4.4 Comparative Analysis of Transition Strategies

The four transition control architectures suggested in the previous section are thoroughly compared both quantitatively and qualitatively in this section. With the help of the waypoint generator described in Chapter 3, each tactic was put into practice inside the complete mission simulation environment. We can evaluate each strategy's performance in terms of a set of key metrics by looking at a standardized mission profile. The goal is to determine the most reliable and effective strategy for the hybrid wing UAV by identifying the trade-offs present in each approach. Key parameters are as follows:

- **Forward-Transition Cruise Establishment Time:** Time from the start of pitch-over until the vehicle's forward speed stabilizes within $\pm 2\%$ of the target cruise velocity.
- **Backward-Transition Overshoot:** Maximum horizontal (X-axis) displacement beyond the intended hover point during transition back to vertical flight (in percentage).
- **Peak Elevator Deflection:** Maximum elevator angle (deg) commanded in either transition direction.
- **Peak Thrust Demand:** Maximum total thrust command (normalized to cruise thrust) required in the transition phases.
- **Altitude Deviation:** Maximum deviation (m) above or below the nominal altitude path during the transition.

TABLE 4.1: Comparison of Transition Strategies

Strategy	Cruise Establishment(s)	Backward Overshoot (m)	Peak Elevator (°) (F/B)	Peak Thrust (×Cruise)	Altitude Deviation (m) (F/B)
1	13	2.6%	16°/23°	2.1	4.6/4.2
2	29	11%	25°/2.8°	2.5	14/22.5
3	46	3.4%	25°/15.4°	2.1	16.5/3.5
4	25	15%	25°/23°	5.6	15/1.6

4.5 Discussion and Summary of Trade-offs

The results clearly indicate that there is no single "perfect" strategy; each involves a distinct set of engineering trade-offs. The table 4.1 provides a quantitative summary of the findings. In the table, the abbreviations F/B are used for forward and backward transitions, respectively.

Strategy 3 can be immediately identified as the least viable option. While simple in its control logic in the forward transition, its poor performance in both altitude stability (forward case) and cruise establishment time, coupled with high control effort approaching saturation (the elevator deflection reached saturation), makes it unreliable and inefficient.

Strategy 1 uses a fixed incidence angle. It establishes a cruise in an astounding 13 seconds, making it the most efficient. With a very small backward overshoot of 2.6%, it shares the lowest peak thrust requirement of 2.1 times hover thrust, making it power-conscious. It has outstanding altitude stability that is balanced for both forward (4.6m) and backward (4.2m) transitions. A high peak lift deflection (23°) during backward transition is the only factor taken into account. This is a small and tolerable trade-off for better performance in all other crucial metrics, though, because it still falls below the saturation limit and happens during a deceleration phase.

Strategy 2 performs poorly in terms of altitude stability, with deviations of 14m and 22.5m, and also saturates the elevator during the forward transition. This can demonstrate a significant inefficiency during the forward transition. Taking account of moderately good performance in backward transition and a reliable cruise establishment time of 29 seconds, this strategy can come out to be balanced across all the key parameters.

Strategy 4 demonstrates a "brute force" approach. While it achieves the best altitude hold during the difficult backward transition (1.6m deviation), this performance comes at an extreme cost. It requires a peak thrust of 5.6 times the cruise thrust, more than double any other strategy, placing immense strain on the propulsion system. This also comes at the significant cost of poor positional accuracy during backward transition phases, with a backward overshoot of 15%. While the overshoot could potentially be mitigated with a more precise and complex braking algorithm, in its current form, it makes precise landings difficult. In comparison, it provides a moderate performance across all the key metrics and emerges as a balanced solution, taking account of the capability of a wider transition range of threshold velocities because of the dual controller attitude scheme, as well as the thrust augmentation.

4.6 Conclusion

This thorough analysis clearly shows that the most appropriate and reliable control architecture for this hybrid wing UAV is Strategy 1 (Blended Control with Fixed Incidence Angle). It is the most comprehensive and dependable option for real-world mission profiles since it provides the best balance of transition efficiency, flight path stability, landing accuracy, and low power consumption.