

# MATHEMATICAL REFORMULATION OF THE KOLMOGOROV-RICHARDSON ENERGY CASCADE IN TERMS OF VORTEX STRETCHING

TSUYOSHI YONEDA, SUSUMU GOTO, AND TOMONORI TSURUHASHI

**ABSTRACT.** In this paper, with the aid of direct numerical simulations (DNS) of forced turbulence in a periodic domain, we mathematically reformulate the Kolmogorov-Richardson energy cascade in terms of vortex stretching. By using the description, we prove that if the Navier-Stokes flow satisfies a new blowup criterion in terms of the enstrophy production rate, then the flow does not blow up. Our DNS results seem to support this blowup criterion. Next, we mathematically construct the hierarchy of tubular vortices, which is statistically self-similar in the inertial range. Under the assumptions of the scale-locality of the vortex stretching/compressing (i.e. energy cascade) process and the statistical independence between vortices that are not directly stretched or compressed, we can derive the  $-5/3$  power law of the energy spectrum of statistically stationary turbulence without directly using the Kolmogorov hypotheses.

## 1. INTRODUCTION

Since the seminal study by Orszag and Patterson (1972) [21], the numerical integration (i.e. the direct numerical simulations, DNS) of the Navier-Stokes equation without any turbulence model has been playing important roles in turbulence researches; see Ref. [12] for a review of DNS of turbulence. One of the most important features unveiled by DNS of turbulence is that turbulence is not random but composed of coherent motions. In particular, recent DNS [7, 9, 18, 19] of turbulence at sufficiently high Reynolds numbers have revealed that there exists a hierarchy of coherent vortices in developed turbulence.

In the present study, we investigate the energy cascade picture [23, 5] in turbulence of an incompressible fluid with uniform density and kinematic viscosity  $\nu$  under periodic boundary conditions in three orthogonal directions; and, on the basis of the picture, we develop arguments on the global-in-time smooth solution of the Navier-Stokes equation. Since we need external force to drive flow in a periodic cube, we impose body force  $f$  which injects the kinetic energy at a large scale  $\mathcal{L}$ . Here, we define the Reynolds number by

$$(1.1) \quad Re = U\mathcal{L}/\nu$$

with  $U$  being the characteristic velocity directly driven by  $f$ . When  $Re$  is sufficiently high (more concretely, higher than  $O(10^4)$  [4]), turbulence is composed of vortices with various length scales. We reemphasize that these vortices are coherent

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**David Nelson**



## **Mathematical Reformulation Of The Genera:**

*Foundations of Computational Intelligence Volume 3* Ajith Abraham, Aboul-Ella Hassanien, Patrick Siarry, Andries Engelbrecht, 2009-04-27 Global optimization is a branch of applied mathematics and numerical analysis that deals with the task of finding the absolutely best set of admissible conditions to satisfy certain criteria objective functions formulated in mathematical terms Global optimization includes nonlinear stochastic and combinatorial programming multiobjective programming control games geometry approximation algorithms for parallel architectures and so on Due to its wide usage and applications it has gained the attention of researchers and practitioners from a plethora of scientific domains Typical practical examples of global optimization applications include Traveling salesman problem and electrical circuit design minimize the path length safety engineering building and mechanical structures mathematical problems Kepler conjecture Protein structure prediction minimize the energy function etc Global Optimization algorithms may be categorized into several types Deterministic example branch and bound methods Stochastic optimization example simulated annealing Heuristics and meta heuristics example evolutionary algorithms etc Recently there has been a growing interest in combining global and local search strategies to solve more complicated optimization problems This edited volume comprises 17 chapters including several overview Chapters which provides an up to date and state of the art research covering the theory and algorithms of global optimization Besides research articles and expository papers on theory and algorithms of global optimization papers on numerical experiments and on real world applications were also encouraged The book is divided into 2 main parts The Origins of International Economics: General equilibrium in international trade Robert William Dimand, 2004 A collection of materials reprinted from various sources The Collected Scientific Papers of Paul A. Samuelson Paul Anthony Samuelson, 1972 The col scient pap P A Samuelson Ed R C Merton v 3 **The Expanding Worlds of General Relativity** Hubert Goenner, Jürgen Renn, Jim Ritter, Tilman Sauer, 1998-12-01 The past decade has seen a considerable surge of interest in historical and philosophical studies of gravitation and relativity due not only to the tremendous amount of world wide research in general relativity and its theoretical and observational consequences but also to an increasing awareness that a collaboration between working scientists historians and philosophers of science is in this field particularly promising for all participants The expanding activity in this field is well documented by recent volumes in this Einstein Studies series on the History of General Relativity as well as by a series of international conferences on this topic at Osgood Hill 1986 Luminy 1988 and Pittsburgh 1991 The fourth of these conferences hosted by the Max Planck Institute for the History of Science was held in Berlin from 31 July to 3 August 1995 with a record attendance of some 80 historians and philosophers of science physicists mathematicians and astronomers Based on presentations at the Berlin conference this volume provides an overview of the present state of research in this field documenting not only the increasing scope of recent investigations in the history of relativity and gravitation but also the emergence of several key issues that will probably remain at the focus of

debate in the near future RELATIVITY IN THE MAKING The papers of this section deal with the origins and genesis of relativity theory

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themes that are of general concern The introduction by Professor W A Robson which was not part of the original lecture series is in itself a critical assessment of the field that will be read with close attention

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category theory Alain Badiou's set theoretical model of truth procedures and his relational sheaf based theory of phenomenology are then integrated within the Peircean logical context Finally the book opens the path towards a more naturalist interpretation of the abductive models developed in Peirce and Badiou through an analysis of several recent attempts to reformulate quantum mechanics with categorical methods Overall the book offers a comprehensive and rigorous overview of past approaches to iconic semiotics and abduction and it encompasses new extensions of these methods towards an innovative naturalist interpretation of abductive reasoning

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theory The analysis of these alternative approaches as well as of earlier alternative approaches to gravitation within classical physics turns out to be crucial for identifying the necessities and contingencies in the actual historical development

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