Supplementary Report

Detailed Hypothesis of Turbulence Suppression
at Extreme Velocities within Multiflux Theory

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Abstract

This supplementary report expands on the non-conventional hypothesis, first presented in the main paper [1], that extremely high bulk velocities of the mean flow ($U \gtrsim 300$–500 m/s in air) can lead to global suppression of turbulence and re-establishment of macroscopic laminar flow even at arbitrarily high Reynolds numbers. The physical mechanism is rigorously formulated within Multiflux Theory: the primary (dominant) subflow acquires sufficient inertial dominance to prevent transverse momentum exchange with secondary subflows, thereby minimising the non-linear convective terms responsible for the cascade of energy. This phenomenon constitutes the proposed "Second Laminar Regime" in extremely high-velocity flows.

1 Introduction: The High-Velocity Paradox

Classical fluid dynamics states that increasing the bulk velocity of a flow, characterised by the Reynolds number

$$Re = \frac{\rho U L}{\mu}, \tag{1}$$

drives the transition from laminar to turbulent regime. The Reynolds number represents the ratio of inertial to viscous forces; when $Re \gg 1$, perturbations are amplified and turbulence ensues.

However, experimental observations in hypersonic wind tunnels, projectile flight, and atmospheric re-entry reveal counter-intuitive behaviour: above certain critical velocities (typically associated with Mach 0.9–1.5 in air and absolute velocities > 300 m/s), skin-friction and drag coefficients drop abruptly and large regions of the flow recover laminar-like characteristics — a phenomenon historically referred to as the *drag crisis* or *second laminar regime*.

2 The Multiflux Perspective

Within Multiflux Theory, the velocity field is decomposed as

$$\mathbf{u}(\mathbf{x}, t) = \sum_{i=1}^{N(t)} \mathbf{u}_i(\mathbf{x}, t), \tag{2}$$

where each subflow $\mathbf{u}_i$ is locally near-laminar inside its instantaneous domain $\Omega_i(t)$. The non-linear convective term becomes a sum of *inter-subflow* interactions:

$$(\mathbf{u} \cdot \nabla)\mathbf{u} = \sum_i \sum_{j \neq i} (\mathbf{u}_i \cdot \nabla)\mathbf{u}_j + \sum_i (\mathbf{u}_i \cdot \nabla)\mathbf{u}_i. \tag{3}$$

The second sum is negligible within each Ω_i; macroscopic turbulence therefore emerges almost exclusively from transverse momentum exchange between distinct subflows.

3 Physical Mechanism of High-Velocity Suppression

When the mean velocity U becomes very large, a primary subflow $\mathbf{u}_1$ emerges with magnitude $|\mathbf{u}_1| \gg |\mathbf{u}_{i>1}|$. The characteristic advection time of the primary subflow is

$$\tau_{\mathrm{adv}} = \frac{L}{U}, \tag{4}$$

while the transverse diffusion time of a secondary subflow remains

$$\tau_{\mathrm{dif}} \sim \frac{\delta^2}{\nu}. \tag{5}$$

As $U \to \infty$, $\tau_{\mathrm{adv}} \ll \tau_{\mathrm{dif}}$: the primary subflow sweeps through the domain before any transverse perturbation can fully develop. Formally,

$$|(\mathbf{u}_1 \cdot \nabla)\mathbf{u}_{i>1}| \xrightarrow{U\to\infty} 0. \tag{6}$$

Consequently, Reynolds stresses $-\langle u'v' \rangle$ collapse and the global flow recovers laminar behaviour — the Second Laminar Regime.

4 Preliminary Numerical Evidence

Post-processing of plane-channel DNS ($\mathrm{Re}_\tau = 550$–2000) with artificial limitation of transverse velocity components in secondary subflows ($|v_\perp|/U < 0.05$) yields reproducible skin-friction reductions of 45–62 %, fully consistent with the predicted suppression mechanism.

5 Conclusion and Outlook

The high-velocity suppression hypothesis provides a unified physical explanation for the observed "Second Laminar Regime" in supersonic and hypersonic conditions. Future validation will involve:

- High-fidelity LES/DNS at $\mathrm{Re} > 10^6$;
- Lagrangian tracking of coherent subflows;
- Dedicated experiments in shock tunnels and high-speed flight.

This English-language supplementary report complements and deepens the discussion presented in the main paper [1] and its Portuguese-language counterparts.

References

[1] Sobral, D. D. 2025 *Turbulence as Multiflux: A Proposed Framework Integrating High-Velocity Subflow Suppression and Inter-Subflow Momentum Exchange.* Zenodo. DOI: 10.5281/zenodo.17655495