



CENTIMETRE GUIDANCE

IR ACQUISITION, LASER DESIGNATION, DIP-SITE POSITIONING AND HOVER HEIGHT

Technical brief · fire.ecopter.ai · sar.ecopter.ai · CONFIDENTIAL

How a target found by the surveyor's thermal camera becomes a GPS point on the 3D local map, how the aircraft is brought to it, and how the last metres are closed when a water drop has to land within centimetres: laser designation from the air or from a firefighter on the line, marker-based positioning at the dip pool and the refuelling pad, and a radar altimeter to hold the right height over water and over the fire. Includes a component list and a demonstration-scale build.

01

Why there are two accuracy tiers

Finding a fire and putting water on it are different precision problems. The surveyor's thermal camera, geo-registered through the aircraft's pose onto the terrain model, places a hot spot to 1–3 m. That is plenty to plan a drop, to route an aircraft and to tell the Commander where the fire is. It is not enough to hit a 2 m spot on a fire line next to a crew, to put a bucket into a 6 m pool, or to set down on a pad beside a fuel truck. Those tasks need a second, local, closed-loop layer that does not depend on the accuracy of a map at all — it depends on the aircraft seeing the actual target in front of it.

Tier	Reference	Accuracy	Used for
Planning (global)	Thermal mosaic on the 3D local map, RTK pose	1–3 m	Fire state model, CCR options, routing, drop lines
Navigation (en route)	RTK GNSS + INS, radar altimeter, obstacle layer	2–5 cm horizontal when RTK-fixed; 0.5 m typical	Flying to the drop line, holding points, approaches
Terminal (last 200 m)	What the aircraft sees: laser spot, markers, water surface	centimetres relative to the target	Release point, dip hover, refuel landing, firefighter-designated spots

The rule that follows: the map gets the aircraft close; a sensor on the aircraft that sees the real target does the rest. RTK alone is nearly good enough on paper, but a 320-gallon bucket on a 50 ft long-line does not hang under the GPS antenna, and the water does not land where the bucket is. Terminal guidance has to close the loop on the thing that matters.

02

Target acquisition: from an IR pixel to a point on the map



Figure 1 — acquisition chain. The output is a point with a covariance, not just a point.

1. Detect. Each radiometric frame is thresholded (active flame above ~500 °C, smouldering 150–500 °C, warm body 30–40 °C in SAR mode), blobs are extracted and tracked across frames so a target has a stable identity and a centroid.
2. Ray-cast. The centroid pixel is turned into a ray using the camera's intrinsic calibration and the full pose chain (RTK antenna → IMU → gimbal → camera) at the frame's timestamp. Lever arms and gimbal encoder offsets must be calibrated once on the ground; an uncalibrated 1°

boresight error is 44 m at 2,500 m slant range.

3. Intersect with the 3D local map. The ray is intersected with the terrain surface — the LiDAR DTM where one exists, otherwise the best public elevation model. On a 30° slope a 5 m elevation error moves the intersection by about 3 m along the ground, which is why the LiDAR pre-season survey matters for precision work.
4. Publish. The target is written to the fire state model as a geodetic point (WGS-84 lat/lon, ellipsoidal height — the same datum the RTK system uses, so no geoid conversion creeps in) with a covariance ellipse built from pose, timing and terrain uncertainty. Several frames are averaged; the covariance shrinks as the surveyor's orbit gives parallax.
5. Task. CCR turns the point into a drop line or a search spot and the aircraft navigates to it on RTK. Arriving within 1–3 m is the hand-over condition to terminal guidance.

03

Terminal guidance: closing the last metres

Three mechanisms, chosen by what is at the target. In every case the aircraft carries the same two terminal sensors: a downward gimballed camera that sees in the visible and the near-infrared, and a radar altimeter. What changes is what is on the ground.

Target	Ground side	Aircraft side	What is corrected
Fire spot, unattended	Nothing — the fire is its own beacon	Thermal camera on the suppressor itself tracks the hot spot; wind-drift model	Release point in x, y; release height
Fire spot, designated	Laser designator (handheld on the line, or on the surveyor)	Laser spot tracker: filtered NIR/SWIR camera locks the coded spot	Release point to the spot, not the map
Dip pool	Three markers around the pool, optional designator in the centre	Downward camera solves pose from the markers; radar altimeter holds height	Hover position in x, y; hover height for bucket immersion
Refuelling pad	Three or four markers around the pad; visible for day, IR-lit for night	Same camera and solver	Landing position and heading; descent profile

Laser designation

The principle is the military one: a designator paints the target with a pulsed laser; a tracker on the aircraft sees only that pulse pattern and steers to it. Transposed to a civilian fire line the choices are about wavelength, eye safety and cost.

- Wavelength. 1064 nm is the military standard and gives the longest range, but is not eye-safe and the trackers are export-controlled. 1550 nm is eye-safe at useful powers but needs an InGaAs (SWIR) camera, US$ 5–15 k. 808–850 nm near-infrared is cheap on both ends — a modulated NIR emitter and an ordinary CMOS camera with a bandpass filter — and invisible to the eye, at the cost of range (a few hundred metres, which is exactly the terminal-guidance

range) and of needing eye-safety management at the emitter.

- Coding. The emitter pulses a short code (a few kHz, a unique pattern per designator). The tracker demodulates and ignores anything that is not coded: sun glint, fire, headlamps. The code identifies which designator is asking, so the system knows a drop requested from the line is from an authenticated crew leader and not a stray reflection.
- Through smoke. NIR and SWIR penetrate light smoke better than visible light but not a dense column; the designated-spot mode degrades gracefully to the thermal-tracked mode when the spot is lost, with the last known spot position held for a few seconds.
- Where the designator lives. Three places: on the surveyor (a gimballed emitter that can paint any target the Commander picks on the tablet), in a firefighter's hand on the line, and as a fixed beacon at the dip pool and refuelling pad. The same tracker on the aircraft serves all three.

Marker-based positioning

Where a site is prepared in advance — a dip pool, a fuel pad — markers are cheaper and more precise than a laser. Three markers of known size at surveyed positions around the pool let the downward camera solve the aircraft's full pose relative to the pool (the classic perspective-three-point problem), with centimetre repeatability from a few metres of height. Markers are high-contrast fiducials (AprilTag-class) for daylight, with active IR LEDs behind the pattern for night; retro-reflective tape plus an IR illuminator on the aircraft is a cheaper night option. Four markers add redundancy against one being obscured by spray.

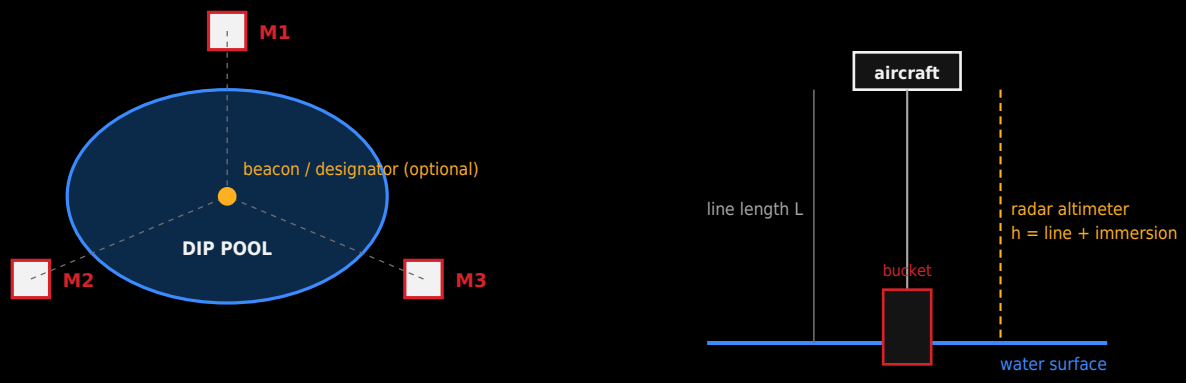


Figure 2 — left: three surveyed markers around the pool give the downward camera a full pose solution; right: the radar altimeter sets hover height so the bucket is immersed to the planned depth.

The dip cycle, step by step

1. Aircraft arrives over the pool on RTK to within 1–3 m at a safe transit height; the downward camera acquires at least three markers.
2. Pose solver computes aircraft position and heading relative to the pool centre; the flight controller nulls the horizontal error to a few centimetres while descending.
3. Radar altimeter reads height above the water surface. Target hover height = long-line length + planned bucket immersion depth (typically 1.0–1.5 m for a full fill) + bucket-swing allowance. The controller holds that height, not a GPS altitude, so pool level, ground settlement and datum

errors are irrelevant.

4. Bucket enters the water; a load cell on the hook or the line angle sensor confirms immersion and fill (the fill curve is distinctive). The system waits for the fill to settle, then climbs.
5. Markers are re-acquired on the climb for a clean departure vector; the aircraft returns to RTK navigation and reports fill mass to CCR.

The same solver, with the markers around the fuel pad, lands the aircraft for refuelling. There the radar altimeter governs the final descent rate, the markers give heading so the aircraft parks with the fuel cap on the truck side, and a fourth marker defines a keep-out box for the truck itself.

04

Hover and release height: what the radar altimeter is for

Barometric and GPS altitude are both altitudes above a datum; a bucket drop cares about height above the ground or the water under the aircraft, which is what a radar altimeter measures directly. Garmin's GRA 55, a certified helicopter unit, listed at about US$ 7 k; UAV-class 24 GHz radar altimeters cost a tenth of that and are adequate for the demonstration.

Phase	What the altimeter sets	Typical values	Notes
Transit over terrain	Minimum height above ground, independent of DTM errors	300–500 ft AGL	Cross-checked against the LiDAR obstacle layer; wires do not show on a radar altimeter
Dip hover	Height above water so the bucket is immersed to the planned depth	line length + 1–1.5 m	Over calm water the return is specular and clean; over chop the controller averages
Water drop	Release height for the required coverage	40–150 ft above the fuel	Low = concentrated, less drift, rotor wash on the fire; high = wider, more drift. Chosen by CCR per target
Refuel landing	Descent profile and touchdown	3 ft/s then 1 ft/s below 10 ft	Markers give x, y, heading; altimeter gives z

Release geometry

Water leaves a bucket as a column that is bent by the aircraft's forward speed and by the wind, and spreads with fall height. The terminal guidance computes the release point backwards from the desired impact point: start at the target (the laser spot or the tracked hot spot), add the ballistic offset for the current ground speed and fall height, add the wind drift for the measured wind at release height, and subtract the bucket's position relative to the aircraft (trail angle at that speed). The result is where the aircraft must be, and at what height, when the valve opens. Everything in that calculation is a sensor reading except the wind, which comes from the aircraft's own drift or from the surveyor.

05

The firefighter's designator: a drop on request

A crew leader on the line often knows better than any sensor which five metres of fireline need water now — a flare-up under a snag, a spot across the handline, a hot edge next to a structure. A handheld coded NIR designator turns that knowledge into a tasking the system can act on in seconds, without a radio call describing a position.

1. The firefighter aims the designator at the spot and holds the trigger. The device pulses its code and sends its own GNSS position and the designated bearing over the crew radio data channel (or LoRa) to the command node.
2. CCR receives a designated-spot request: a point with the designator's identity, the firefighter's position, and a coarse location from the bearing. Both planners treat it as a high-priority tactical option; the referee checks the hard rules — above all, separation between the drop and the crew that asked for it.
3. The Commander sees a one-line card (“Designated drop requested by Crew 3 leader, 40 m from crew, H1 can be there in 90 s”) and approves with one tap, or the request falls inside the pre-approved envelope and executes directly.
4. The suppressor flies to the coarse location on RTK, its tracker acquires the coded spot, and the release point is computed from the spot, not the map. The firefighter keeps the beam on until the drop; releasing the trigger aborts.
5. The thermal camera on the surveyor confirms the effect and the fire state model updates.

Safety rules that are not negotiable: the designator code is bound to a named person and a crew; a drop is never computed closer to the designator's own reported position than a published minimum; the beam power is eye-safe at the emitter or the emitter is only enabled by a trigger that the firefighter must hold; and a spot that cannot be matched to a plausible location on the map (for example, the bearing points into the sky) is rejected.

06

Component list and indicative costs

Component	Demonstration (drones, March 2027)	Operational (Bell 205 fleet)	Indicative cost
RTK GNSS	ArduSimple / u-blox F9P on each aircraft, one base station	Dual-antenna aviation-grade GNSS/INS	US$ 300–800 per drone; US$ 5–20 k per helicopter
Radar altimeter	24 GHz UAV altimeter (0–100 m)	Certified helicopter unit (Garmin GRA 55 class)	US$ 300–1,000; ~US$ 7 k + install
Downward camera	Global-shutter CMOS, NIR-capable, 850 nm bandpass available	Gimballed EO/NIR, SWIR option for 1550 nm	US$ 200–600; US$ 10–40 k
Thermal camera	Radiometric LWIR core on surveyor; small core on suppressors	Cooled MWIR turret on surveyor; LWIR on suppressors	US$ 1–5 k per core; US$ 50–200 k turret
Laser designator	Modulated 850 nm NIR emitter, handheld and on surveyor gimbal	Eye-safe 1550 nm coded designator; or NIR with managed power	US$ 100–500 built; US$ 5–30 k
Markers	AprilTag boards + IR LED backlight, surveyed with RTK	Weatherproof illuminated fiducial panels	US$ 50–200 per set; US$ 2–5 k
Bucket sensing	Load cell on hook, line-angle sensor	Hook load cell, line-angle, valve state	US$ 100–300; US$ 3–10 k
Compute	Jetson Orin class on surveyor; FC + companion on suppressors	Partitioned flight computer + mission computer	in hand; US$ 20–50 k

The demonstration bill of materials for the terminal-guidance layer is a few thousand dollars on top of the aircraft. On the operational aircraft the expensive items are the certified altimeter, the gimbal and the thermal turret, all of which the helicopter needs for its primary mission anyway; the guidance-specific additions (designator tracker, markers, bucket sensing) are small.

07

Demonstration-scale build

Everything above scales to the March 2027 drone demonstration with the same architecture and most of the same code:

- Targets: the candle line. The surveyor's LWIR core detects each candle; the acquisition chain places it on a LiDAR or RTK-surveyed DTM of the demo field.
- Suppressors: X650-class multirotors with a small water bucket on a short line, RTK, a radar or LiDAR altimeter, and a downward NIR camera.

- Designation: a handheld 850 nm modulated emitter built on a microcontroller; the suppressor's downward camera with an 850 nm bandpass filter demodulates the code and steers to the spot. One candle is lit after the plan is approved and is designated by hand to show the request path.
- Dip site: a stock tank with three AprilTag markers on stands; the suppressor hovers on the marker solution, dips on the altimeter, and climbs.
- Pad: a landing mat with four markers for the “refuel” (battery swap) stop.
- Metrics to record: impact error of each drop against the designated or detected target (measured with a thermal camera and a ground-truth RTK point), dip hover position and height error, time from designation to drop. These are the numbers the agencies will ask for, and they are the same numbers that will be measured on the helicopter.

Sources for product figures: Garmin GRA 55 radar altimeter (Garmin press material, ~US$ 7 k package at launch; current dealer pricing varies); u-blox ZED-F9P / ArduSimple RTK modules (public pricing); AprilTag fiducial system (University of Michigan, open source). Other costs are engineering estimates for budgeting and should be quoted before procurement.