Comparative Study of Sequencing and Control for Aircraft Armament Release Mechanism

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***Abstract*— End-to-end command-to-separation timing for aircraft armament release is seldom reported, yet it governs sequencing safety and performance. We implement a latency-aware supervisory architecture in which a Raspberry-Pi sequencer issues mode-dependent commands (Auto, Manual, failsafe Jettison) and an Arduino actuator layer enforces positive-separation confirmation and diversion to Jettison on fault. Two representative mechanisms- a suspension latch and a geared claw were designed in SolidWorks, 3D-printed and exercised on a five-station bench rig with inert articles. Using standardized metrics (actuation, release, activation) with controller-side time stamping, the suspension mechanism consistently outperforms the claw across all modes: actuation and release are shorter by around 0.45s (38-43%). Activation shows no systematic difference because it includes a deliberate 3s interlock shared by both mechanisms. A decomposition of pre-release timing attributes the claw's delay to a slower unlock phase. The resulting 0.45s gain expands sequencing margin and supports tighter inter-station spacing under the same guard times and the fallback preserves failsafe behavior. Experiments were conducted on a laboratory bench with 3D-printed hardware and inert training articles; flight condition validation under vibration and dynamic loads is left to future work.**

Index Terms—Armament release, armament sequencing, positive separation, jettison, supervisory control, claw mechanism, suspension mechanism.

I. INTRODUCTION

Safe aircraft-store release is a robotics and control problem: the onboard system must execute deterministic multi-station sequencing, guarantee positive separation and preserve flight safety under routine and emergency operations, yet classic stores integration literature focuses on aerodynamic compatibility rather than the end-to-end command to mechanism latency that actually gates the release event. Early compatibility work established wind tunnel methods and envelope thinking for clearing stores but treated the release controller as a black box with no timing visibility [1]. Cavity/internal-bay modeling then coupled flow solvers with rigid body dynamics to predict controlled separations, advancing trajectory fidelity while still omitting measured actuation or separation latencies from real mechanisms [2].

More recently, internal-bay drop tests show that aircraft store compatibility degrades as angle of attack increases, underscoring the need for release systems whose timing remains predictable across flight states [3]. Open-source CFD pipelines now credibly reproduce high-speed cavity separations and generic test cases but they evaluate what happens after a release command-not how fast a command propagates through the mechanism to positive separation [4]. A complementary strand treats bombing effectiveness through accuracy metrics and delivery vs ballistic error decomposition, which informs when to command a drop but does not quantify controller latency at the instant of release [5]. On the hardware side, recent reviews document the shift from pyrotechnic devices to non-explosive actuators (NEAs) to reduce shock and enable resettable hardware- an evolution that elevates the importance of redundant separation paths for fail-operational behavior in safety critical release chains [6]. At the aircraft level, center-of-gravity management ties sequencing policy to platform stability, so mechanism choice and timing windows must also respect CG constraints during multi store release [7].

This paper treats armament release as an end-to-end control problem and report measured actuation and release times for two representative mechanisms- suspension and claw, exercised under Auto, Manual and Jettison modes on a multi station test bench using standardized timing metrics (actuation, successful-release, activation).

We show that the suspension mechanism achieves a consistent 40% reduction in actuation and release latency relative to the claw across modes, enabling tighter sequencing windows and more stable CG management in multi-store release, thereby complementing aerodynamics and accuracy centric studies with controller to mechanism timing evidence.

The remainder of the paper details system architecture and instrumentation, presents aggregate statistics with uncertainty and discusses control implications for sequencing policy, positive separation and fail-safe operation.

TABLE I. BACKGROUND STUDY OF REPRESENTATIVE WORKS VS RELEASE-SYSTEM CRITERIA (E, R, PS, CG, MC)

Ref	E	R	PS	CG	MC
Moore	✓	✗	✗	✗	✗
Song	✓	✗	✗	✗	✗
Lee	○	○	○	○	✗
Zhou	✗	✗	✗	✓	✗
This paper	✓	✓	✓	✓	✓

Criteria: E = Empirical Testing (wind-tunnel/bench evidence); R = Modes & redundancy (fail-safe ops like Auto/Manual/Jettison, overrides); PS = Positive-separation sensing (e.g., reed/micro-switch confirming store departure); CG = CG-aware sequencing policy (release order chosen to manage Center of Gravity shift); MC = Mechanism comparison (head-to-head). Symbols: ✓ addressed with evidence; ○ mentioned conceptually/ simulation; ✗ not addressed.

II. System Architecture

The proposed armament system integrates both hardware and software components to ensure reliable sequencing, redundancy and pilot override capabilities. Figure 1 displays the overall flowchart of the system, where the bomb release can follow either auto sequencing or manual control depending on mission requirements and failure conditions. Figure 2 depicts a Raspberry Pi 4-based software control panel governing the automatic sequencing logic, jettison control and system display. The panel allows pre-mission programming of the release order to preserve the aircraft's center of gravity. During flight, if a failure is detected, the system immediately alerts the pilot and disables auto sequencing, shifting seamlessly to manual control.

Figure 3 illustrates the Arduino-based hardware control system which provides visual status indicators and directly actuates firing and jettison switches.

A joystick module with safety cover enables the pilot to switch between auto and manual modes. In auto sequencing, the system releases bombs in a pre-programmed order; in manual mode, individual bombs can be released

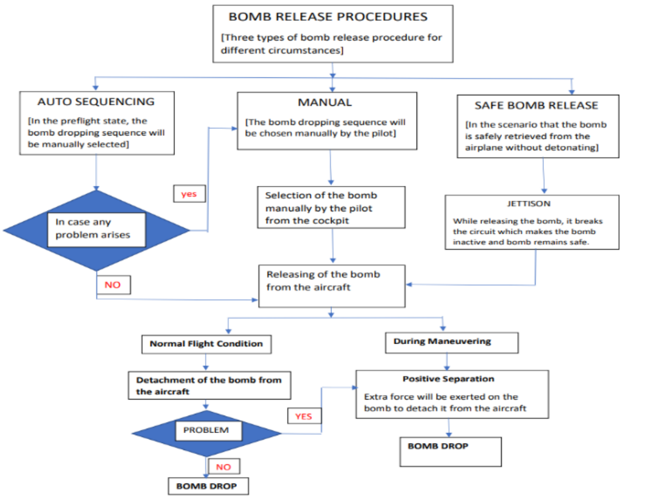

Fig. 1. Supervisory payload-release program flow

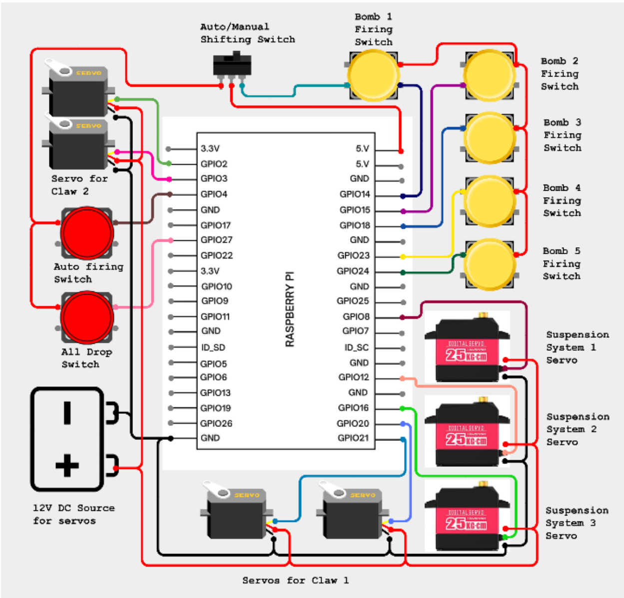

Fig. 2. Raspberry Pi GPIO map for the payload-release controller

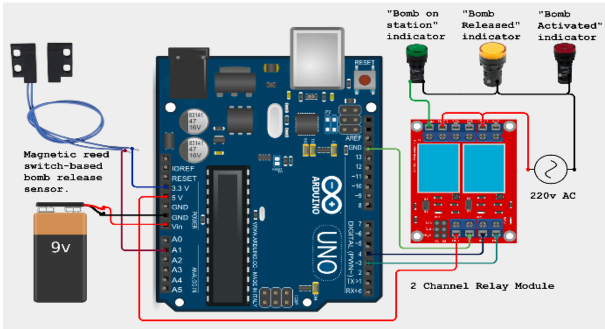

Fig. 3. Arduino-based actuator control layer

independently. In emergency jettison, bombs are released in an inactive state, ensuring aircraft safety during recovery. Positive separation is ensured through a magnetic reed switch mechanism and spring assisted push action, particularly within the suspension system.

Overall, the architecture embodies a redundant sequencing control system:

- Primary - Raspberry Pi for sequencing logic.
- Secondary - Arduino for direct hardware actuation.
- Pilot override - Manual and jettison switches as failsafe.

This layered control strategy ensures that under any failure condition, bomb deployment can be completed safely and predictably. Following historical literature, we use the term "bomb" to denote an inert wooden payload in our bench tests.

III. Experimental Setup

Two types of release mechanisms were designed in SolidWorks, 3D-printed and integrated on the bench rig. Figure 4 presents the suspension system that uses dual hooks driven by a servo with a spring-assist for positive separation; it self-recenters after release and is rated to 25 kg. Figure 5 shows the claw system: a servo-driven, gear-coupled pair of jaws (10 kg per claw) used to grasp and release; in parallel use, extended trials revealed gear vulnerability.

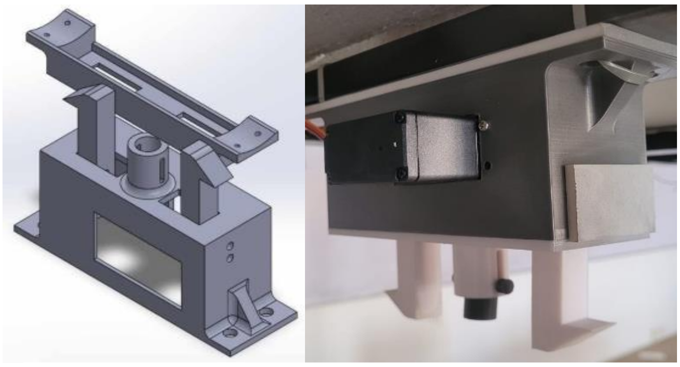

*Fig. 4. **Suspension release mechanism**- SolidWorks CAD (left); 3D-printed prototype mounted on the bench rig with a side-mounted servo (right)*

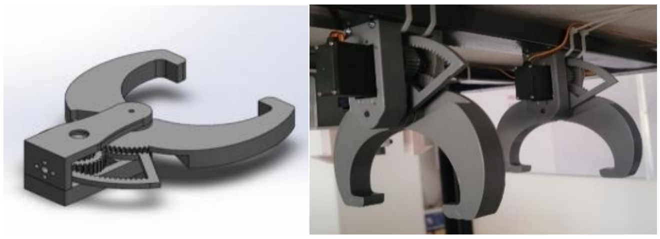

*Fig. 5. **Claw release mechanism**- SolidWorks CAD (left); 3D-printed prototype integrated with servo on the bench-top rig (right)*

TABLE II. PHYSICAL SPECIFICATIONS OF PROTOTYPE RELEASE MECHANISM

Mechanism	Suspension System	Claw System
Envelope **L × W × H** (cm)	21×6×14	18×15×16
Max Load (kg/N)	25	15
# Parts	8	16
Servo Model	S8503	MG996R
Materials	PLA	PLA

Figure 6 reveals the experimental platform which was constructed from stainless steel with dimensions of 1.83 m × 0.61 m × 1.83 m, accommodating five inert bomb stations. It was configured with three suspension systems and two claw systems to allow direct comparison of both mechanisms. Five wooden bombs were used, four weighing 2.2 kg each and one weighing 3.5 kg.

Each mode was tested under repeated trials (n=5 per bomb, per mode). The following metrics were measured:

- Actuation Time - elapsed time between switch activation and mechanism initiation.
- Release Time - elapsed time from switch activation to complete bomb separation.
- Activation Time - elapsed time until the bomb became live, confirming electrical continuity through the circuit.

Figure 7 shows the supervisory control panel used in the bench tests: mode selection, auto-sequence firing, per-station manual firing and an Activation/Jettison switch. A three-LED stack per station indicates circuit available (green), bomb activated (red) and bomb successfully released (yellow). All

*Fig. 6. **Bench-top test rig**: mock airframe with five inert bombs mounted on interchangeable release stations (suspension/claw), with the supervisory control panel and display at right; used for latency measurements across Auto/Manual/Jettison modes.*

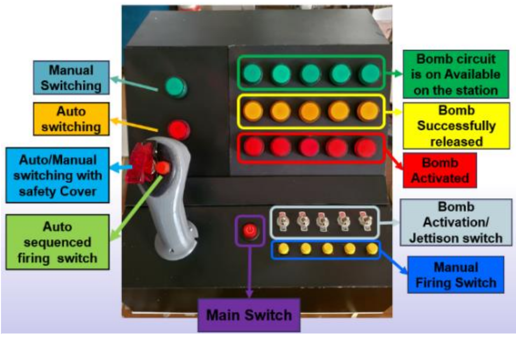

*Fig. 7. **Supervisory control panel**: mode control's switches, auto-sequence firing, manual firing and activation/jettison switch; status indicators for circuit available, bomb activated and successfully released; main power switch shown.*

switch states are read by the controller and time-stamped during the trials.

This setup provided a controlled environment to evaluate the comparative timing performance of suspension and claw mechanisms across Auto Sequencing, Manual and Jettison modes.

All tests used inert, bench-top dummy wooden bombs; no energetic materials or pyrotechnics were involved. The work concerns timing and control only, with positive separation confirmation and a fail-safe jettison path.

IV. Result and Discussion

The experimental evaluation compared the suspension and claw bomb release mechanisms across Auto Sequencing, Manual and Jettison modes. The timing results across these modes are summarized in table III.

Figure 8 demonstrates the suspension mechanism reduces actuation time by 0.43-0.47s (39-43%) relative to the claw in every mode (e.g., Auto: 0.69 ± 0.07 s vs. 1.16 ± 0.04 s). Figure 9 shows a comparable reduction for release time, 0.43-0.47s (38-40%). Variability is modest for both mechanisms (SDs 0.04-0.07s).

Figure 10, the aggregated view, confirms these gains: actuation and release mean differences cluster near −0.45s (negative favors suspension) with 95% CIs not overlapping zero across modes. In contrast, activation exhibits no consistent advantage because it includes a fixed ≈ 3s safety interlock common to both mechanisms so the differences hover near zero in the forest plot.

Figure 11 decomposes the pre-release timing to explain why suspension is faster. Clearance is small (≤ 0.1 s) for all conditions, whereas unlock dominates and is consistently slower for the claw due to the geared jaw train. This mechanism-intrinsic delay accounts for the ≈ 40% advantage observed in actuation and release. The 0.45s reduction expands sequencing margin in Auto/Manual modes and allows tighter inter-station spacing under the same guard time. The Jettison path maintains comparable behavior and provides a fail-safe fallback when separation is not confirmed.

Tests were performed on a laboratory bench with 3D-printed hardware and inert bombs; validation under airborne vibration and dynamic loads is left for future work.

TABLE III. TIMING RESULTS (MEAN ± SD) FOR SUSPENSION AND CLAW MECHANISMS UNDER AUTO, MANUAL AND JETTISON MODES

Mechanism	Metric	Auto	Manual	Jettison
Suspension System	Actuation	0.69 ± 0.07 (s)	0.68 ± 0.06 (s)	0.67 ± 0.05 (s)
	Release	0.73 ± 0.07 (s)	0.72 ± 0.07 (s)	0.71 ± 0.05 (s)
	Activation	3.42 ± 0.22 (s)	3.53 ± 0.23 (s)	3.51 ± 0.11 (s)
Claw System	Actuation	1.16 ± 0.04 (s)	1.15 ± 0.06 (s)	1.10 ± 0.04 (s)
	Release	1.20 ± 0.05 (s)	1.18 ± 0.05 (s)	1.14 ± 0.05 (s)
	Activation	3.35 ± 0.23 (s)	3.23 ± 0.12 (s)	3.42 ± 0.15 (s)

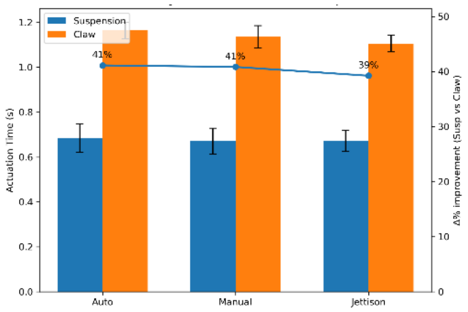

Fig. 8. Actuation time by mode for suspension vs. claw; line shows % improvement of suspension over claw.

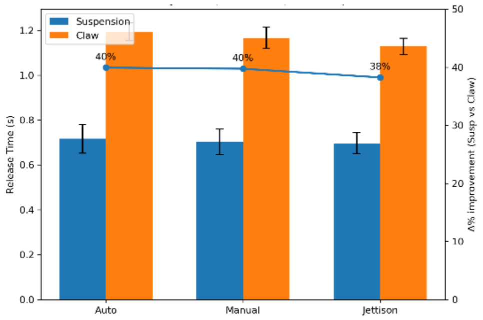

Fig. 9. Release time by mode for suspension vs. claw; line shows % improvement of suspension over claw.

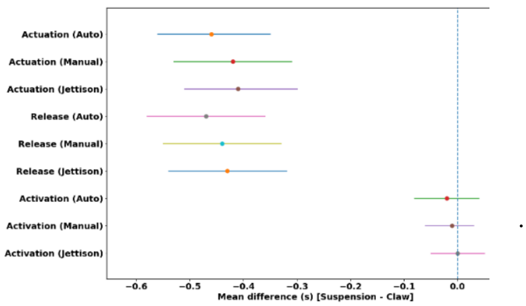

Fig. 10. Mean differences with 95% CIs across metrics and modes; negative values favor suspension.

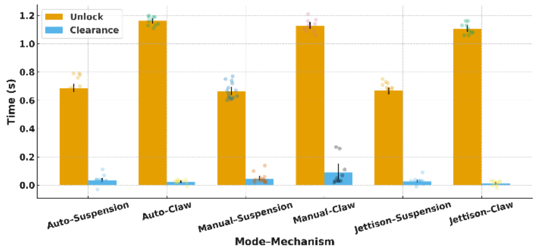

Fig. 11. Pre-release components (Unlock, Clearance): means with 95% CIs and per-trial points across mode-mechanism pairs.

V. Conclusion

We presented a robotics-inspired, redundant sequencing controller (Raspberry Pi + Arduino) and a lab testbed to benchmark Suspension vs Claw release mechanisms in Auto, Manual and Jettison mode. Trials completed without jams; the only notable issue was minor gear-related variability with Claw under parallel operation.

From a control and systems perspective, the latency and variance advantages of Suspension translate to tighter sequencing windows and more stable center-of-gravity trajectories during multi-store release, while the Auto → Manual → Jettison redundancy ensures fail-safe behavior under faults. The proposed benchmarking procedure (metrics, modes, and summary statistics) provides a reproducible baseline for future armament-sequencing controllers.

Future work will (a) validate under flight conditions (load/vibration/thermal), (b) integrate sensor fusion for positive-separation confirmation and health monitoring, (c) quantify network delays and close the loop with latency-aware scheduling and (d) explore optimization/learning methods to adapt sequencing to aircraft dynamics and mission constraints.

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