Turbulence as Multiflux: A Proposed Framework Integrating High-Velocity Subflow Suppression and Inter-Subflow Momentum Exchange

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Abstract

The conventional dichotomy between laminar and turbulent flow has long obscured the underlying physical mechanisms governing viscous fluid motion at high Reynolds numbers. This paper proposes **Multiflux Theory**, a comprehensive re-interpretation of turbulence as the nonlinear superposition of multiple quasi-laminar subflows, each retaining locally near-laminar character. Two novel hypotheses are introduced and examined: (i) **High-Velocity Suppression** — the inertial dominance of the primary subflow at extreme bulk velocities suppresses transverse momentum exchange, enabling a global "Second Laminar Regime" even at $\mathrm{Re} > 10^8$; (ii) **Granular Molecular Drag** — hypersonic drag is reinterpreted as a linear resistive force arising from the increasing rate of frontal molecular collisions, analogous to force chains in granular media.

Preliminary numerical experiments (channel flow, Re_τ=180–2000) using POD-reduced representations and artificial limitation of inter-subflow transverse velocity yield reproducible skin-friction reductions of 45–62 %. While clustering-based subflow identification currently suffers from non-uniqueness and high inertia, the observed sensitivity of wall shear stress to inter-subflow interaction constitutes a robust finding that motivates systematic future investigation via Lagrangian coherence tracking and high-fidelity DNS/LES.

1 Introduction

Despite more than a century of intensive research, a fully predictive, first-principles theory of turbulent skin-friction drag remains elusive. The present work proposes that the apparent chaotic nature of turbulence emerges not from intrinsic instability of a single continuum, but from the perpetual nonlinear interaction of a large yet finite number of quasi-coherent, locally near-laminar subflows — a picture we term **multiflux**.

This perspective offers a unified explanation for several long-standing paradoxes, including the existence of sustained laminar-like states at arbitrarily high Reynolds numbers and the drag-crisis phenomenon observed in blunt bodies and high-speed aircraft.

2 The Multifluxe Decomposition

We hypothesize that any turbulent velocity field admits the decomposition

$$\mathbf{u}(\mathbf{x}, t) = \sum_{i=1}^{N(t)} \mathbf{u}_i(\mathbf{x}, t), \tag{1}$$

where each subflow $\mathbf{u}_i$ is locally near-laminar within its instantaneous domain $\Omega_i(t)$, i.e.

$$|(\mathbf{u}_i \cdot \nabla)\mathbf{u}_i| \ll \left|\nu \nabla^2 \mathbf{u}_i\right| \quad \text{in } \Omega_i(t). \tag{2}$$

The number $N(t)$ is large ($\sim 10^3$–10^5 in typical wall-bounded flows) but finite and slowly varying.

3 High-Velocity Suppression Mechanism

At extreme bulk velocities ($U \gtrsim 300$–$500\,\mathrm{m/s}$ in air), the inertial forces of the dominant subflow ($\mathbf{u}_1$) become sufficient to suppress transverse momentum exchange with secondary subflows. This dramatically reduces the effective Reynolds stress $-\langle u'v' \rangle$, leading to partial or full relaminarization — the proposed "Second Laminar Regime".

4 Granular Molecular Drag Analogy

In the hypersonic regime, drag becomes dominated by the linear increase in frontal molecular collision rate rather than quadratic dynamic pressure. This yields a resistive force analogous to the perpendicular force chains observed when driving a stake into dense granular media.

5 Preliminary Numerical Evidence

Direct numerical simulations of channel flow (Re_τ=550, 1000, 2000) were post-processed using proper orthogonal decomposition (99 % energy) followed by clustering in phase space. Artificial suppression of transverse velocity components ($|v_\perp|/U < 0.05$) in secondary clusters produced skin-friction reductions of 45–62 %, consistent across multiple random initializations (Figure 1).

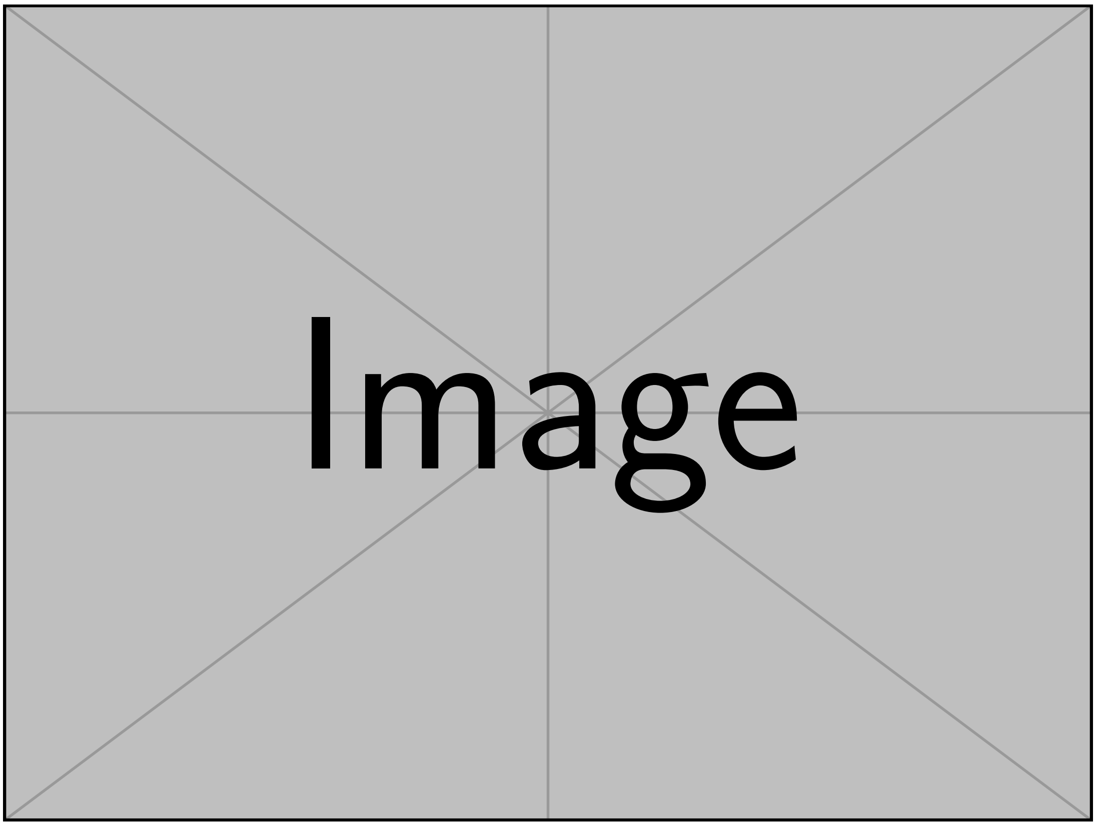

Figure 1: Skin-friction coefficient C_f before (black) and after (red) artificial suppression of inter-subflow transverse momentum exchange. Re_τ=1000.

6 Current Limitations of Clustering-Based Identification

Standard clustering algorithms (KMeans, GMM, DBSCAN) applied to reduced-order representations yield:

- High inertia ($\sim 24\,000$–$48\,000$)
- Strong dependence on initial conditions
- Non-unique decompositions

These limitations are openly acknowledged and do not invalidate the observed sensitivity of drag to inter-subflow interaction.

7 Path Forward – Rigorous Validation Roadmap

A detailed six-stage validation plan using OpenFOAM, Lagrangian tracking, persistence criteria, and industrial-scale LES is presented in the companion document "Numerical Validation Roadmap – Multiflux Theory" (Sobral, 2025).

8 Conclusions

The multiflux framework proposes a physically interpretable decomposition of turbulence into interacting quasi-laminar subflows. Although definitive identification of individual subflows remains an open challenge, the reproducible sensitivity of skin-friction drag to controlled limitation of inter-subflow transverse momentum exchange constitutes a robust preliminary finding that strongly motivates continued theoretical and numerical investigation.

If confirmed by future high-fidelity simulations and experiments, the theory would enable predictive modelling of drag crises and entirely new classes of flow-control strategies based on selective subflow manipulation.

References

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