

Ballast

A rugged handheld inventory scanner for warehouse crews — a shock structure first, and a computer second.

2D IMAGER SLATE / BASE VARIANT
PROGRAM DOCUMENT / 2026

THE DEVICE IN ONE BREATH

A purpose-built scanning tool whose enclosure is engineered, not styled.

A picker walks aisles, pulls a trigger, reads a label, keys a count, and moves on — one-handed, gloved, for a twelve-hour shift. When a pallet shifts and the device hits concrete, it survives. Every surface here earns its shape from grip, drop, seal, or scan. Nothing is decorative.

The bar is the enterprise tool a fleet manager buys twenty-five thousand of and never thinks about again, because it just works. This book carries the whole program — the industrial design, the human-factors argument in real units, the technical specification, and the cost and manufacturing case — as one designed object.

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A NOTE ON THE NUMBERS

Every load-bearing figure in this book traces to its engineering source. Where a claim carries risk — the drop rating, the ingress protection, the shift battery — the language is deliberately exact and is not tightened for effect.

Design story & form language

Three form moves, in priority order: the wedge, the scan brow, the waist. Read together they say one thing – this is a tool that was drawn by an engineer who respected the user's shift.

THE THESIS

Shock structure first. Computer second.

The device reads as one continuous polymer core with four elastomer corners that are visibly added armor — a two-material honesty, not a painted-on look. You can see, holding it, where the energy goes.

It is not a smartphone that got a rubber case. Where the category leaders sit, we differ on a cleaner shock-corner geometry and a grip cross-section tuned to the gloved hand — and both are argued downstream in millimeters, not adjectives.

WHAT THE FORM REFUSES

No chrome. No gloss accents. No faux-carbon texture. No aggressive facets. No unnecessary parting-line drama. Surfaces are matte, radii are generous and consistent, and every visible screw, seam, and boss has a stated reason.

1

The wedge

Not a flat slab. In profile a shallow wedge — thicker at the top where the scan engine, exit window, and antenna live (22 mm), tapering to 15 mm at the display bottom. Mass sits where the window aims forward; the taper nudges the screen toward the eye.

2

The scan brow

The top face angles forward ~15° into a distinct brow that houses the imager window behind a recessed protective ledge. It is the one place the form is allowed to be assertive: it signals *this end points at the barcode* — and on a face-down drop, the brow ledge hits before the glass.

3

The waist

The mid-body pinches inward on both long sides — a shallow concave scallop — so the fingers wrap a narrower cross-section (62 mm) than the display width (78 mm). It is what makes a five-inch device still feel *held* rather than gripped-around.



PLATE 01 — REAR

Acoustic vent, dovetail accessory rail, dual-latch battery door, and the gold-plated pogo dock array. The two-material honesty reads at a glance: hard graphite body, near-black elastomer armor.

DESIGN STORY

THE LOAD PATH

Drop energy travels corner, to shell, to frame, to distributed — never corner to PCB.

INNER FRAME

Die-cast magnesium AZ91D — the structural spine the PCB, display, and battery bay mount to. Category-correct stiffness per gram, so the board never flexes in a drop.

CORNER ARMOR

TPU bumpers stand 3 mm proud of the hard shell — that standoff is the crush stroke. Across the drop-orientation set, elastomer touches concrete first, never polymer, never glass.

OUTER HOUSING

20% glass-filled polycarbonate, two shells on a single perimeter parting line. Stiff at the seal lines; tough enough to yield before it shatters.

PERIMETER SEAL

One continuous liquid-silicone gasket, an unbroken loop captured in a machined gland and compressed by eight captive Torx-plus fasteners. One seal is the whole ingress game.

FEWER HOLES, FEWER FAILURE POINTS

Every opening in a sealed device is a seam that can leak. The design has exactly one external port.

A single USB-C sits behind a captive, tethered plug in an O-ring gland. Everything else is contactless: charging and data run through the pogo-pin dock on the lower rear, so the primary daily interface — drop into cradle — is free of any openable door.

The battery is user-removable and hot-swappable behind its own captive dual-latch door with its own gasket, so a shift-change swap never breaches the main enclosure seal.

Two latches, so a single knock can't pop it; latches recessed, so a drop lands on bumper.

Speaker and mic sit behind acoustic membrane vents — ePTFE that passes sound and pressure but blocks water and dust. No open grille anywhere on the device.

The result is a sealed core that stays sealed through the one operation a fleet performs a hundred times a day.

ONE ENCLOSURE, TWO OPTICS

Both the base 2D imager and the long-range variant exit through the *same brow window*, pull the *same trigger*, and land on the *same board connector*. The window is sized for the larger module's field of view; the base unit simply under-fills it.

WHAT A VARIANT CHANGE COSTS

One module

Swapping optics is a module change on the line, not a re-architecture. If the program later names a specific engine, the enclosure was purpose-built to accept a range behind that common window — a swap, not a redesign.

The device, all ways

Five frames, each captioned with what it proves. A product is only as honest as the angle you are afraid to show — so here is the hand, the hip, and the live screen alongside the studio shot.

PLATE 02 — IN THE HAND

Held one-handed, gloved, wrist neutral.

The whole ergonomic case, made visible. An insulated freezer glove closes a secure wrap around the 62 mm waist; the thumb falls naturally to the front scan key and the keypad below. This is the large-hand-in-a-bulky-glove governing case — and it still lands one key, not two.

GOVERNING CASE

95th-percentile male hand · Thinsulate-class glove



PLATE 03 - THE CARRY STORY

Seated in the nylon hip holster on a work belt. A sprung retention catch grabs the body so a one-handed draw and re-seat works by feel; the dovetail rail (rear) is the single interface the clip, holster, hand strap, and pistol grip all share.



PLATE 04 - THE LIVE SCREEN

Scan, then key a count - the core loop, thousands of times a shift. The physical keypad carries the numbers; touch carries navigation and confirm. At ≥ 600 nits, optically bonded and AR-coated, the screen reads at a sunlit dock.

Human factors, in real units

“Ergonomic” without a named population is the failure this program forbids. Every number below is anchored to a hand – the fifth-percentile female bare hand to the ninety-fifth-percentile male insulated hand – and a control set that serves both ends serves everyone between.

THE CRUX OF THE WHOLE ARGUMENT

Two hand states control two different decisions.

SMALL & THIN-GLOVED

A picker in a 13-gauge nitrile knit glove – the warehouse default – is close to the bare hand dimension. This is the governing case for **reach and target acquisition**: the smallest user must still reach every control.

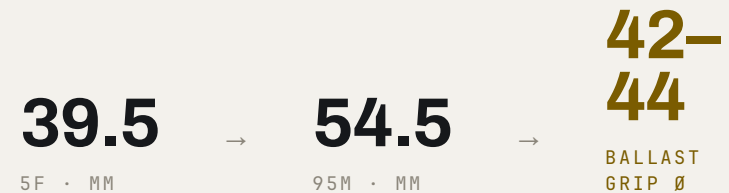
LARGE & INSULATED

A picker in a Thinsulate freezer glove adds real bulk. This is the governing case for **grip span, key pitch, and clearance**: the largest hand in the bulkiest glove must still wrap the grip and land one key.

The waist is set at **62 mm across the grip faces** against a depth of 17–18 mm and a concave scallop. It is not chosen; it is earned. The number holds the whole envelope in a secure grip – narrower would flatter the small gloved hand but feel pinched and unstable in the large bare hand, and it would steal the volume the battery and frame need.

THE LOAD-BEARING FIGURE

Hand Grip Diameter – the circle a closed hand grips comfortably – is what a hand wrapping the waist actually experiences. The comfortable band runs from the smallest to the largest hand:



The functional grip diameter the hand experiences at the 62 mm waist is **~42–44 mm bare** – just above the smallest hand's comfortable wrap, well inside the largest. Even the worst case, a large hand in an insulated glove, stays at or under a secure closable diameter.

The numbers that prove it is designed for the gloved hand.

NOT TABLE-STAKES.
THE DIFFERENTIATORS.

3.0_N

TRIGGER ACTUATION

Target, in a 2.8–3.2 N band. Low enough to survive 2,000 pulls a shift, high enough to keep a 2× margin over an accidental fire.

≥50%

DETENT SNAP RATIO

The load-bearing spec. It is what makes the click legible through a nitrile or insulated glove – and what prevents the double-pull.

10.5_{mm}

KEYPAD KEY PITCH

Set by the insulated-gloved thumb – the widest, least precise digit. A molded valley between domed keys sheds the thumb off the neighbor.

45–48%

CENTER OF MASS, FROM BASE

Just below the grip. It drops the wrist's forward-tip corrective torque to near zero – an entire fatigue channel removed by getting balance right.

THE SHIFT, SUMMED

A shift is not twelve hours of grip. It is a cycle repeated hundreds of times – walk, draw, aim, scan, read, key a count, re-holster – with the device in forceful use maybe 10–20% of the time. The hand strap ships *standard*: it takes the device's weight so the grip fully relaxes between reads, converting the carry load from a static hold to near zero. That single decision is why a firm 90A grip and a 360 g device are a shift the hand survives.

FRONT SCAN KEY

≥ 20 × 14 mm, raised proud, ringed by a tactile fence standing 1.5–2 mm proud – the tallest, most prominent feature on the device, found by feel without looking. Twin side keys carry the identical spec, so there is no handedness SKU.

DISPLAY TO EYE

The wedge taper (~2.7°) plus the natural reading carry posture present the screen normal within ~15° of the line of sight – the readable, low-glare band. Honest, and deliberately not over-tilted.

Technical specification

The base 2D-imager slate — the hero variant — with the configurable deltas noted where the platform flexes. Where a claim carries risk, the wording is exact and is not tightened. A spec sheet earns trust by refusing to overclaim.

PHYSICAL & ENVIRONMENTAL

Dimensions

L × W × D

168 × 78 × 22–15 mm

Shallow wedge: 22 mm at the scan brow tapering to 15 mm at the display bottom. Width 78 mm at display, pinching to a 62 mm grip waist. Bumpers stand ~3 mm proud.

Weight

360 g target / 380 g ceiling

Standard battery, 2D base variant. Co-signed by ID and human factors — the render-lock gate. Under the ~400 g all-shift comfort ceiling, with 20 g absorbing production mass creep.

Balance point

45–48% of length, from base

Neutral-hang. Battery mass low-and-centered counterweights the brow, killing forward-tip corrective torque across a shift.

Operating temp.

–20°C to +50°C (–4°F to +122°F)

Cold-store / freezer capable. Category-verified against Zebra TC53 & Datalogic Skorpion X5 vendor specs, 2026-08-23. The -20°C case governs the drop design.

Humidity

5% to 95%, non-condensing

Category-standard band for the sealed rugged class; category-verified, same sources.

COMPUTE, DISPLAY & POWER

Display

5.0" LCD, ≥600 nits, portrait

720×1280 default (1080×1920 optional). Optically bonded; chemically-strengthened aluminosilicate cover glass, AR + oleophobic. Capacitive multi-mode touch: bare / glove / wet. Bonding is also a drop decision — the stack resists glass cracking.

Scan engine — base

2D area imager

Zebra SE4720-class, *representative* of the base-2D class. The specific SKU is the client's open program decision and moves only this line — one enclosure accepts a range behind a common window and trigger.

Connectivity

WiFi 6 / 6E · Bluetooth 5.x · NFC

WiFi 6E + BT ride the QCS-class SoC; NFC for fleet pairing and tap-to-config. Optional 5G / LTE WWAN is a configurable fleet adder.

Battery

20 Wh smart, user-removable, hot-swap

Li-ion. Designed for a full 12-hour shift (varies with use). An internal bridge cell holds the device alive during a swap — zero-downtime fleet on two packs per device, main seal never broken. Charge 0–40°C ambient.

168 mm

LENGTH

62 mm

GRIP WAIST

360 g

TARGET WEIGHT

5.0"

DISPLAY, PORTRAIT

20 Wh

HOT-SWAP PACK

–20→50°C

OPERATING RANGE

Base 2D-imager slate, the hero variant. Configurable deltas — long-range optics, 1080p display, 5G / LTE, XLR mass and boot — are carried on the facing page. One enclosure, honestly configurable.

RUGGEDNESS, STATED EXACTLY

Three claims a spec sheet is tempted to shorten into a lie. Here they stay honest.

DROP

Designed to survive repeated 1.8 m (6 ft) drops to concrete, bare, across the operating temperature range – tested to MIL-STD-810H Method 516.8 Procedure IV; confirmed in DVT drop validation.

Not a certified claim – MIL-STD-810 issues no certificate; the only honest verbs are “tested to” and “compliant with the method.” The -20°C case governs, since modules are least shock-tolerant cold. An optional snap-on boot pushes the claim to the ~2.4 m class.

INGRESS PROTECTION

IP65 and IP68 – dust-tight; sealed against water jets (65) and continuous immersion (68), per IEC 60529.

Two distinct ratings, both carried, never collapsed into one. IP65 = protected against low-pressure jets from any direction; IP68 = protected against continuous immersion beyond 1 m at the specified depth. Independent third-party test is required for the rating claim. The enclosure targets a continuous single-loop LSR gasket seal.

SHIFT BATTERY

20 Wh hot-swap pack – designed for a full 12-hour shift (varies with use); hot-swap for zero-downtime fleet operation.

A designed-to target, not a flat guarantee. Real-world runtime varies with scan intensity, display brightness, and radio use. The 20 Wh bay meets the brief's core 12-hour requirement per the confirmed power budget.

CONFIGURABLE DELTAS

Same enclosure, same trigger, same window. A configuration change, not a second product.

Long-range optics

2D long-range imager (Zebra SE55-class, representative):
~5.6 cm to >12.2 m (40 ft).
For forklift / aisle-runners
reading high-rack pallet labels.

XLR mass

+~20–35 g at the brow; snap-on
boot re-balances and ships
standard if the bare unit
breaches 380 g or CoM > 50%.
Variant honesty: mass sits higher
and forward. Not the hero.

Display option

1080×1920 (+ cost).
720p is the delivered default;
1080p is a live cost lever.

WWAN

5G / LTE.
Fleet-choice adder, not in base.

On the scan engine

The SE4720-class and SE55-class names are **representative of the class**, standing in for the client's still-open scan-engine decision. The enclosure was purpose-built to accept a range behind one window – so naming the final engine is a line change, not a redesign.

THE FACE, SPECIFIED

“Every control is designed to the gloved hand first. The bare hand is the easy case.”

Scan trigger	2.8–3.2 N (target 3.0 N), 1.2–1.5 mm travel, snap ratio $\geq 50\%$ Snap ratio is the load-bearing spec – legible click through nitrile or insulated glove, no double-pull. Twin side keys carry the identical spec: no handedness SKU.
Front scan key	$\geq 20 \times 14$ mm , raised proud, ringed by a 1.5–2 mm tactile fence Sized for the insulated-glove contact patch. The tallest, most prominent feature – found by feel, without looking.
Keypad	Physical numeric, 4-row block , ≥ 10.5 mm pitch, ≥ 3 mm valley, domed & backlit, home-key nib Pitch and molded valley set by the insulated-gloved thumb. The 4-row layout holds length at 168 mm while keeping every key inside the smallest hand's no-regrip thumb arc.
Glove operability	Nitrile knit → insulated freezer glove Whole control set designed to the 5th-%ile-female → 95th-%ile-male hand range. Smallest bare hand reaches every control; largest insulated hand lands one key, not two.
Grip durometer	Single TPU Shore 90A (corners + grip, one overmold) Firm control feel; the standard hand strap takes the carry load so sustained grip force stays low.

MATERIALS & FINISH

Outer housing 20% glass-filled polycarbonate; inner frame die-cast magnesium AZ91D; corners and grip a single TPU Shore 90A overmold – one durometer, one overmold. Matte texture throughout; a directional micro-rib in the waist scallop adds grip security without a gloss line.

Cost & manufacturing

A real BOM against named suppliers, the make-vs-buy call for every major block, the tooling to cut it, and a per-unit cost anchored to the category's real market price — not floated.

BASIS, STATED ON THE FACE
25,000 UNITS / YEAR · USD
CHINA-PLUS-MEXICO CONTRACT BUILD
NRE AMORTIZED 3-YR / 75,000 UNITS
BASE 2D-IMAGER SLATE · 2026-08-23

THE NUMBER, BUILT FROM THE BLOCKS

Per-unit COGS, ex-works, base 2D slate @ 25k/yr.

BOM – materials	\$241.50
Conversion – assembly, test, IP-seal test, packaging	\$18.00
<i>Direct cost</i>	\$259.50
CM margin + overhead + yield loss (~10% of direct)	\$25.95
<i>Ex-works factory cost, before NRE</i>	\$285.45
NRE amortization (÷ 75k over 3 yr)	\$13.77

Per-unit COGS, ex-works

Single-durometer path. Dual-durometer adds ~\$1/unit all-in – felt in tooling NRE, not piece price.

≈ \$299

HONEST, SO A BAND — NOT ONE FALSE-PRECISE NUMBER

~\$255

LEAN

Merchant-OEM engine, lower SoC tier,
720p, 18 Wh, NRE÷100k

~\$299

CARRY — DELIVERED
DEFAULT

Brand-class engine, QCS6490, 720p,
20 Wh, single-durometer, NRE÷75k

~\$355

RICH

Premium engine, top SoC + 8/128, 1080p,
dual-durometer, NRE÷50k

THE CREDIBILITY CHECK

Enterprise handhelds run a ~3.5–4.5× COGS-to-street multiple. A ~\$299 COGS implies a ~**\$1,047–\$1,347 street price** – landing squarely inside the verified category band (Zebra TC53 \$1,168–\$1,453; Datalogic Skorpion X5 ~\$1,168–\$1,410). Not so low it implies a toy; not so high it prices out. The COGS is anchored to a real market price, not floated.

BOM BY COST BLOCK, LARGEST FIRST

Three modules dominate – scan engine, compute, display. The enclosure, where the clean-sheet ID earns its keep, is a small BOM share but carries most of the tooling NRE.

Compute – QCS-class SoC		\$58.00
Scan engine – 2D, OEM-contracted		\$55.00
Display + touch + optical bond		\$38.00
Main PCBA – fab + SMT		\$30.00
Enclosure – Mg frame, shells, TPU, LSR		\$23.25
Battery – smart hot-swap pack		\$16.00
Keypad + trigger		\$7.75
Sensors + misc		\$7.50
Connectivity – WiFi6 + BT + NFC		\$6.00

BOM subtotal, before conversion & NRE

\$241.50

MAKE-VS-BUY – THE GOVERNING PRINCIPLE

Buy the modules where a merchant market already leads at volume. Make the enclosure – the one place a clean-sheet ID beats the shelf, and the one place the ruggedness claim is won.

MAKE

Enclosure – Mg frame, PC-GF20 shells, TPU overmold, continuous LSR gasket, dock. Off-the-shelf rugged housings don't exist at this form.

MAKE

Keypad + trigger – custom geometry tooled to our layout, built by a keypad house. Make the design; buy the build.

BUY

Scan engine – decades of decode & optics no clean sheet beats. Design the aperture to accept a range.

BUY

Compute silicon – buy the QCS SoC; *integrate on the main PCBA* at 25k/yr to kill the SoM margin.

BUY

Display, battery, radios – Tier-2 panel, pack house on merchant cells, radios ride the SoC.

BUY

Final assembly + test – contract-manufactured, dual-sourced China + Mexico.

ONE-TIME INVESTMENT, AMORTIZED OVER 3 YR

~\$1.03M of tooling, certification, and engineering — \$13.77 a unit at 75,000.

Enclosure tooling Hardened steel, SPI Class 101/103, seal-line tolerance	\$205k
Magnesium die-cast tooling AZ91D HPDC, H13, ~300k-shot asset	\$48k
Certification & compliance MIL-STD-810H, IP65/68, FCC/CE/IC, battery	\$155k
Engineering / DFM / EVT-DVT-PVT	\$350k
Firmware / BSP / scan SDK	\$220k
Fixtures / jigs / calibration rigs	\$55k

Total NRE · single-durometer **~\$1.033M**

Amortization window is the biggest lever — a live slider in the simulator. At ±25,000 (single year) the per-unit NRE would be \$41.32; the model amortizes over the 3-year tool life and states the assumption on its face.

THE LONG-RANGE VARIANT — A DELTA, NOT A RE-PRICE

Shared aperture, shared trigger, shared enclosure means the long-range unit is a module swap on the same line. The delta is almost entirely the engine.

Scan engine (SE55-class, representative)	+\$60–120
Enclosure, tooling, trigger, board	\$0
Optional extra boot (LR runs harder)	+\$3
<i>Long-range COGS at carry</i>	~\$392

LANDED COST — THE CHINA-PLUS-MEXICO HEDGE

Ex-works is the factory gate. Qualify both lines — China as cost-primary, a Mexico line for a North-America-landed, tariff-hedged fleet. Landed COGS at carry: **~\$310–\$325/unit** by line mix and the prevailing duty rate, which is a re-check-at-order item because it moves with policy.

PROTOTYPE TO PRODUCTION

~12–18 months, ID freeze to first production shipment.

A device that must survive a drop, hold a seal, and pass radio cert cannot run to a consumer-gadget timeline. The seal validation and drop campaign are gates, not checkboxes.

0 DFM + design freeze 6–10 WK HF-joint calls lock; detailed mechanical + electrical design; DFM on every made part. Nothing tools until the numbers freeze.	1 Bridge tooling 4–6 WK Aluminum bridge tools for real parts fast; module eval units ordered. Cheap insurance before the \$50k+ steel.	2 EVT 8–12 WK First integrated units. Prove electronics, scan engine, display, radios together. Engine + SoC lead times are the #1 schedule risk – order early.	3 DVT 10–16 WK Production-intent parts off hard tools. The drop campaign, IP65/68 seal validation , and pre-scan cert run here. This is the gate that confirms the 1.8 m claim.	4 Certification 8–14 WK Formal FCC/CE/IC + EMC, IP, full 810H suite, battery. FCC/CE is the largest block – book lab slots early. Budget one re-spin.	5 PVT 6–10 WK Full line at rate on real tools. Prove yield, cycle time, per-unit seal test. Dual-line qualification, China + Mexico.	6 Ramp / MP 4–8 WK First salable units; ramp to the 25k/yr run rate. Component allocation and the second-line qualification set the pace.
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THE THREE LONG POLES

One – the HF-joint design freeze, which gates all tooling. Two – production tool cutting, ~\$1M of tools at 6–10 weeks each, run in parallel. Three – the certification campaign, FCC/CE plus the MIL-STD-810H drop validation. Order the scan engine and the SoC first of all: both run 8–16 weeks at allocation.

12–18

MONTHS · ID FREEZE → FIRST SHIPMENT

Honest, and category-appropriate. The gates that make it longer than a consumer device are exactly the gates that make it a tool a fleet trusts.

A tool drawn by an engineer who respected the user's shift — and a program that told the truth about what it costs and how long it takes to build.

Every load-bearing figure in this book traces to its engineering source, and every claim that carries risk is stated exactly. The drop rating is design-supported and DVT-proven, never certified — because the standard issues no certificate. Ingress is two distinct ratings, both carried. The shift battery is a designed-to target. The scan engines named are representative of their class, holding the place for a decision that is the client's to make. That discipline is not a limitation of the work. It is the work.

THE PROGRAM, IN NUMBERS

360 g

TARGET WEIGHT, 2D BASE

1.8 m

BARE DROP, DESIGN-SUPPORTED

IP65 + IP68

TWO DISTINCT RATINGS

≈ \$299

PER-UNIT COGS, EX-WORKS @ 25K/YR

12–18 mo

ID FREEZE TO FIRST SHIPMENT

BASIS

25,000 units / year · USD · base 2D-imager slate · China-plus-Mexico contract build · NRE amortized over a 3-year, 75,000-unit program life · component prices dated 2026-08-23, re-checked quarterly.