

Fractional-Order Entropy Diagnosis of Flow Structure Orderliness in Near-Ground UAV Flight

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Introduction

Near-ground flight improves UAV efficiency via ground effect, but the role of flow structure orderliness remains unclear. We propose fractional-order entropy to diagnose orderliness and reveal its correlation with efficiency.

Key Findings

- **New method:** New method: Fractional-order entropy diagnosis
- **New discovery:** Optimal efficiency \leftrightarrow min S_f
- **Mechanism:** Orderly flow suppresses dissipation
- **Application:** Theoretical basis for energy-saving control

Methods

Data: Quadrotor UAV, 9450 propeller, $h/R=0.4\sim 3.0$

CFD: SST $k-\omega$, MRF, 980k cells

Fractional-order entropy: $S_f = H_{PE}(D^\nu L(t))$

Parameters: $\nu=0.5, m=3, \tau=1$

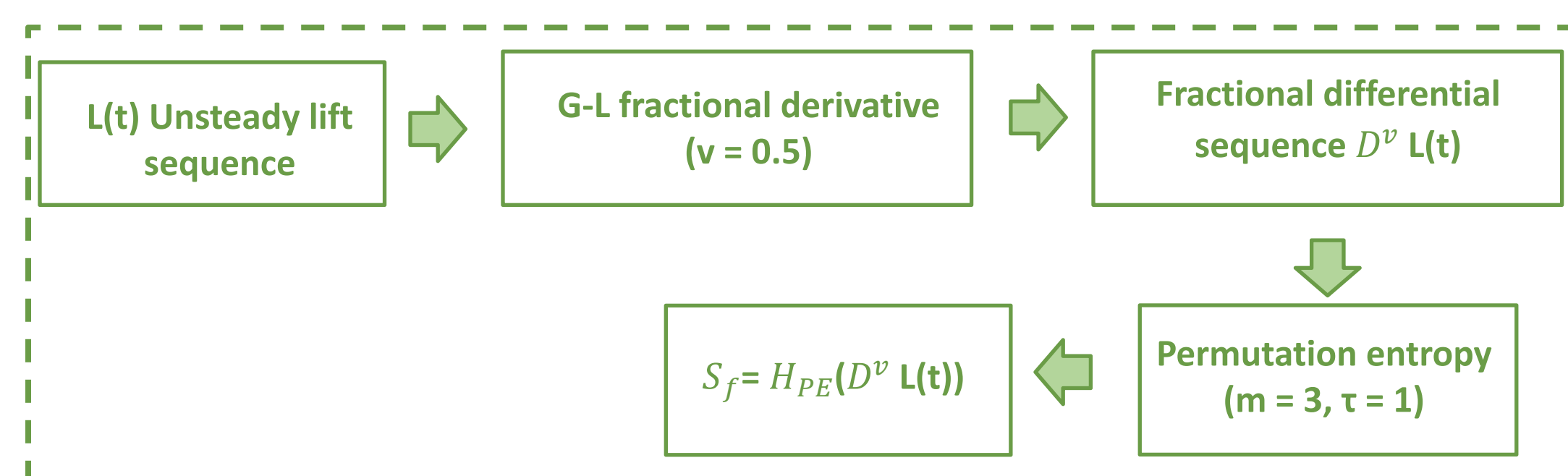
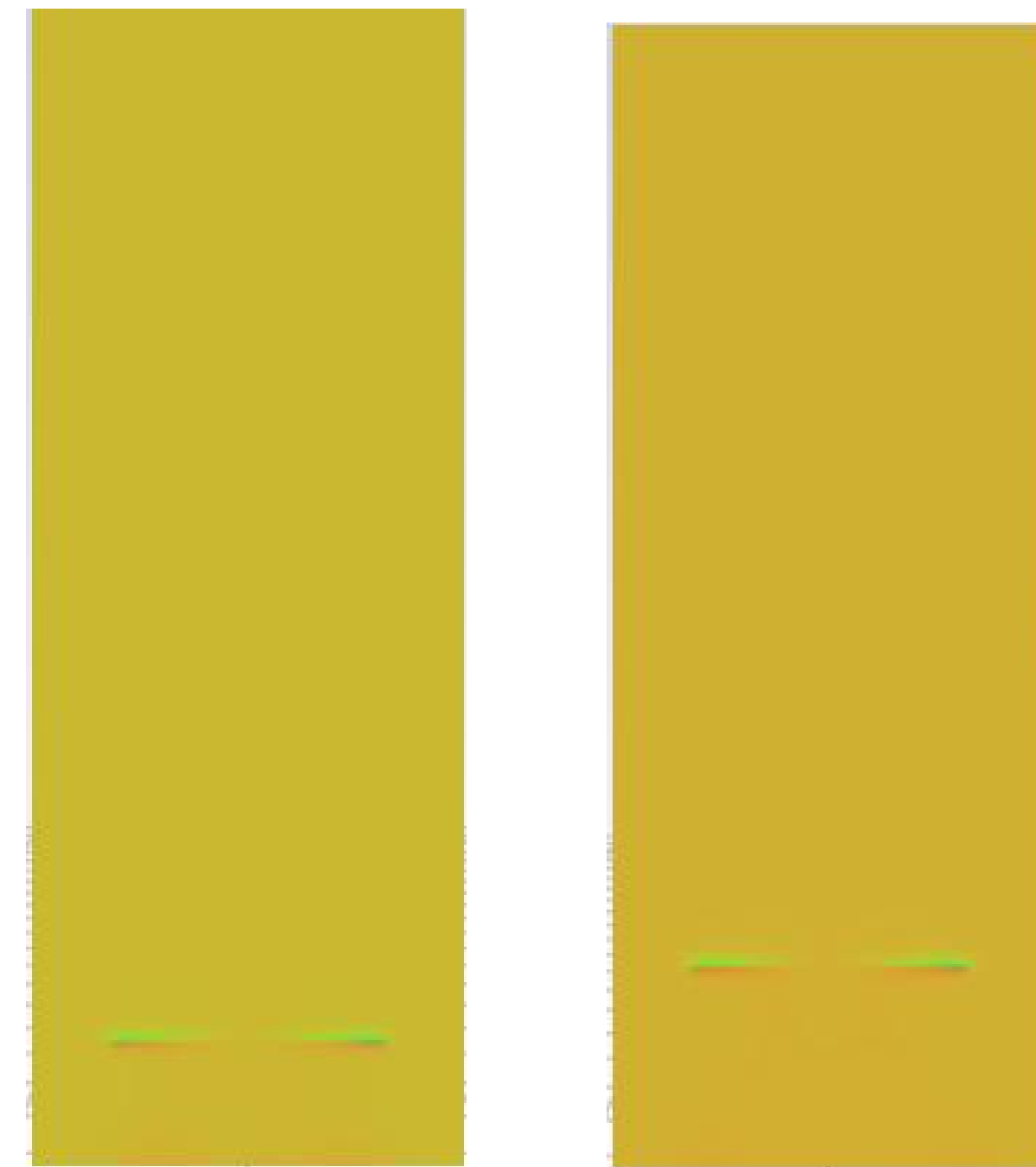


Figure 1. Fractional-order entropy diagnosis framework.

Analyses



- **Small S_f (orderly flow) \rightarrow Suppresses dissipation**
- **Large S_f (chaotic flow) \rightarrow Energy dissipation dominates**

Figure 2. Comparison of flow field structures at different ground clearance. Left: $h/R = 0.8$ (Ordered flow field, regular ground vortex) Right: $h/R = 1.4$ (Disordered flow field, vortex breakdown)

Results

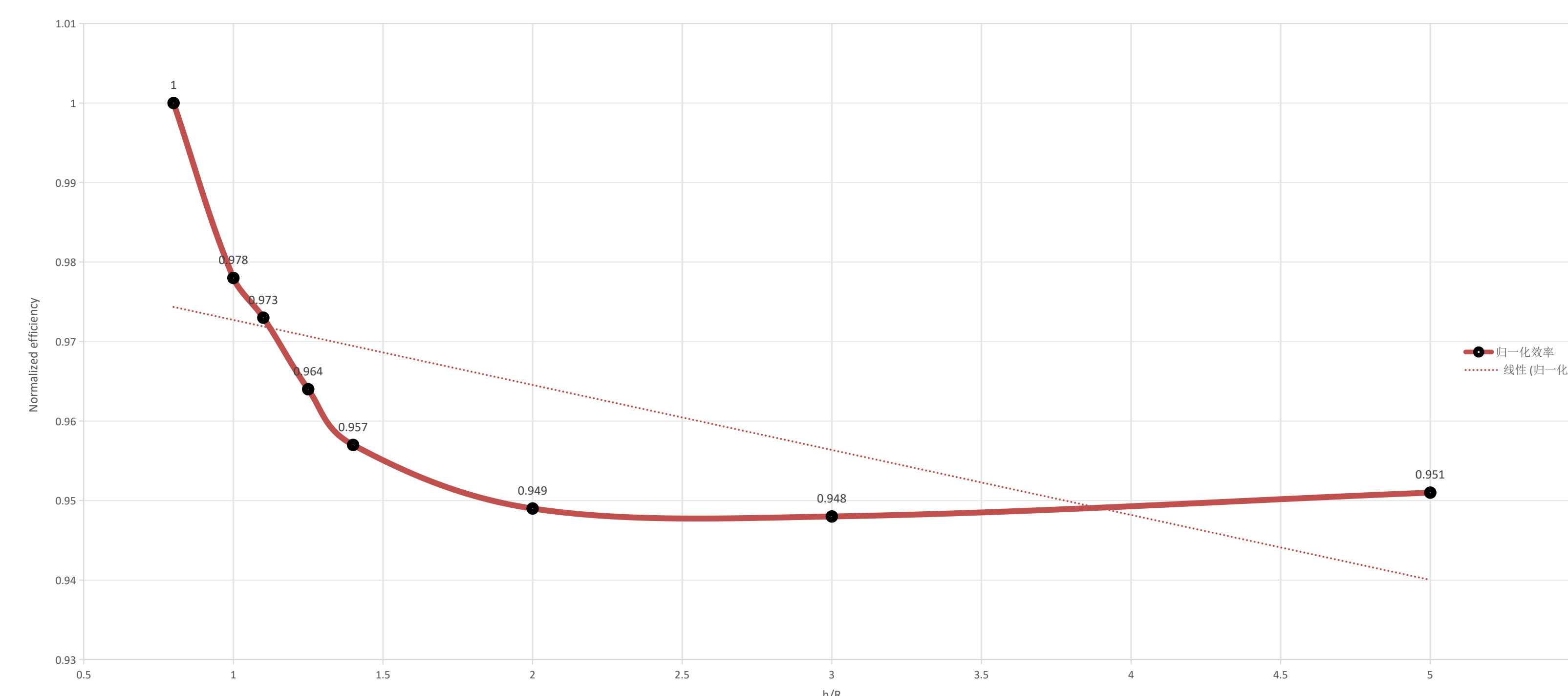


Figure 3. Aerodynamic efficiency as a function of normalized ground clearance h/R .

- **Optimal efficiency occurs at $h/R \approx 0.8$, where S_f reaches its minimum**
- **S_f minimum \leftrightarrow η maximum**
- **Strong monotonic correlation exists**

Conclusions

This study confirms that the physical essence of optimal near-ground efficiency is flow orderliness. Fractional-order entropy provides a quantitative diagnostic tool for this mechanism. Future work may combine real-time flow sensing to achieve autonomous energy-saving flight control.

References

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Acknowledgments

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