algorithm create a well-rounded and robust numerical method that provides accelerated convergence, while unconditionally preserving the positivity of model equation variables. Numerical simulations of various flows involving premixed combustion demonstrate that the proposed MG method increases the efficiency by a factor of up to eight (8) times with respect to an equivalent single-grid method, and by two (2) times with respect to an artificially-stabilized MG method.

Keywords: multigrid, positivity preservation, turbulence models, combustion,

*Corresponding author

Email addresses: markw@iscfdc.co.il (M. Wasserman), yairm@iscfdc.co.il (Y. Mor-Yossef), aer9801@technion.ac.il (J. B. Greenberg)

[1]Scientist

[2]Chief Scientist

[3]Professor