Department of Mathematics, Rhodes University

Exploring Fluid Dynamics: The Role of Mathematicians

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What is Fluid Dynamics?

Fluid dynamics is a sub-discipline of **fluid mechanics** that deals with the science of fluid flow, i.e the science of fluids (liquid and gases) in motion.

Natural flows and weather
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Boats
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Power plants
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Human body
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Cars
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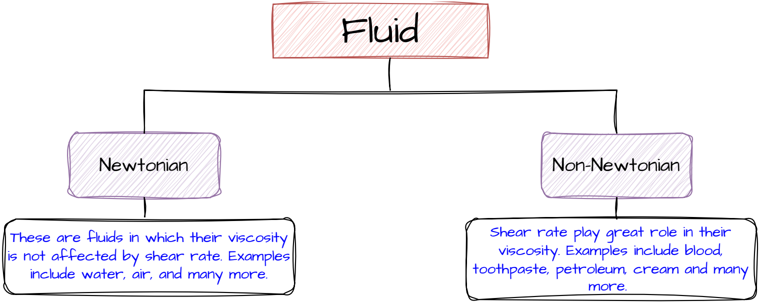
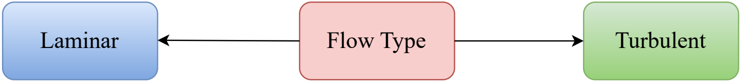
Introduction

What is a fluid?

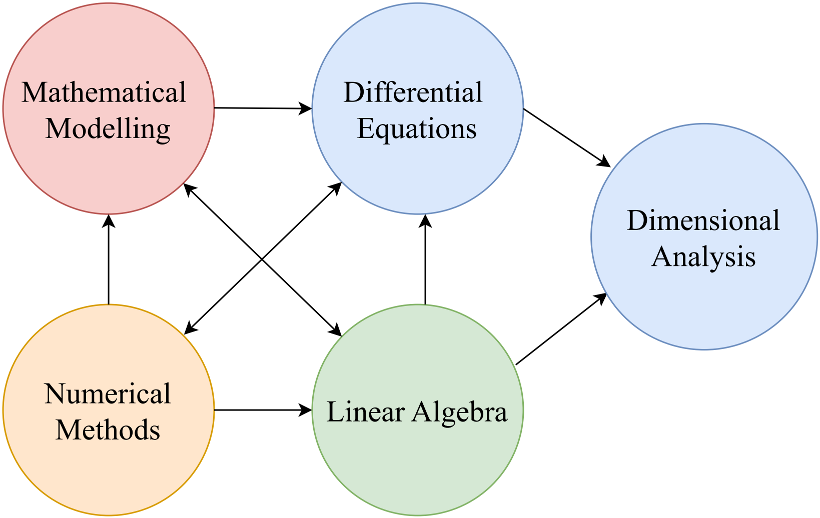
A fluid is any substance that flows or deforms continuously when subjected to a **shear stress**. Examples of fluids include water, blood, oil, honey, sauce, paint, and many others.





Introduction

The Mathematics of Fluid Dynamics



The Mathematics of Fluid Dynamics

Continuity Equation

The continuity equation describes the transport of some quantity. It is also call the conservation of mass.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = \mathbf{0}. \tag{1}$$

ρ = density, t = time, $\mathbf{u}$ = velocity vector.

Navier-Stokes Equation

The flow of fluids are generally modelled using the famous Navier-Stokes equation:

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u}\right) = -\nabla \mathbf{p} + \mu \nabla^2 \mathbf{u} + \rho \mathbf{g} + \text{other forces}. \tag{2}$$

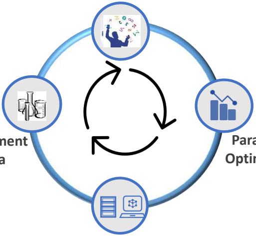
μ = viscosity, $\mathbf{g}$ = gravity, $\mathbf{p}$ = pressure.

Modeling Industrial Problems

Problem Definition

Mathematical Description

Conceptualization phase



Virtual Experimentation

Virtual prototype

Digital Twin

7

A BRIEF LOOK INTO MY WORLD OF FLUID DYNAMICS

NUMERICAL HEAT TRANSFER, PART B: FUNDAMENTALS
https://doi.org/10.1080/10407790.2023.2290189

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Magnetic feature and regression analysis of Reiner-Philippoff boundary layer flow

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ABSTRACT

The design and optimization of magnetic fluid-based processes, such as magnetohydrodynamic power generation and magnetic drug targeting, have become significant in recent times. To understand the magnetic and radiation features, as well as the sensitivity of engineering physical quantities to each dimensionless parameter in fluid flow, the Reiner-Philippoff (RP) fluid is best suited in this instance, as it exhibits shear-thickening, shear-thinning, and Newtonian behavior. The non-similar transformation is used to transform the partial differential equations that describe the flow into two-variable differential equations. The transformed dynamical equations are solved numerically using a spectral-based numerical technique; namely, the bivariate simple iteration method (BSIM). The effects of magnetic field strength and radiation parameter on the stretching and shrinking sheets are examined. The investigation reveals that both the magnetic

ARTICLE HISTORY
Received 28 July 2023
Revised 31 October 2023
Accepted 17 November 2023

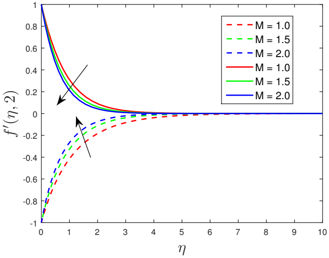
KEYWORDS
Boundary layer flow; magnetic; radiation; Reiner–Philippoff fluid

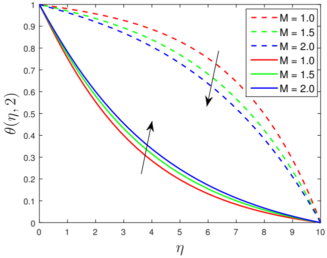
$$\frac{1}{\rho}\frac{\partial \tau}{\partial y} - \frac{\sigma B^2 u}{\rho} = u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}, \quad (3)$$

$$\frac{\sigma B^2 u^2}{\rho c_p} + \frac{\kappa}{\rho c_p}\frac{\partial}{\partial y}\left(\frac{\partial T}{\partial y}\right) - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} = u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}, \quad (4)$$

The conditions of flow at the wall and far-field are

$$\left.\begin{array}{l} v(x,y)=0, \quad u(x,y)=\xi u_w, \quad T(x,y)=T_w, \quad \text{at} \quad y=0, \\ T(x,y)\to T_\infty, \quad u(x,y)\to 0, \quad \text{as} \quad y\to\infty. \end{array}\right\} \quad (5)$$





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Research Work

Received: 10 March 2023 | Revised: 27 June 2023 | Accepted: 22 August 2023

DOI: 10.1002/zamm.202300217

ZAMM

ORIGINAL PAPER

Surface dynamics on Jeffrey nanofluid flow with Coriolis effect and variable Darcy regime

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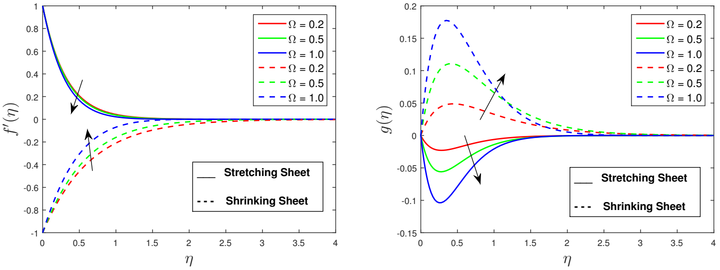
Stretching and shrinking application ranges from aerodynamic extrusion of plastic sheets, biological implants, condensation of metallic plates to the design of musical instruments. To emphasize the need for proper fluid flow in the mammalian system, the phenomenon of stretching or shrinking suppresses muscle strains and cramps, and also prevents stroke and heart disease. For further insight into the dynamics of blood with Prandtl number of 21.0 in a rotating system, the present study theoretically investigates the flow of a Jeffrey fluid induced with gold nanoparticles over a rotating sheet. The homogenization of the gold nanoparticle with the base fluid is due to the Tiwari-Das approach. To investigate the flow profiles and dynamics of the sheet, the spectral local linearization method (SLLM) is used to obtain approximate solutions to the resulting system of nonlinear differential equations. The results obtained using the SLLM

$$\nabla \cdot \vec{q} = 0. \tag{6}$$

$$\rho\left(\frac{D\vec{q}}{Dt} + 2\vec{\Omega} \times \vec{q} + \vec{\Omega} \times (\vec{\Omega} \times \vec{r})\right) = -\nabla p + \nabla \cdot \tau + \vec{J} \times \vec{B} - \mu \frac{\vec{q}}{K}. \tag{7}$$

$$\rho c_p\left(\frac{DT}{Dt}\right) = \kappa \nabla^2 T - \nabla q_r' - Q_* \triangle T. \tag{8}$$



Open Problem in Fluid Dynamics

The Millennium Prize Problems

In 2000, the Clay Mathematics Institute (CMI) identified seven mathematical problems that remained unsolved. Anyone who provides a rigorous proof for any of these problems will be awarded a prize of one million dollars.

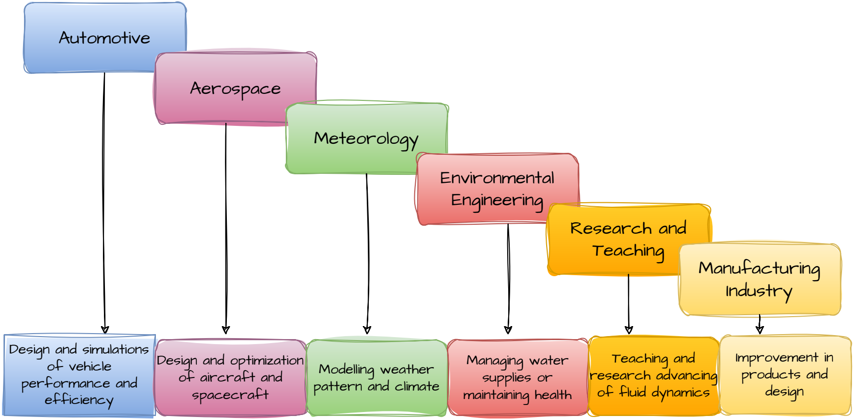
The Problems

Among the seven Millennium Prize Problems, six remain unresolved to date. Notably, a complete and rigorous proof of the Navier-Stokes equation is one of the seven Millennium Prize Problems.

Navier-Stokes Equation

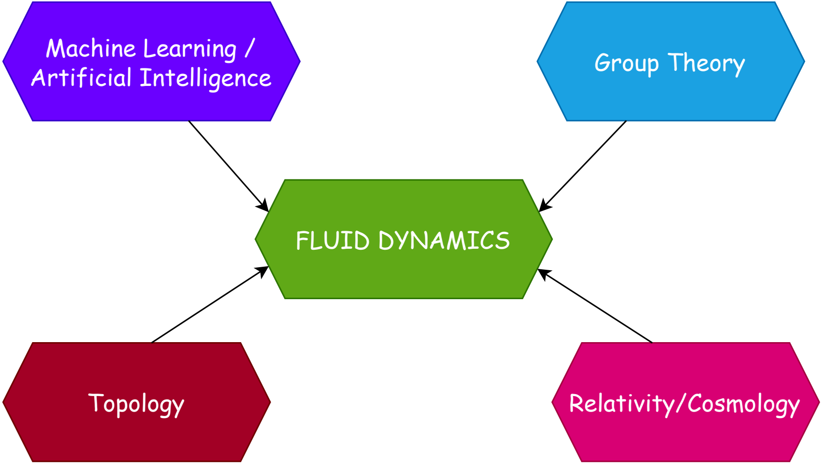
There is no proof for the most basic questions one can ask: do solutions exist, and are they unique?

Opportunities in Fluid Dynamics



In all these opportunities, the ability to conceptualize a problem, model it, and provide a solution is crucial. These are key attributes of a mathematician.

Research Collaboration



$$(\text{THANK YOU})^n$$

$$n \in N, n > 1$$

Everything flows, even the mountains will flow...if you wait long enough!

-Markus Reiner