**RC Trainer Aircraft with Custom Flight Controller: R2Flight v1**

**System Specification Document Rev 1**  
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**Revision History**

| **Revision** | **Date** | **Comments** |
| --- | --- | --- |
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**1. Purpose**

The purpose of this document is to define the system-level design of a radio-controlled (RC) trainer aircraft powered by a 7.2 V 3600 mAh NiMH battery and controlled through a custom-designed flight controller. This aircraft serves as a platform for stable, docile flight suitable for training and for testing flight control algorithms. The document establishes the technical specifications, performance expectations, and integration requirements of the airframe, propulsion system, and avionics.

**2. Scope**

This project covers the design, integration, and testing of:

* A high-wing trainer airframe constructed from foamboard or balsa.
* A custom-designed flight controller with IMU sensors, RC receiver interface, and PWM outputs.
* A four-channel RC link for throttle, elevator, rudder, and aileron control.
* Manual RC operation and stabilized flight modes managed by the custom flight controller.

Future expansions such as GPS navigation, telemetry, and autonomous flight are not part of this baseline project.

**3. Constraints**

* **Power Source:** Limited to a 6-cell 7.2 V NiMH battery pack (about 300 g), which introduces weight and voltage sag constraints compared to LiPo.
* **Weight Limit:** All-up weight (AUW) shall remain ≤600 g to preserve trainer-class handling with the selected wing.
* **Endurance:** Target flight times of 20–35 minutes depending on average current draw and usable NiMH capacity.
* **Thrust:** Propulsion expected at about 400–500 g static thrust, implying modest climb and relaxed cruise.
* **Servos:** Powered by ESC BEC, number and torque limited to typical 9 g class servos.
* **Airframe:** Must be sufficiently stiff for the short span and include washout to prevent tip stall.
* **Flight Controller:** Must operate within the ESC BEC’s 5 V supply and generate reliable outputs at ≥50 Hz loop rate.

**4. References & Assumptions**

* Motor and prop performance based on typical 2212 1400 KV data with 8×6 E-prop on 2S NiMH.
* NiMH pack continuous current estimated at 20–30 A with 10C burst.
* ESC assumed configurable to NiMH mode or cutoff disabled.
* Airframe geometry: high wing, 3–4 degrees dihedral, tractor layout, rectangular wing planform.
* Flight controller target: STM32 or RP2040-class MCU with standard IMU.

**5. System Requirements**

**5.1 Functional Requirements**

* The aircraft shall generate ≥400 g thrust to sustain flight with an AUW up to 600 g.
* The propulsion system shall integrate with a 6-cell 7.2 V 3600 mAh NiMH battery pack.
* The flight controller (FC) shall:
  + Accept RC receiver inputs.
  + Provide PWM outputs to one ESC and three servos.
  + Operate in manual pass-through and stabilized auto-level modes.
* The ESC shall provide a regulated 5 V BEC output to power the receiver, servos, and FC.
* The system shall support ≥20 minutes endurance at cruise throttle under typical conditions.

**5.2 Non-Functional Requirements**

* **Reliability:** Motor, ESC, and FC shall operate without overheating under continuous use.
* **Maintainability:** All connectors (XT60, servo plugs, motor bullets) shall be modular for easy replacement.
* **Safety:** The FC shall enter failsafe (throttle cut, control surfaces neutral) on RX signal loss >1 s.
* **Usability:** The trainer shall demonstrate stable, forgiving handling with smooth stall behavior.
* **Regulations:**

• Regulatory Scope:

* + - Canada: Transport Canada CAR Part IX – Subpart 1 (Micro RPA <250 g)
    - USA: FAA Advisory (Model Aircraft Exception / Recreational UAS <250 g)
* **Aviation Requirements:**
  + Fly below 122 m (400 ft) and within visual line-of-sight (VLOS).
  + Stay away from airports, aircraft, and people.
  + No registration or pilot certificate required in either country for <250 g recreational use.
  + Operation must not be reckless or negligent (CAR 900.06 / FAA 49 U.S.C. 44809).
* **Radio & EMC Compliance:**
  + Canada: ISED RSS-Gen, RSS-210 (or RSS-247) and ICES-003.
  + USA: FCC Part 15 Subpart C (unlicensed transmitters) and Part 15 B (digital emissions).
  + RF modules must carry valid ISED ID and FCC ID labels.
  + Transmit power, duty cycle, and frequency hopping must remain within licence-exempt limits.
* **Latency:** FC control loop ≤20 ms (≥50 Hz update).

**6. Hardware Specification**

**6.1 Power System**

* **Motor:** 2212 1400 KV BLDC
* **Propeller:** 8×6 “E” prop (baseline)
  + About 12–16 A on 2S NiMH
  + About 90–130 W input
  + About 400–500 g static thrust
* **ESC:** 30 A with 5 V BEC
  + Battery mode: NiMH or cutoff disabled
* **Battery:** NiMH 7.2 V 3600 mAh (about 300 g)
  + Usable capacity: 2.5–2.9 Ah
  + Peak current: about 36 A, safe continuous: 20–30 A
* **Connectors:** XT60 (ESC and battery)
* **Wiring:** 12 AWG for battery leads, 14 AWG ESC–motor
* **Receiver Power:** ESC BEC → FC + 3 servos

**7. Mechanical Specification**

* **AUW:** 550–600 g target
* **Wing Planform:** Rectangular, 34 in span × 7.5 in chord
* **Wing Area:** about 255 in²
* **Aspect Ratio:** about 4.5
* **Wing Loading:** about 11.1–12.0 oz/ft² at 550–600 g
* **Estimated Stall Speed:** about 14–16 mph (sea level, CLmax about 1.3–1.5)
* **Typical Cruise Speed:** about 18–22 mph
* **Configuration:**
  + High wing, 3–4 degrees dihedral total
  + Wing incidence about +2 degrees
  + Motor: about 2 degrees down and 2 degrees right thrust
* **CG:** 25–30 percent of chord (start at about 28 percent)

**6.3 Control Surfaces**

* **Ailerons:** depth about 1.6–1.9 in (20–25 percent chord), span about 10–12 in per panel
* **Elevator:** ±0.35–0.55 in (low/high rates)
* **Aileron:** ±0.30–0.50 in (low/high rates)
* **Rudder:** ±0.60–0.80 in
* **Expo:** about 30 percent on all

**6.4 Expected Performance**

* **Takeoff:** short hand-launch or very short roll on smooth surface
* **Climb:** steady, trainer-like with conservative pitch
* **Cruise Current:** about 4–7 A depending on trim and prop condition
* **Flight Time (usable 2.5–2.9 Ah):**
  + 5 A avg → about 30–35 min
  + 7 A avg → about 21–25 min

**7. 1Software Specification (Flight Controller)**

The FC firmware implements modular layers:

* **Input Handling:** RC receiver input decoding (PWM/PPM/SBUS).
* **Sensor Fusion:** Gyroscope and accelerometer processed with complementary filtering to provide roll/pitch estimates.
* **Control Laws:** PID loops calculate corrective surface deflections for pitch, roll, and yaw stabilization.
* **Mode Management:** Manual pass-through and auto-level stabilized modes selectable via RC switch.
* **Failsafe Routine:** Loss of RC signal for more than 1 second results in throttle cut and control surfaces neutral.
* **Telemetry:** UART debug stream outputs loop rates, sensor health, and control effort for analysis.

**7.1.1 Control Software**

* **Modes:** manual pass-through and stabilized auto-level
* **Control Laws:** PID loops for pitch, roll, yaw
* **Failsafe:** throttle cut and neutralize surfaces if RX lost >1 s
* **Loop Rate:** 50–100 Hz, ≤20 ms latency
* **Debug and Telemetry:** UART serial output for sensor and control data

**7.2 Hardware Interfaces**

* **MCU:** STM32 (F103/F405) or RP2040
* **Sensors:**
  + MPU6050 or ICM-20689 (gyro and accel)
  + Optional: BMP280 barometer, NEO-6M GPS
* **Inputs:** RC receiver (PWM, PPM, or SBUS)
* **Outputs:** 4 PWM channels (ESC and 3 servos)
* **Power:** ESC BEC 5 V → FC and servos, with local 3.3 V regulator
* **Wiring Map**
* Battery (XT60 female) → ESC (XT60 male) → Motor (3 bullets)
* ESC BEC 5 V → Flight Controller → Receiver and Servos
* FC PWM outputs → ESC (throttle) and Servos (aileron, elevator, rudder)

**9. Build Guidelines**

* Mount NiMH pack near CG.
* Keep power leads short to reduce voltage drop.
* Vent ESC and motor for cooling.
* Use a wattmeter for full-throttle test; reduce prop if current exceeds about 16–18 A.
* Confirm motor and ESC are warm but safe after a 60 s WOT run.
* Add about 1–2 degrees washout at the wing tips for stall gentleness.

**11. Design**

**11.1 System Design**

The RC trainer aircraft system is designed as a modular, trainer-class platform. The system integrates the propulsion unit, flight controller, control surfaces, and airframe to achieve stable flight under NiMH power constraints. Subsystems are interconnected using standard modular connectors (XT60, servo plugs) to maximize maintainability. The architecture prioritizes stability and safety: the high-wing airframe provides passive stability, while the flight controller offers active stabilization through sensor-driven feedback loops.

A top-level block diagram would include:

* **Power Subsystem:** Handles power management. 7.2 V NiMH battery, ESC with BEC
* **Avionics with Actuation Subsystem:** Handles flight logic. Custom FC with MCU, IMU, and RC receiver + BLDC motor, propeller, and three 9 g servos
* **Airframe Subsystem:** Handles mechanics. Foamboard/balsa structure, high wing, control surfaces

A diagram of a diagram of a plane system

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A diagram of a system

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There are two three dimensions for these subsystems: Electronics Hardware, Mechanical, and Software.

**11.2 Electronics Hardware Design**

**{Hardware Diagram}**

**{Components table description and responsibility}**

**{Circuit Schematic}**

**11.2.1 Avionics and Actuation Subsystem**

**{Hardware Diagram}**

**{Components table description and responsibility}**

**{Circuit Schematic}**

**11.2.2 Actuation and Propulsion System**

**{Hardware Diagram}**

**{Components table description and responsibility}**

**{Circuit Schematic}**

**11.3 Software Design**

* A close-up of a computer program

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Project Structure

A screenshot of a computer program

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A screenshot of a computer program

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**11.4 Mechanical Design**

**A drawing of a metal object

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**A blueprint of a building

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11.4.1 Wing Geometry and Structure

* Planform: Rectangular, span 34.0 in, chord 7.50 in, area 255 in².
* Incidence: +2.0° relative to fuselage reference line.
* Dihedral: 3.5° total (1.75° per panel). Practical tip rise target: 0.50 in at each wingtip when center joint is flat and panel raised.
* Washout: 1.5° over the outer 4.0 in of each panel. Build aid: pack the trailing edge by 0.10 in over that 4.0 in during gluing.
* Ailerons: Depth 1.70 in (about 23 percent chord), span 11.0 in per panel, hinge gap 0.03 to 0.06 in.
* Spar and Joiner:
  + Main spar centerline at 25 percent chord, 1.88 in aft of LE.
  + Foamboard wing: internal spar height 1.00 in, thickness 0.19 in foamboard web with 0.25 in × 0.50 in spruce cap strips top and bottom from root to 12 in outboard each side.
  + Dihedral brace: 1/8 in birch ply, 6.0 in long, 1.00 in tall, dry-fitted to achieve 1.75° per side.
* LE and TE:
  + LE doubler 0.25 in wide balsa strip along full span.
  + TE sanded to 0.06 to 0.08 in thickness for a clean hinge line.
* Servo Bays: One 9 g servo per panel. Cutout center 9.0 in outboard from wing root, 3.50 in aft of LE. Pocket 1.00 in × 0.50 in × 0.90 in deep.
* Control Horns: Hole center 0.40 in from hinge line, arm height 0.60 to 0.80 in.
* Hardware: 2 mm pushrods with snap links, exit slots 0.40 in aft of hinge line.

Wing mounting to fuselage

* Wing saddle width 2.50 in.
* Nylon bolts option: two M4 bolts, centers 1.25 in to each side of fuselage centerline, fore bolt 1.00 in aft of wing LE at fuselage, aft bolt 2.25 in aft of LE.
* Rubber band option: 0.25 in dowels through fuselage sides, front dowel 0.75 in aft of wing LE, rear dowel 2.00 in aft of LE, 1.00 in above fuselage deck.

Tolerances: spar location ±0.03 in, incidence ±0.25°, dihedral tip rise ±0.10 in, aileron depth ±0.10 in.

**11.4.2 Fuselage Geometry and Layout**

* Overall length: 29.0 in nose to tail-post.
* Cross section:
  + Width 2.50 in at wing bay, height 3.00 in.
  + Sides 0.19 in foamboard with 0.25 in balsa doublers in the wing bay (length 8.0 in centered on wing).
* Firewall:
  + Location x = 0.00 in at the nose reference.
  + 1/8 in birch ply, 2.50 in × 2.50 in, epoxy bonded and tri-stock filleted.
  + Motor thrust: 2.0° down and 2.0° right. Shim guide: across 1.00 in mount spacing, offset is 0.035 in.
* Wing position:
  + Wing LE at fuselage: x = 7.00 in from nose.
  + CG target is 28 percent chord = 2.10 in aft of wing LE, so CG at x = 9.10 in from nose.
* Battery bay:
  + Internal space 6.50 in long × 1.90 in wide × 1.20 in tall.
  + Bay center x = 9.50 in, bay span x = 6.25 to 12.75 in. Strap tie-downs at x = 8.75 in and 10.25 in.
* Electronics deck:
  + FC plate 2.50 in × 2.00 in, foam or rubber isolation. Plate center x = 10.50 in, z = mid-height.
  + RX shelf on right side, 1.50 in × 1.00 in, antenna tubes routed aft.
* Servo tray:
  + Elevator and rudder servos side by side, tray center x = 15.00 in, z = mid-height.
  + Cutouts 1.00 in × 0.50 in, horn centers 0.50 in above tray.
* Pushrod exits:
  + Rudder exit on left side, x = 22.00 in, 0.75 in above fuselage bottom.
  + Elevator exit on right side, x = 22.00 in, same height.
* Cooling:
  + Inlet under spinner: 0.75 in × 0.50 in slot.
  + Outlet on fuselage bottom at x = 12.00 in, 1.50 in × 0.75 in.

Tolerances: firewall square ±0.25°, wing LE station ±0.06 in, CG window ±0.25 in after balancing.

**11.4.3 Empennage (Tail) Geometry**

* Horizontal stabilizer:
  + Span 12.0 in, root chord 4.00 in, thickness per foamboard.
  + Elevator chord 1.25 in, hinge gap 0.03 to 0.06 in.
  + Incidence 0.0° relative to fuselage reference.
  + Mount plane located at x = 26.00 in from nose, centered vertically.
* Vertical fin:
  + Root chord 3.50 in, height 5.50 in above fuselage top.
  + Rudder chord 1.50 in.
* Control horns:
  + Elevator and rudder horn hole 0.45 in from hinge line, horn height 0.80 in.
* Tail wheel: optional, 0.75 in wheel on 1.2 mm wire, mount at tail-post.

Tolerances: tail plane squareness to fuselage ±0.25°, incidence ±0.25°, surface chords ±0.10 in.

11.4.4 Control Throws and Linkages

* Elevator throw: ±0.35 in low, ±0.55 in high.
* Aileron throw: ±0.30 in low, ±0.50 in high.
* Rudder throw: ±0.60 in low, ±0.80 in high.
* Exponential: 30 percent initial on all channels.
* Linkages: 2 mm wire or 0.047 in music wire, clevis at horn, Z-bend or ball link at servo. Keep servo arm length 0.50 in.
* Differential aileron: optional, 70 percent down vs up using offset horn or radio mix.

11.4.5 Landing and Gear (Optional)

* Hand launch: grip CG location at fuselage sides.
* Fixed main gear: 2.0 mm music wire, axle center x = 3.50 in from nose, wheel dia 1.75 in, track 6.0 in. Gear block 0.50 in × 0.50 in hardwood epoxied to fuselage bottom with ply doubler 2.0 in × 2.0 in.

11.4.6 Materials and Reinforcements

* Foamboard: 0.19 in common foamboard for skins, wing, and tail.
* Ply: 1/8 in birch ply for firewall and dihedral brace.
* Spruce: 0.25 in × 0.50 in caps for wing spar, 0.25 in tri-stock at firewall joints.
* Reinforcement tape: glass filament tape along wing LE and spar line, two passes each side.
* Glue: hot glue for foam joints, epoxy for firewall, spar, and gear block.

11.4.7 Balance and Setup

* Target CG: 2.10 in aft of wing LE at fuselage, equals x = 9.10 in from nose. Acceptable range 1.90 to 2.30 in.
* Battery placement: adjust within the bay to hit CG without extra ballast.
* Control surface neutral: align to fixed surfaces with straightedge before first power up.
* Incidence check: use incidence gauge or smartphone angle app. Wing +2.0°, tail 0.0°, motor 2.0° down and 2.0° right.

11.4.8 Notes for CAD and Templates

* Use the dimensions above to create flat patterns for the wing panels, tail, and fuselage sides.
* In Fusion 360, set origin at firewall center. X axis along fuselage length, Z axis vertical. Place key construction planes at: x = 7.00 in (wing LE), x = 9.10 in (CG), x = 26.00 in (stab mount).
* For dihedral, create a mid-plane at fuselage center, then rotate each wing panel body by 1.75° about the spar line.

**Phase A — System Design**

**Goal:** Freeze mission, constraints, and performance targets so hardware and geometry are sized correctly.

**Key assumptions**

* AUW: 550–600 g
* Wing: rectangular, 34 in span × 7.5 in chord
* Wing area: about 255 in²
* Aspect ratio: about 4.5
* Wing loading: about 11.1–12.0 oz/ft²
* Estimated stall speed: about 14–15 mph at sea level with CLmax about 1.4
* Dihedral: 3–4 degrees total
* Incidence: about +2 degrees
* Motor thrust: about 400–500 g with 2212 1400 KV on 8×6 E prop and 2S NiMH

**Deliverables**

* System block diagram: RX → FC → ESC and servos, power tree, signal map
* Mass budget and CG budget with battery at CG
* Flight envelope: stall about 14–15 mph, cruise about 18–22 mph

**Easiest free sim**

* **XFLR5** for quick feasibility: pick airfoil, create a 2D polar, then a 3D wing and verify CL at 18–22 mph covers lift for 600 g. Check Cm vs alpha and static margin.  
  Quick check: at 600 g and 255 in² you need CL about 0.35–0.45 in level cruise at 20 mph. If your airfoil and incidence hit that with margin, you are good.

**Phase B — Hardware Design**

**Goal:** Select and validate the power train and electronics, sized to the system targets.

**Selections**

* Motor: 2212 1400 KV BLDC
* Propeller: 8×6 E (start), keep 8×4 on hand for current limiting tests
* ESC: 30 A with 5 V BEC
* Battery: 7.2 V 3600 mAh NiMH, about 300 g
* Wiring: 12 AWG battery leads, 14 AWG ESC to motor
* Flight controller: STM32 or RP2040 class, IMU like MPU6050 or ICM-20689
* Receiver: 4 to 6 channels

**Bench tests to pass**

* WOT current on 8×6 E should land about 12–16 A on fresh NiMH
* 60 s WOT thermal check: motor and ESC hot but safe to touch
* BEC sag test: full-stick servo sweeps with motor at 50 percent, FC stays powered

**Easiest free sim**

* Use **XFLR5 drag estimates** to guess cruise power, then verify on the bench with a wattmeter. For full aircraft drag trends, you can move up to OpenVSP later, but XFLR5 plus the bench is the fastest free loop.

**Phase C — Mechanical and Airframe Design**

**Goal:** Lock geometry, structure, and control surfaces so the aircraft is inherently stable and trainer-like.

**Wing**

* Planform: rectangular, 34 in span × 7.5 in chord, area about 255 in²
* Dihedral: 3.5 degrees total. Tip rise per panel about 0.5 in over 17 in half-span
* Washout: about 1–2 degrees
* Ailerons: 20–25 percent chord, 10–12 in span per panel, deflection about ±0.30 to ±0.50 in start

**Tail sizing**  
Use standard tail volume coefficients for trainers and your short moment arm.

* Horizontal tail moment arm l\_t: about 16 in from wing MAC quarter to tail MAC quarter
* Horizontal tail volume V\_h: about 0.55
* Horizontal tail area S\_h: V\_h × S × c̄ ÷ l\_t  
  S ≈ 255 in², c̄ ≈ 7.5 in, l\_t ≈ 16 in → **S\_h ≈ 66 in²**  
  Practical layout: span 18–20 in, chord about 3.3–3.7 in
* Vertical tail volume V\_v: about 0.035 with l\_v ≈ 16 in  
  S\_v ≈ V\_v × S × b ÷ l\_v with b = 34 in → **S\_v ≈ 19 in²**  
  Practical layout: fin height about 6.5 in, root chord about 3.5 in, tip chord about 2.5 in

**Incidences and thrust**

* Wing incidence about +2 degrees
* Motor about 2 degrees down and about 2 degrees right
* CG at 25–30 percent chord, start at about 28 percent

**Control throws to start**

* Elevator: ±0.35 in low, ±0.55 in high
* Aileron: ±0.30 in low, ±0.50 in high
* Rudder: ±0.60 to ±0.80 in
* Expo: about 30 percent on all

**Easiest free sim**

* **XFLR5 full model**: wing plus tail in the 3D module. Set incidences and l\_t. Check static margin about 5–10 percent and verify Cm crosses zero near your trimmed CL. This is the quickest free way to validate stability before cutting foam.

Optional next step if you want a geometry-based solver:

* **OpenVSP + VSPAERO**: build quick solids, run alpha sweep to confirm lift and pitching moment trends match your XFLR5 expectations.

**Phase D — Software and Controls**

**Goal:** Implement a simple, robust control stack with stabilized mode and safe failsafe.

**Architecture**

* Modes: manual passthrough, stabilized auto-level
* Sensors: gyro and accel for angle rates and attitude estimate. Optional baro for smoothing throttle
* Loop rate: 50–100 Hz
* Failsafe: throttle cut and neutral surfaces if RX lost for more than 1 s
* Telemetry: UART text stream for gyro, attitude, PWM outputs, supply voltage

**Tuning sequence**

1. Manual mode ground test: verify directions, center trims, and end points
2. Stabilized mode on bench: check level reference and leveling direction
3. Taxi or hand-held thrust test: verify no oscillation at half throttle
4. First flight: low gain, trim straight and level, then increase gains until crisp without oscillation

**Easiest free sim**

* For controls feel and pilot practice, a general RC sim is fine, but it will not use your airframe.
* If you want to fly your airframe virtually with your mass and geometry, the free path is:  
  **JSBSim** flight dynamics model with your S, b, c̄, tail sizes, and moments, optionally visualized in **FlightGear**. This is more effort than XFLR5 but lets you test trim speed, rotation, and stall cues before the maiden.

**Minimal free simulation workflow to keep it simple**

1. **XFLR5** only
   * Choose airfoil and generate 2D polars at Reynolds about 150k to 250k
   * Build 3D wing at 34 × 7.5 in with incidence about +2 degrees
   * Add tail at the moment arm above, size to S\_h ≈ 66 in² and S\_v ≈ 19 in²
   * Set CG to about 28 percent chord, check static margin 5–10 percent
   * Verify CL required at 18–22 mph is in a low drag region and that Cm vs alpha is gently stable
2. **Optional** OpenVSP + VSPAERO
   * Recreate the geometry in minutes, run an alpha sweep, confirm lift and pitching moment curves look similar to XFLR5
3. **Optional** JSBSim + FlightGear
   * Enter the same geometry, masses, and control limits, then test takeoff, climb, and approach speeds

A collage of model airplanes

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