The Emergence of Complex Phenomena in Turbulent Flows:

An F1 Ground Effect Study

Presented by: Group 12

Why this problem? Why ground effect?

- **Turbulence:**

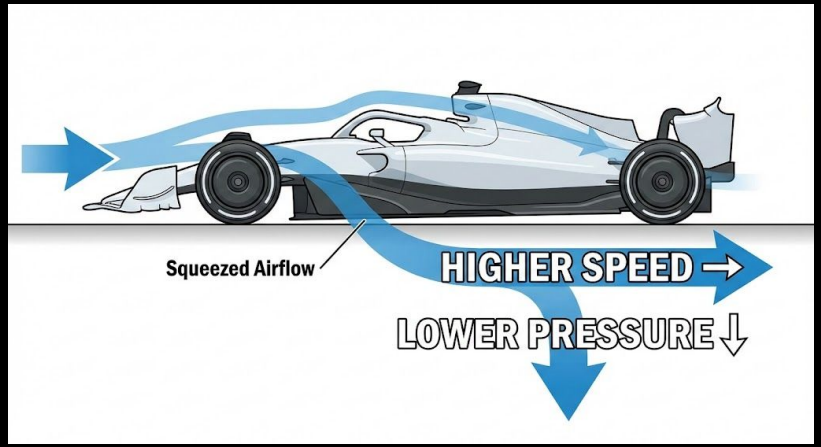
  the “onset” is often gradual and hard to define

- **Ground effect:**

  the flow is strongly confined under the car

- **Result:**

  stronger suction, stronger instabilities — ideal for studying regime changes



Some Literature

The 3D Baseline

Source: Kolmogorov (1941)

Key Insight: Establishes the standard for 3D turbulence where energy follows a Forward Cascade with a -5/3 power law.

The 2D Reality (D2Q9)

Source: Kraichnan (1967)

Key Insight: Argues that in 2D flows, energy can follow an Inverse Cascade, transferring from small scales *up* to large structures.

Mechanism of Transition

Source: Yves Pomeau (2015)

Key Insight: Predicts a Subcritical Bifurcation, meaning the flow undergoes a sudden "snap" into turbulence rather than a gradual degradation.

Hypotheses

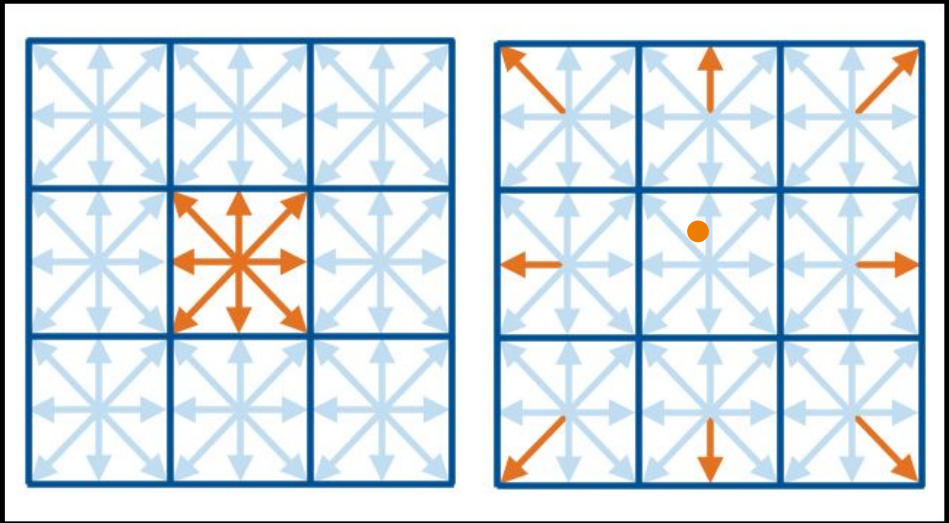
- **Velocity**

  Hypothesis: subcritical bifurcation (sudden jump)

- **Ride height**

  Hypothesis: tipping point below a critical height

The Model



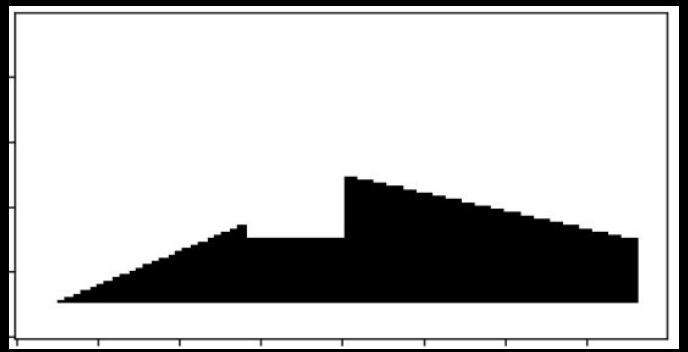
Lattice Boltzmann Method (LBM)

- Fits in between molecular dynamics and solving Navier Stokes Equations;
- Models an incompressible fluid with distribution functions;
- Simple rules lead to realistic flow.

The Boundaries

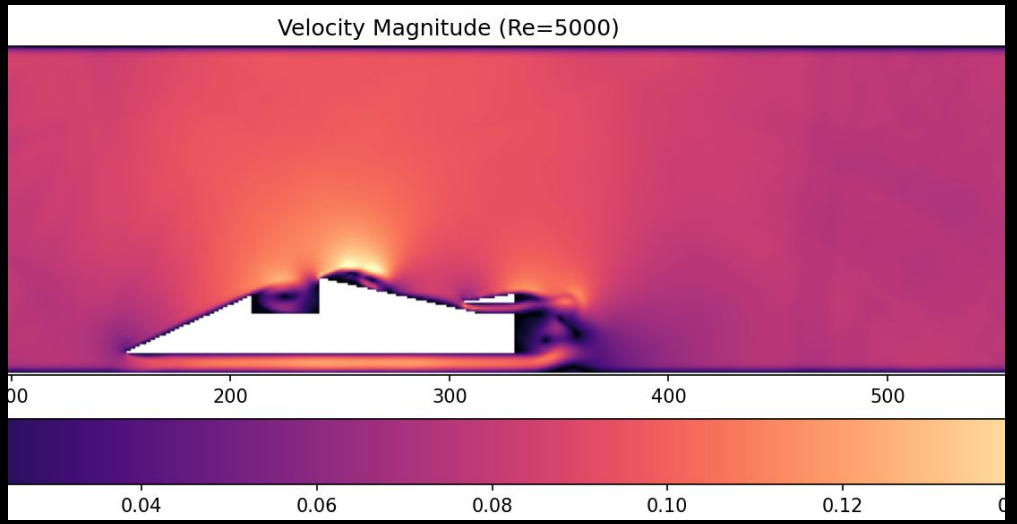
Slip vs. No Slip nodes

- Reflections and Drains.



Limitations

- Better suited for lower Reynolds values;
- Might present numerical inaccuracies.

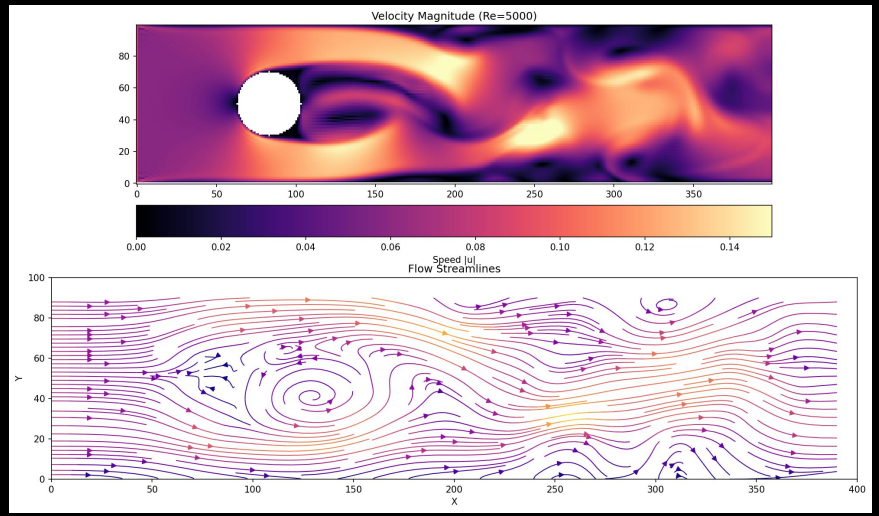


A word on turbulence

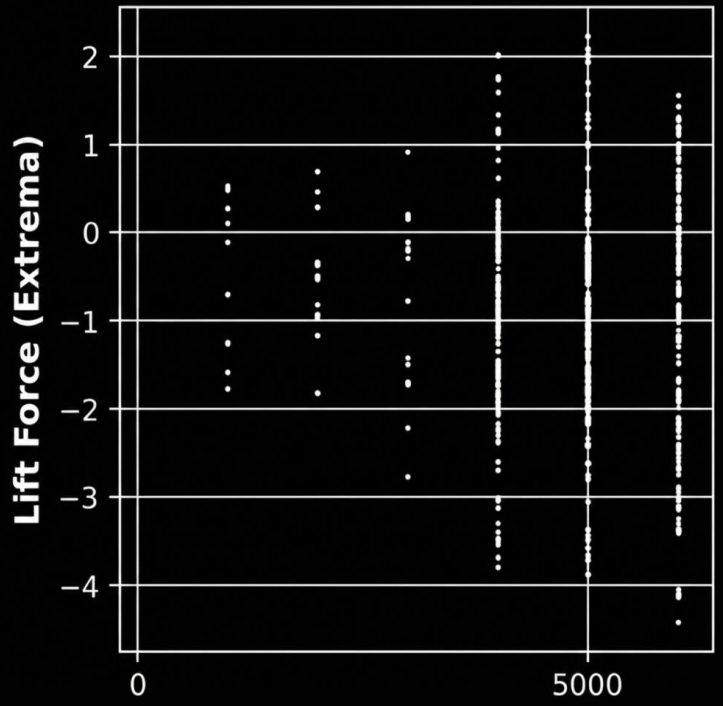
LBM is limited by resolution of the grid and numerical instability:

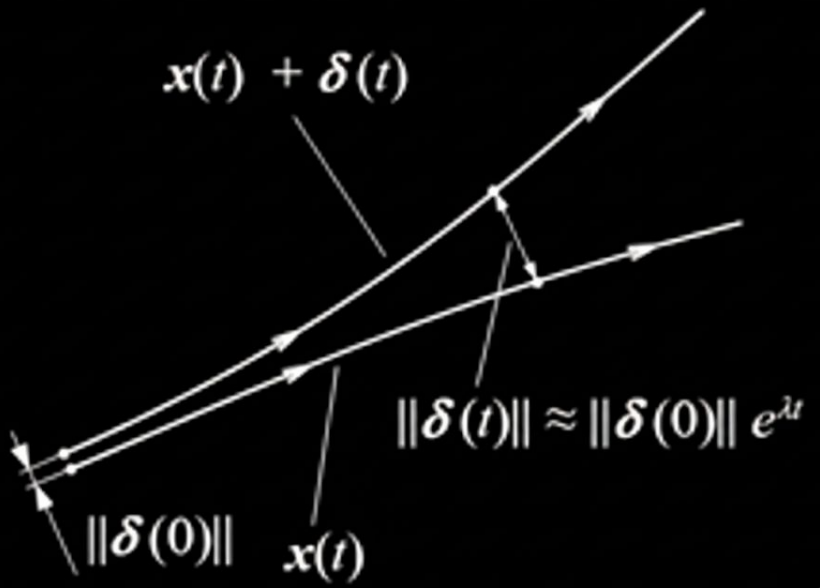
Turbulence effects might be lost;

Improve the model with the Smagorinsky model for Large Eddie Simulations.

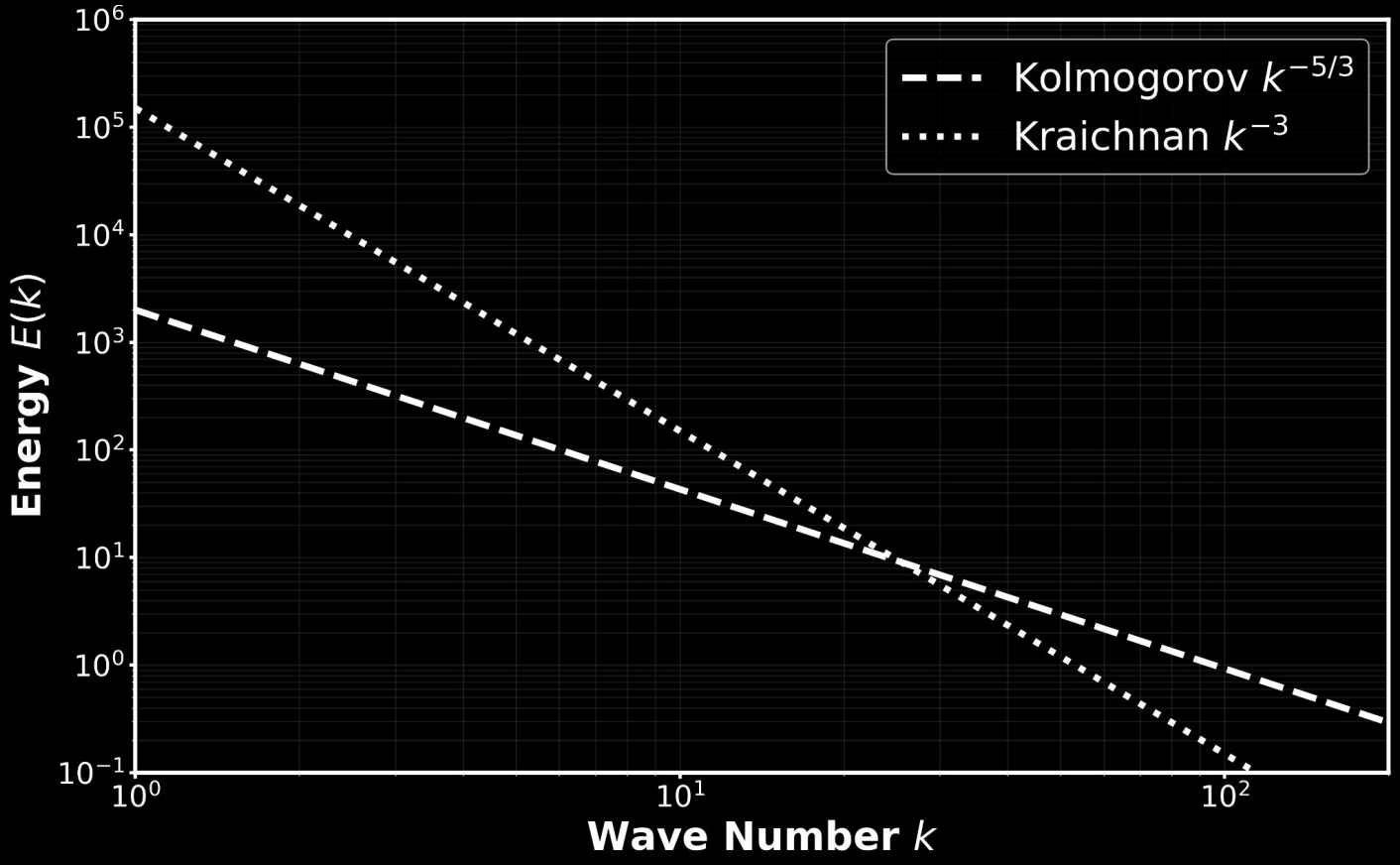


Quantifying Chaos

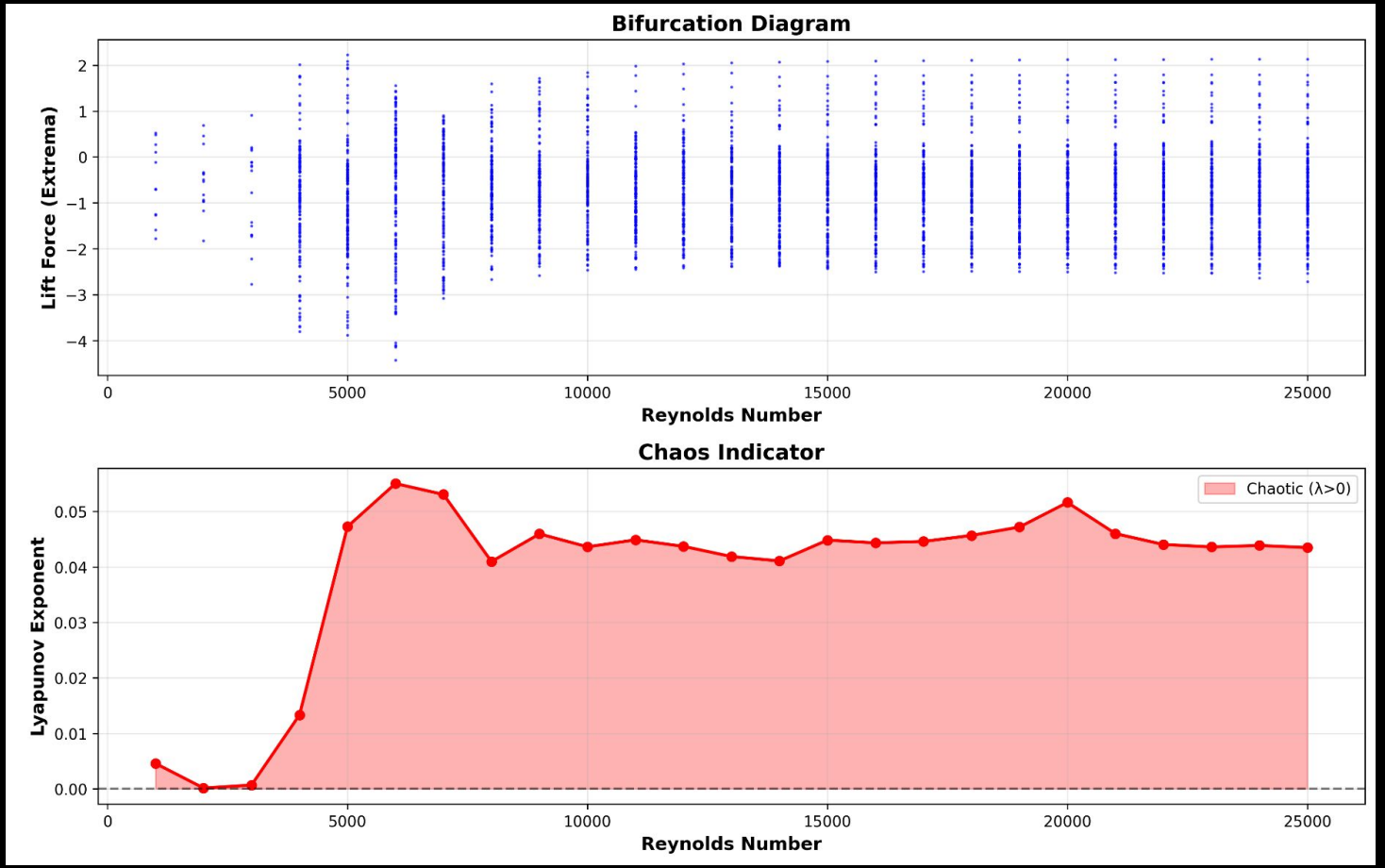




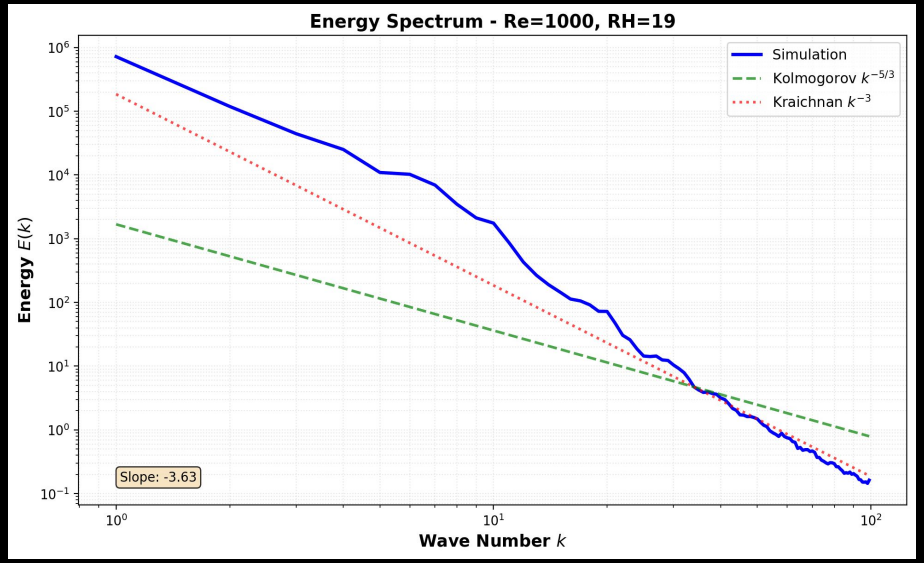
Energy Spectra Analysis: Theoretical Scaling Laws



Reynold's Number Sweep

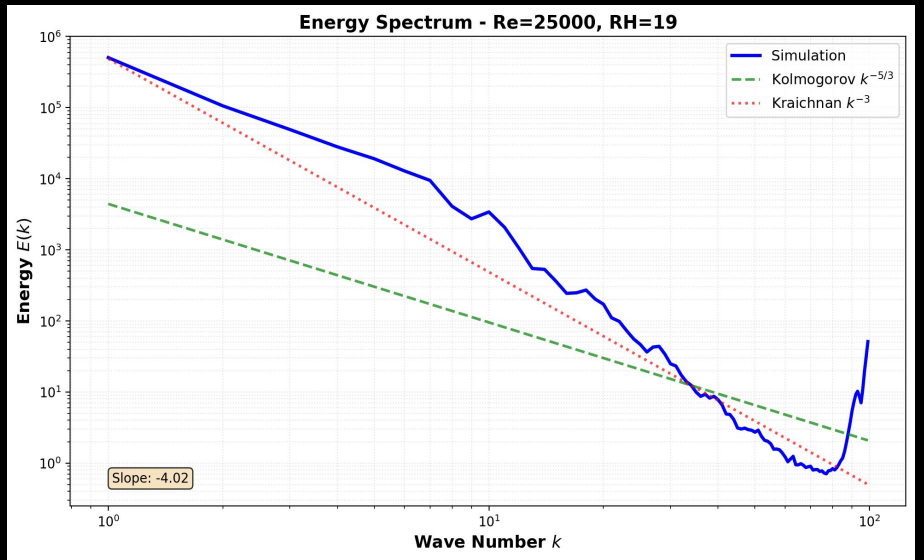


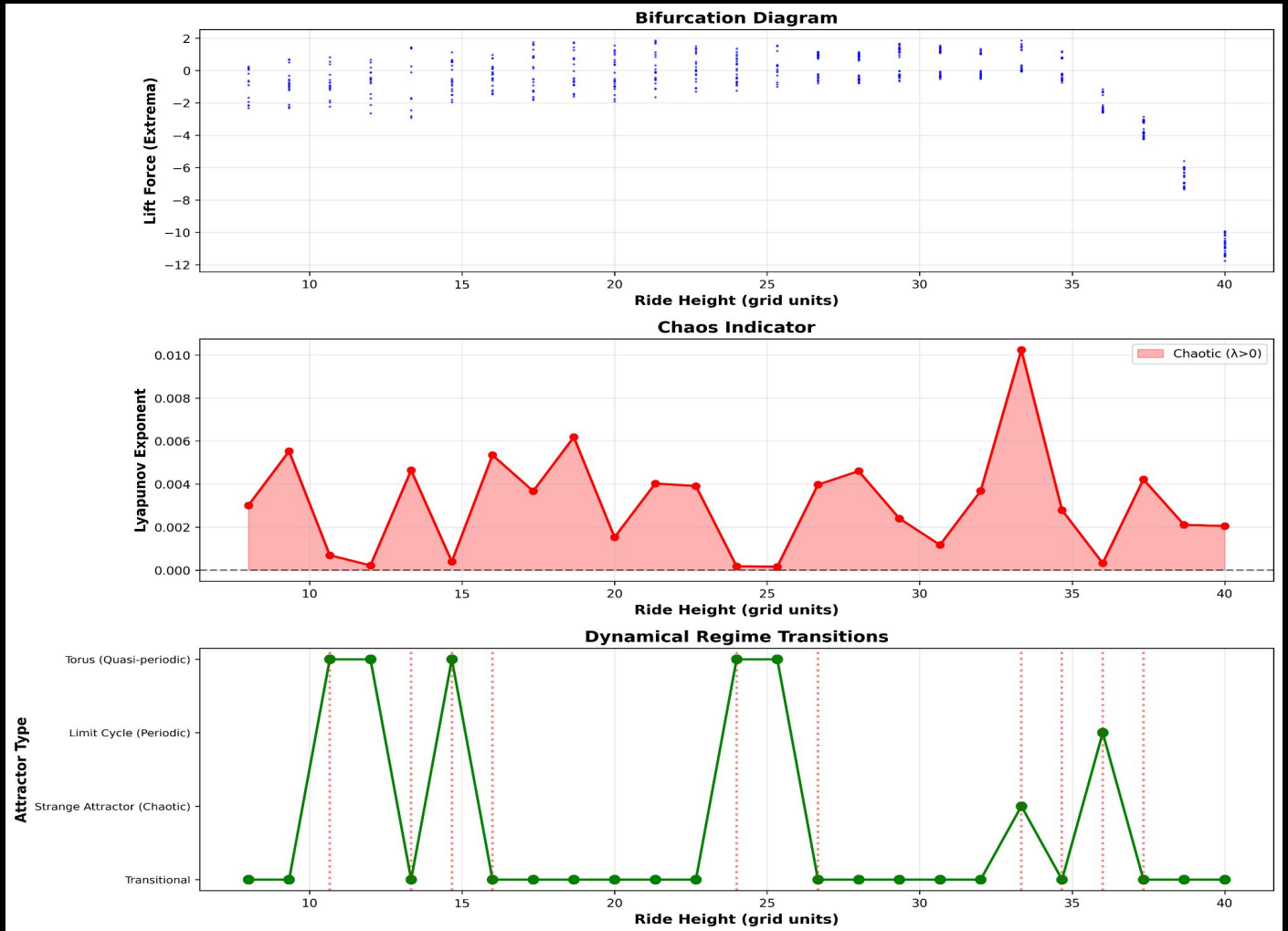
Reynold's Number Sweep: Energy Spectra



Re = 1000

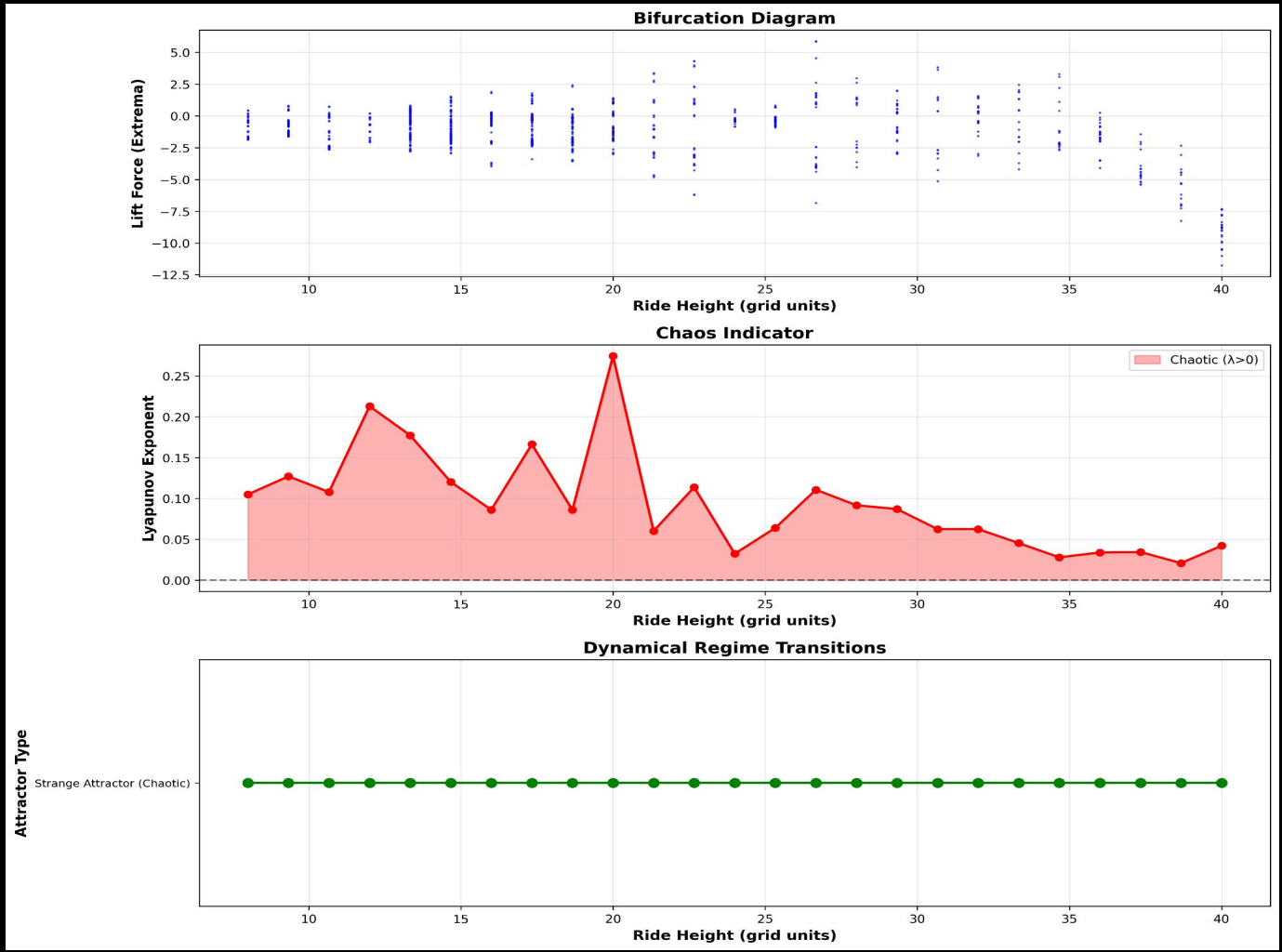
Re = 25 000

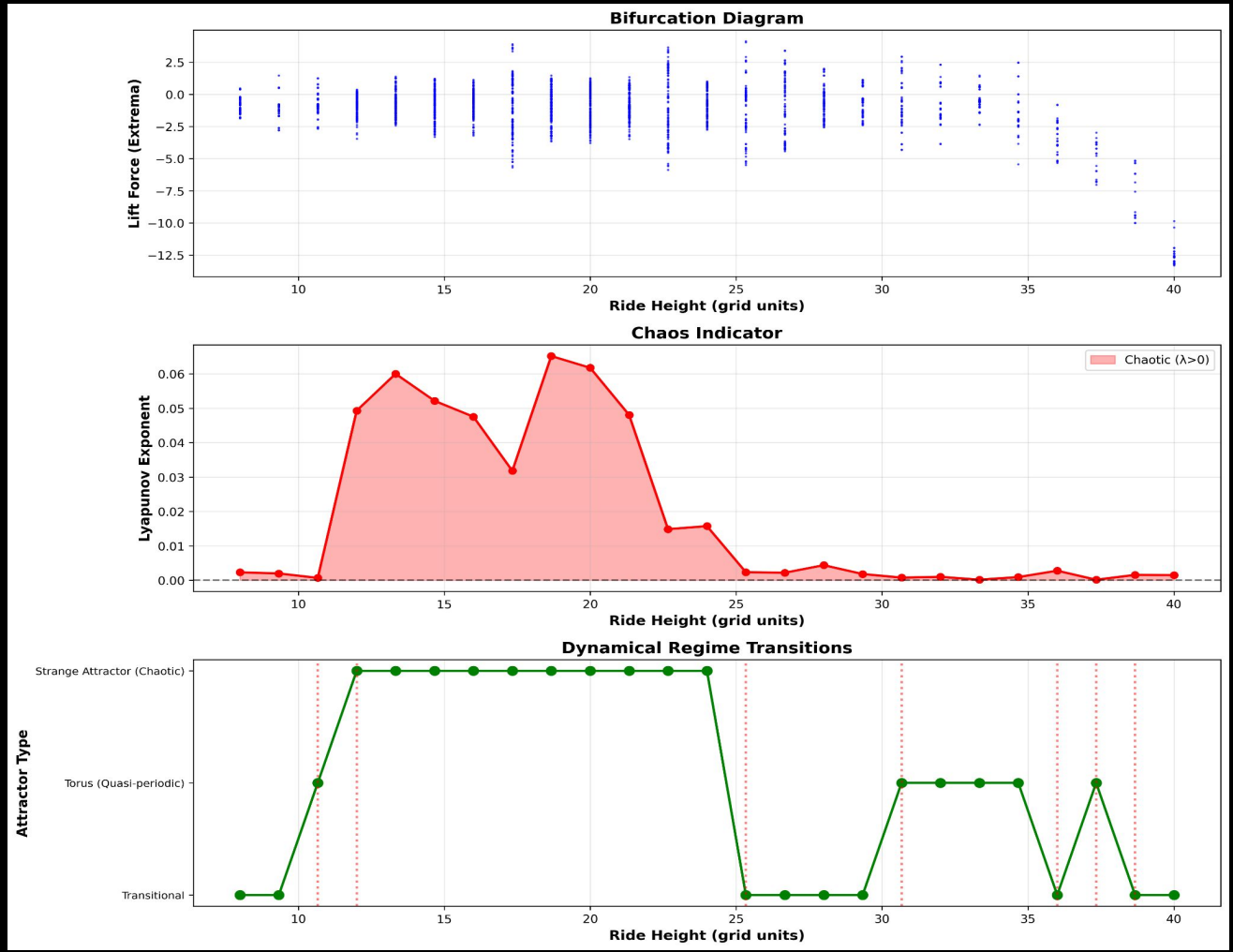




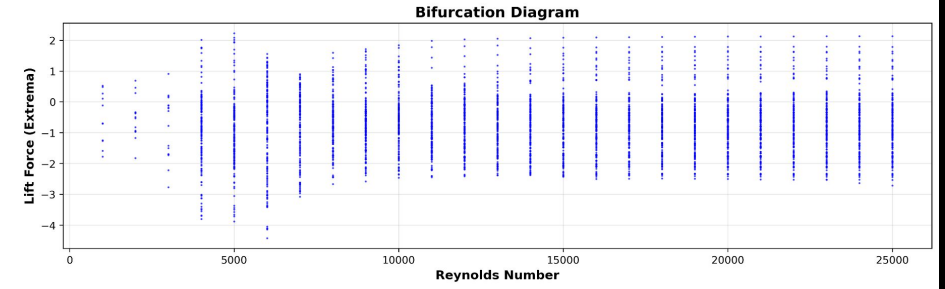
Ride Height Sweep: Re = 500

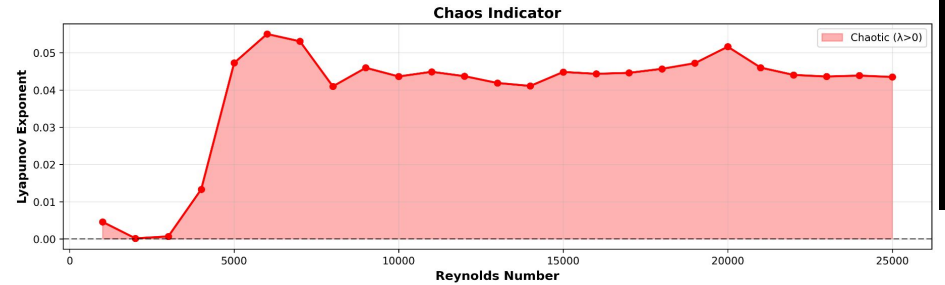
Ride Height Sweep: Re = 10000



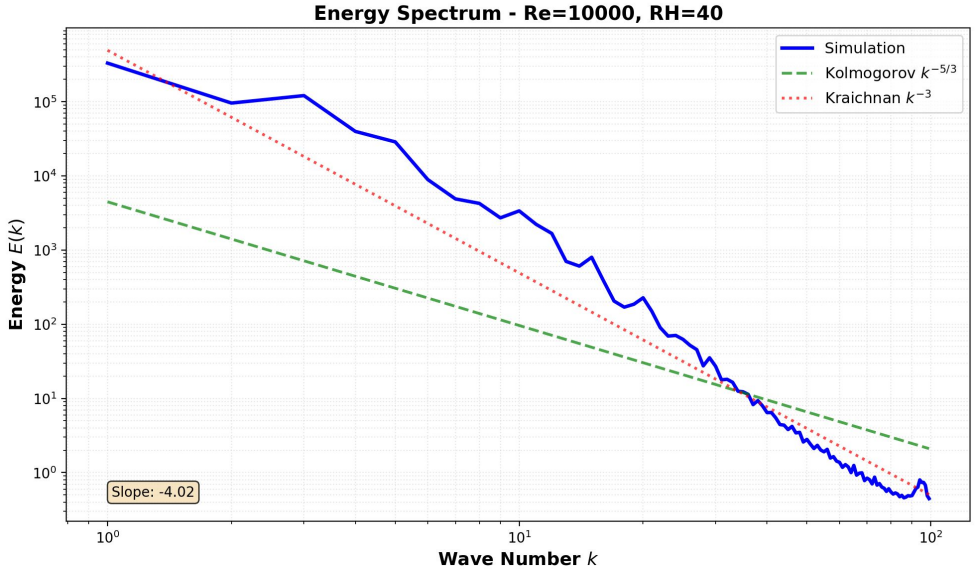


Ride Height Sweep: Re = 5000





Transition Dynamics and Validation



Limitations and Future Work

Dimensionality Limitation

- Current data follows Kraichnan's k^{-3} law, while real-world follows Kolmogorov's $k^{-5/3}$ (2D vs 3D)
- 2D slices cannot capture Tip Vortices

Realism

- Current study Reynolds number 10k
- In F1 context Reynolds number 500k-3M