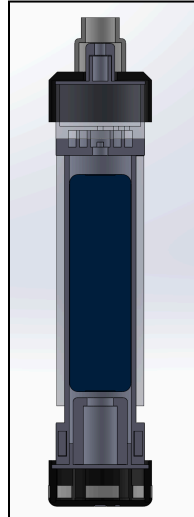


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WiscMed Custom Otoscope Power Handle

(Class 1 Medical Device & IEC60601 Certification)



Problem & Design Objective:

Existing otoscope power handles have several shortcomings that make them poorly suited for the Wispr digital otoscope. Most rely on a rheostat or potentiometer that varies power output rather than providing the full, consistent power the Wispr requires. Many are limited to 2600 mAh lithium-ion batteries, reducing runtime, and they often use proprietary charging docks that force hospitals to purchase dedicated wall-mount chargers. Additionally, they lack any form of battery-life indication, meaning the handle can unexpectedly die during use.

To address these issues, I developed a custom branded power handle with the following requirements:

1. Must charge via USB-C
2. Must accommodate a 3600 mAh lithium-ion battery
3. Must include a top-mounted on/off power button
4. Must incorporate a battery-percentage indicator
5. Must fit within a 1.15 in diameter $\times$ 4.75 in in length cylindrical housing
6. Must be simple to manufacture and cost under \$25 per unit

Challenges:

The first major challenge was mechanical design. The handle consists of a top section that connects to the otoscope head and a bottom section housing the lithium-ion battery. These sections needed to detach and reconnect securely, transfer power safely across the joint, and still feel solid and professional. Creating a compact, durable mechanical and electrical interface between the two required several iterations and careful internal packaging.

The electrical design added another layer of complexity. Supporting USB-C charging and a diffused LED battery-percentage indicator required a custom 0.95-inch circular PCB integrating ISO1008 battery monitoring, a microcontroller, LED drivers, and USB-C power management—all within a highly constrained footprint while maintaining safety and reliability.

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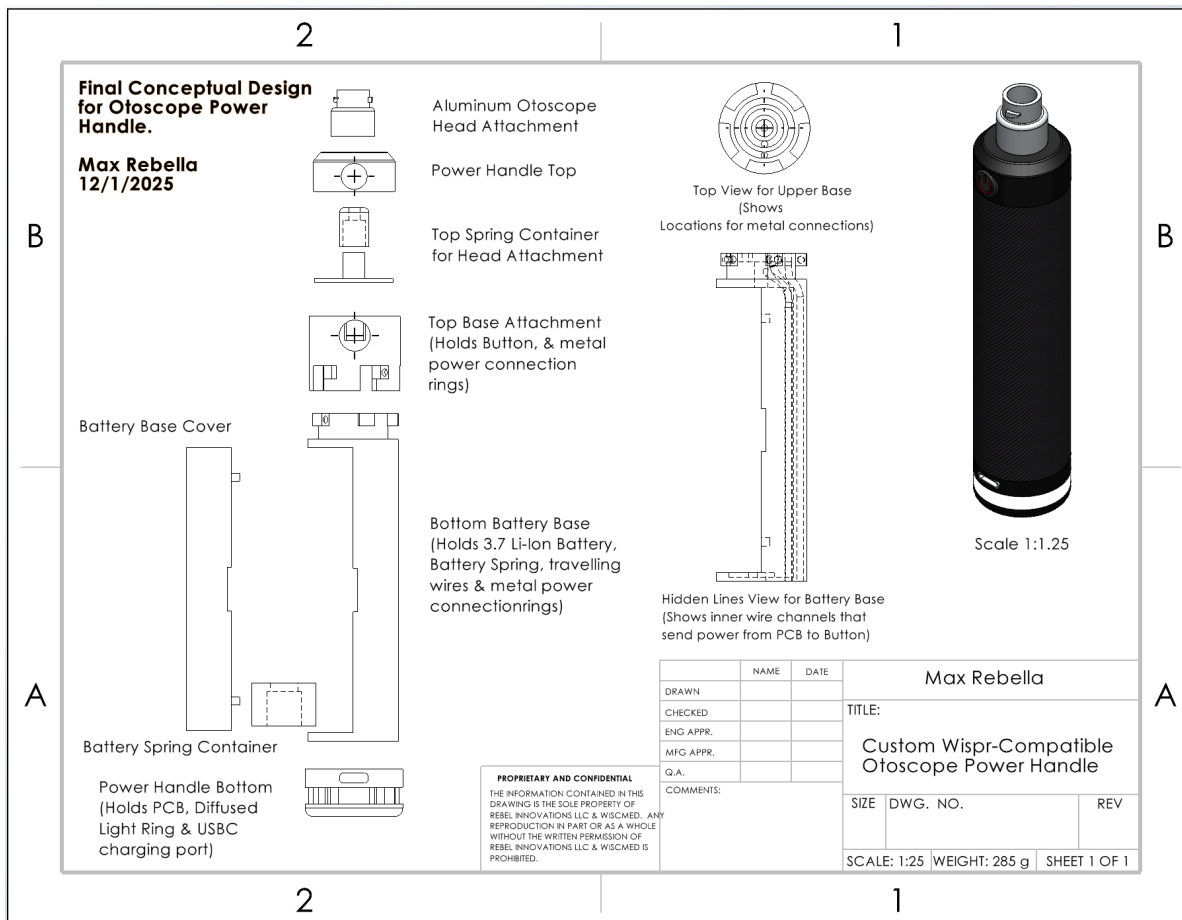
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Solution & Results:

After more than 15 design iterations, I was proud to deliver to WiscMed a mass-manufacturable, FDA and IEC compliant otoscope power handle design incorporating the first microcontroller ever integrated into this type of device, along with full USB-C charging. To enable reliable power and signal transfer between the two separable handle sections, I created a circular attachment system above the battery that routes both power and button-press signals through concentric aluminum or copper contact rings, supported by magnetic and mechanical locking.

I designed the PCB in EasyEDA using a compact 2-layer circular layout. The ATTINY16 microcontroller is programmed via onboard pads and determines battery percentage by sampling voltage at the top and bottom of the lithium-ion cell, driving the RGB LEDs in the diffused light ring accordingly. All firmware was developed in the Arduino environment.

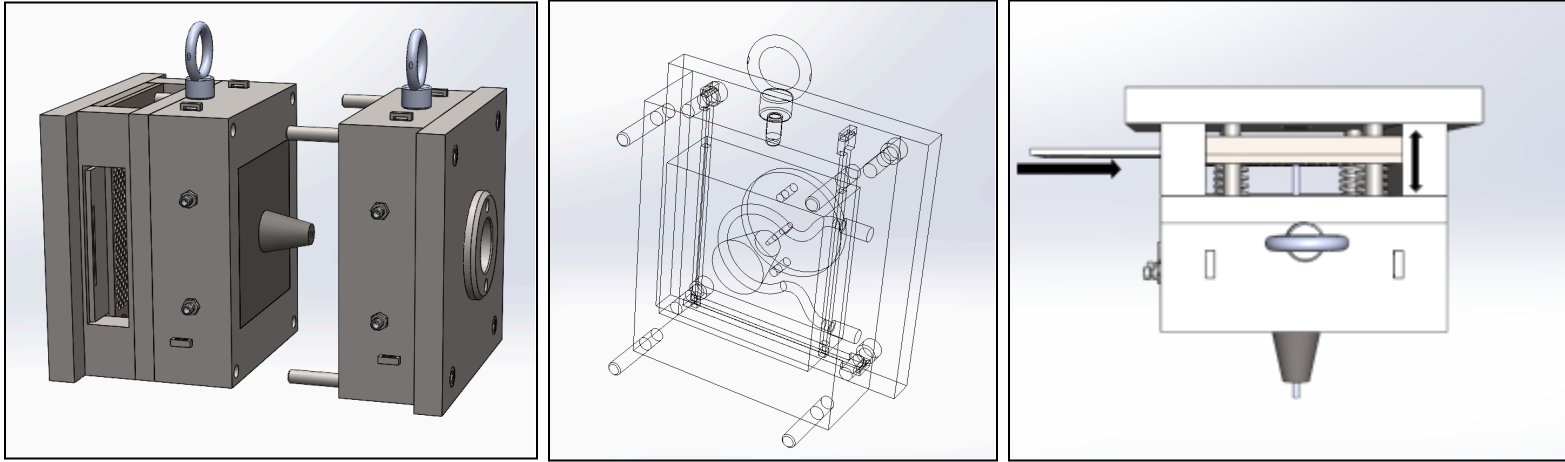
The complete design package—including prototypes, documentation, and compliance requirements—will be transferred to MPR Associates, with the goal of moving into manufacturing and releasing the product as a Wispr accessory before 2027.



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Custom Plastic Injection Mold Base For Efficient Insert Swapping (utility patent pending)



Problem & Design Objective:

In conventional injection molding workflows, each mold insert typically requires its own dedicated mold base. Changing inserts means removing the entire mold assembly from the injection molding machine—a process that often requires crane support and introduces significant downtime. These inefficiencies increase production cost and limit the practicality of medium-volume manufacturing.

To make medium-volume plastic injection molding more affordable and operationally efficient, I designed, manufactured, and am now patenting a new modular mold base system engineered to:

1. Enable rapid insert swapping without removing the mold base from the machine.
2. Securely lock inserts in place while withstanding full clamp forces during operation.
3. Accommodate varied ejector-pin layouts and integrate with hydraulic or mechanical ejection systems.
4. Provide proper gating and flow guidance to ensure material enters the cavity safely and consistently.
5. Maintain structural integrity under clamp pressures exceeding 50,000 lbs and operating temperatures approaching 1,000°C.

Challenges:

A core challenge was ensuring that each mold insert remained completely immobile during injection, where clamp forces exceed 50,000 lbs and molten plastic temperatures approach 1,000°C. Even minor deflection or lateral shift can cause flashing, dimensional errors, or mold damage. To guarantee full rigidity, I designed a system of precision-ground insert-locking pins that engage with machined features on the insert, constraining translation and rotation in all directions while preserving the ability to remove and replace inserts quickly.

An even greater challenge was managing the fact that every insert has a unique ejector-pin layout, making traditional ejector plates incompatible with a modular mold base. To overcome this, I engineered a hydraulic ejection module built directly into the mold base. This module uses a reconfigurable ejector comb—a dense array of hardened pins that slide into the underside of the insert. When the hydraulic cylinder actuates, the comb travels

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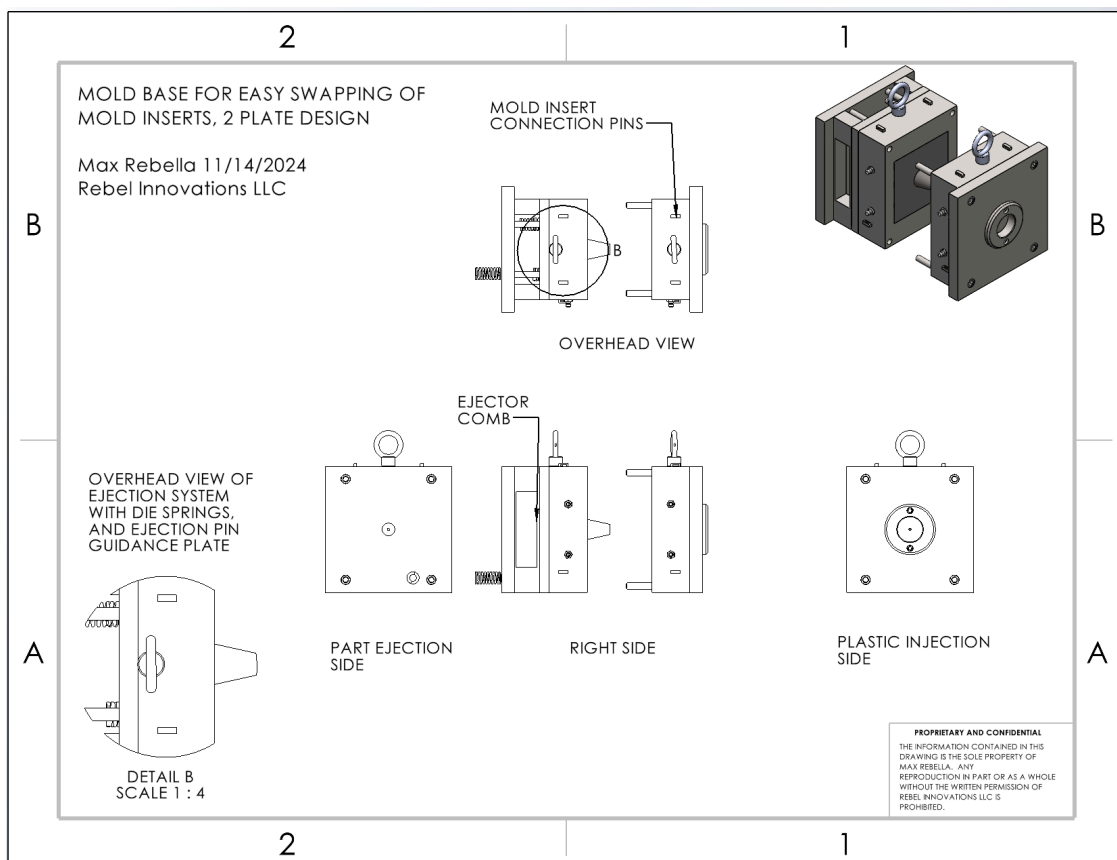
forward to eject the part; when retracted, the comb locks the insert's ejector-pin geometry into a precise, repeatable position. This allows the base to adapt to completely different pin patterns without disassembly.

Together, the insert-locking pins and hydraulic comb system enable secure, high-precision insert mounting and fast changeovers, dramatically improving the efficiency of medium-volume injection molding while maintaining the structural and thermal demands of the process.

Solution & Results:

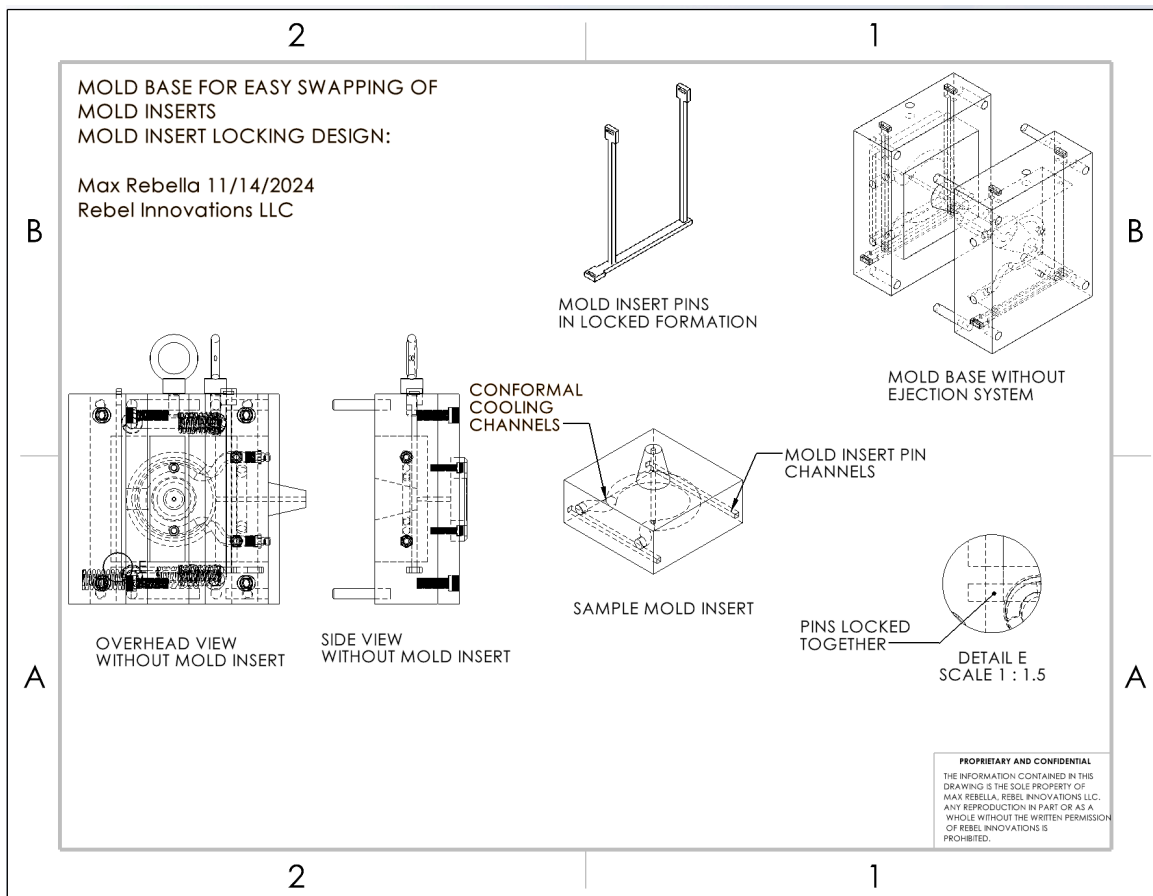
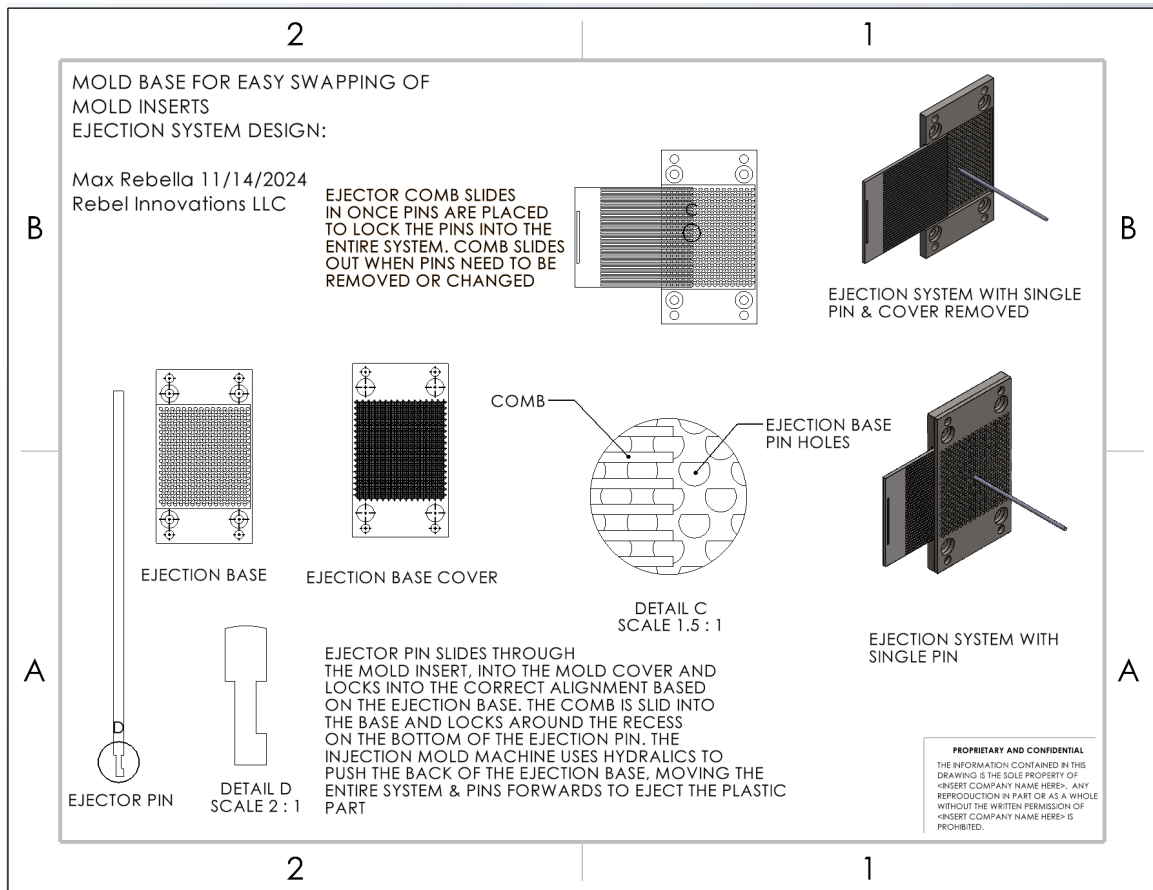
The final design is a modular two-plate mold base centered around two key mechanisms: precision insert-locking pins and a reconfigurable hydraulic ejector system. The base uses 0.25 in² precision-ground locating pins that interface with machined pockets on each insert, fully constraining translation and rotation under clamp loads exceeding 50,000 lbs. Despite this rigidity, the pins can be removed quickly, allowing inserts to be swapped in minutes without removing the mold base from the machine.

To support varied ejector-pin patterns, the mold incorporates a hydraulic ejector module built around a 6×6-inch grid of 760 potential pin locations. Custom ejector pins slide through the cavity side and seat into a comb-style retention mechanism on the ejector plate. When actuated, the comb moves forward as a single unit, ejecting the part while preserving perfect alignment; when retracted, it locks the pins into a stable, repeatable configuration. This eliminates the need for disassembly or plate machining when changing inserts and enables full compatibility with molds that have entirely different ejector layouts. The system maintained structural and thermal stability across high-temperature operating conditions and eliminated flashing and insert shift during testing. Typical insert changeovers—normally 30–60 minutes with full mold removal—were reduced to under five minutes, dramatically improving throughput and maintaining consistent gating and flow characteristics across multiple molds. I am pursuing my second utility patent for this system with Ryan Kromholtz & Manion, S.C., and currently hold a provisional patent, with the full claims and non-provisional application in active development.



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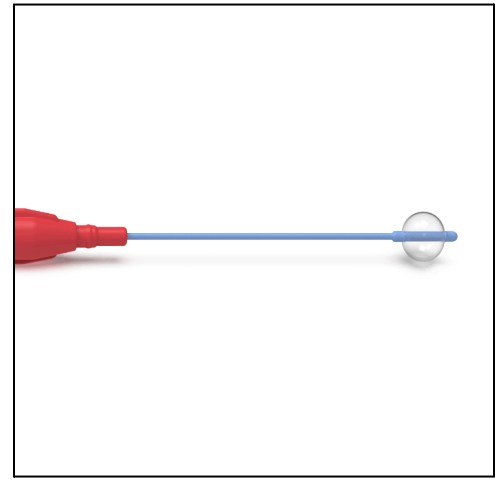
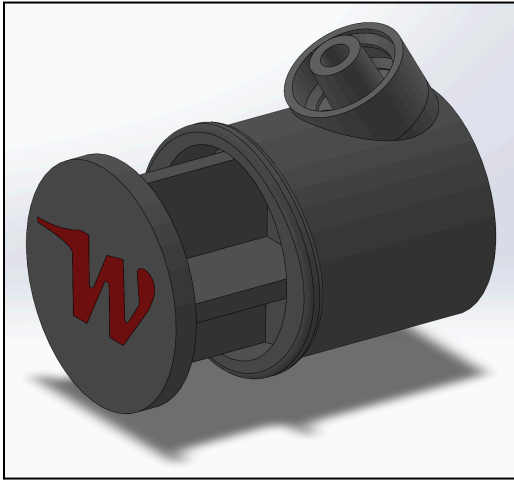


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WiscMed Nasal Foreign Body Extraction Tool

(utility patent pending)



Problem & Design Objective:

Each year in the U.S., roughly 45,000 emergency-room visits involve nasal or ear foreign bodies—most often a child getting a small object, like a bead, stuck in their nose. One challenge WiscMed sales representatives face is price-based pushback when presenting the Wispr digital otoscope against lower-cost alternatives. To create a stronger financial incentive for clinicians to choose the Wispr, I explored opportunities for integrating the device into CPT code assignment and medical billing to provide a clear reimbursement pathway.

Foreign-body extraction already has established CPT codes, meaning successful removal with a Wispr-compatible accessory could qualify for reimbursable billing. With this in mind, I focused on designing an accessory that enables simple, reliable foreign-body extraction, positioning the Wispr for CPT code eligibility and strengthening its economic value to clinicians. In order to viable, I needed to design, test and manufacture a product that:

1. Disposable, inexpensive, and easy to mass-produce
2. Able to interface cleanly with the Wispr's contouring complex geometry and speculum
3. Compatible with the existing KATZ balloon catheter tube (an existing platform of extracting foreign bodies by inflating a small balloon behind the body)
4. Incorporated with WiscMed branding and visual identity

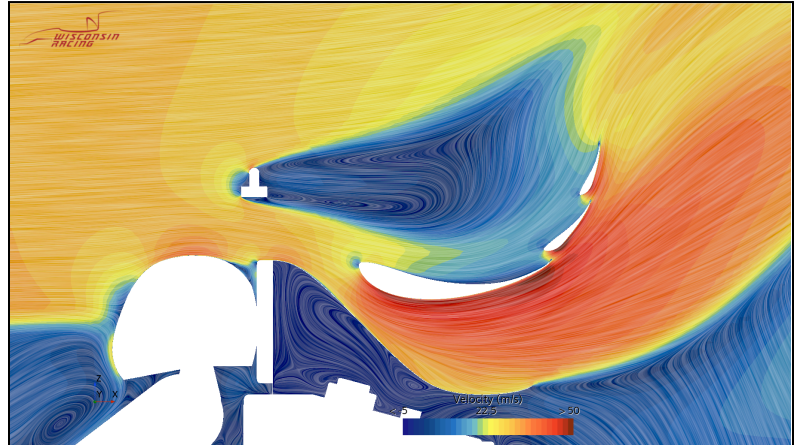
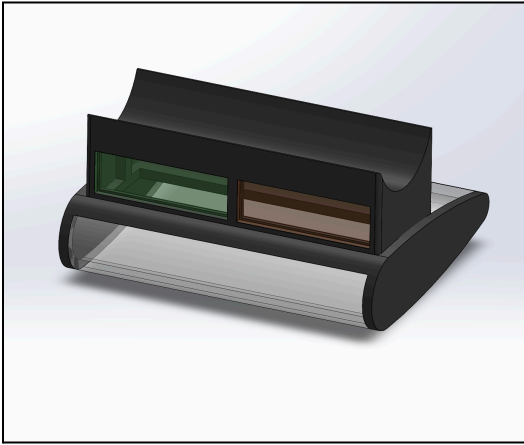
Challenges:

A seemingly simple at first project, several important design challenges appear throughout the process. The syringe-plunger mechanism needed to be fully airtight for the KATZ balloon to inflate, yet early airtight prototypes created too much resistance. By iterating on plunger and tube diameters and replacing the rubber cap with a single O-ring, I achieved a low-resistance, airtight seal. The catheter connection posed another issue: standard luer-lock threads are extremely small, making them difficult to 3D print and costly to injection mold. I resolved this by designing a custom, more manufacturable thread geometry that still formed a reliable, leak-free seal. Finally, the

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Formula SAE Aerodynamic & Electrically Isolated “Ready to Move” Light



Problem & Design Objective:

Formula SAE rules require an illuminated safety light that indicates when the vehicle is energized and capable of motion. Our team’s existing light was a simple rectangular prism—functional, but neither aerodynamic nor visually polished. My objective was to redesign this component into a part that:

1. Fully complied with the 2026 Formula SAE rules (luminous area, placement specifications, and electrical isolation requirements)
2. Housed a self-contained PCB while preventing unwanted color diffusion
3. Minimize weight.
4. Reduce drag from the existing 12.0 N (2.698 lbf)
5. Increase max downforce from the existing 14.5 N (3.260 lbf)
6. Looked clean, modern, and integrated with the car’s hood bar.

Challenges:

I had to coordinate closely with the electrical team to match the internal PCB dimensions with the aerodynamic design and ensure proper isolation. Producing a 3D-printed, truly transparent housing proved difficult—many “clear” filaments still appeared cloudy or accumulated surface imperfections that distorted the light. To fix this, I printed the clear areas using a SLA printer rather than normal resin or FDM prints. Aerodynamically, the ideal profile resembled a small airfoil, but that shape conflicted with the internal packaging needs, manufacturability limits, and aesthetic goals. Balancing all three—electrical requirements, aerodynamic performance, and visual appeal—was the core design challenge.

Solution & Results:

I designed the final housing around a symmetric airfoil profile to minimize form drag while generating a small but measurable amount of downforce. The enclosure was split into two optically isolated chambers: the upper section for the amber/green status LEDs and the lower section for the primary “Ready-to-Move” indicator. This internal partitioning eliminated color bleed and allowed the PCB to be packaged in a compact 12.4-gram assembly.

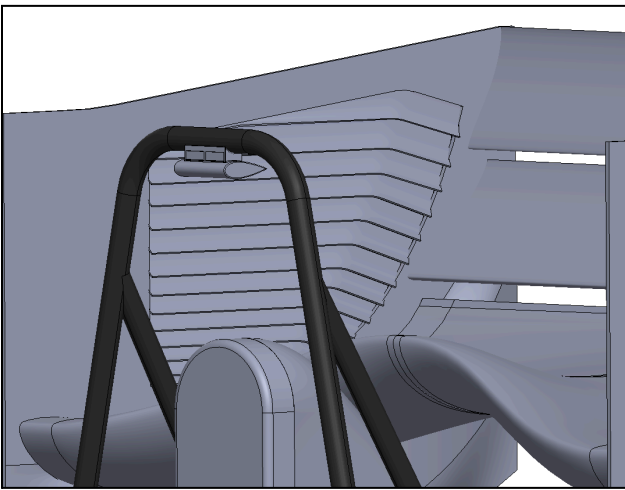
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To quantitatively evaluate aerodynamic performance, I iterated through multiple airfoil geometries using ANSYS Fluent CFD. Each variant was evaluated for drag force, lift/downforce, flow separation behavior, and manufacturability constraints. The main design tradeoff involved balancing the aerodynamic advantages of a larger airfoil cross-section with the need for a visually integrated, rounded form factor compatible with our hood bar and transparent SLA-printed optics.

The finalized design achieved significant performance gains:

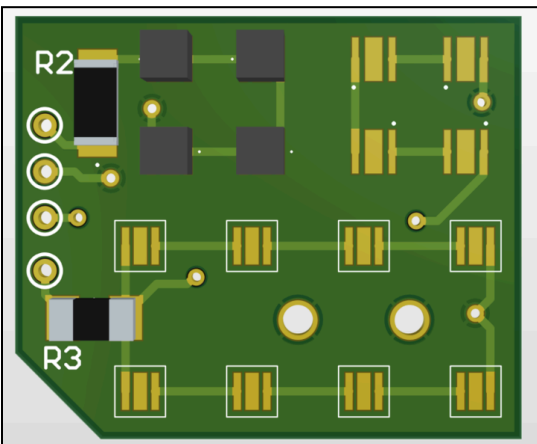
1. Drag reduction: from 12.0 N to 6.4 N
2. Downforce increase: from 14.5 N to 15.8 N
3. Weight reduction: 8.6 grams compared to the previous housing
4. Effective mass reduction at ~88 mph: ~1.43 lb due to improved aero efficiency



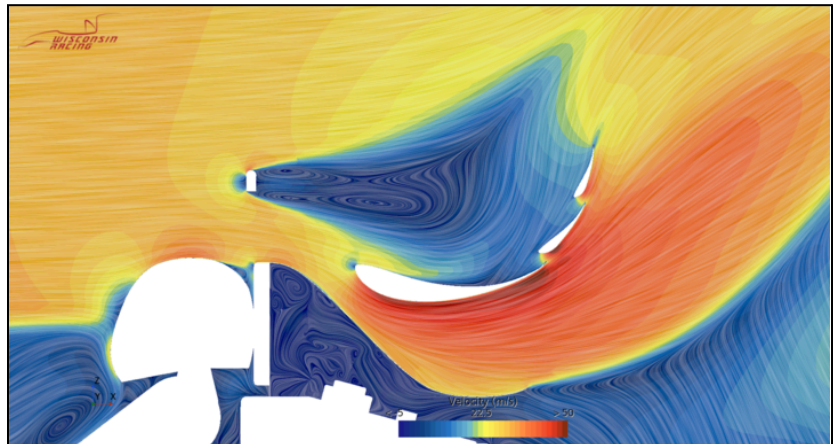
(First Design Integrated Into Full SolidWorks Car Model)



(Original Light: Heavy, Non-Aerodynamic, and Visually Unappealing)



(Final PCB Mock-Up Design. Top Left: Green, Top Right: Amber, Bottom: RML LEDs)

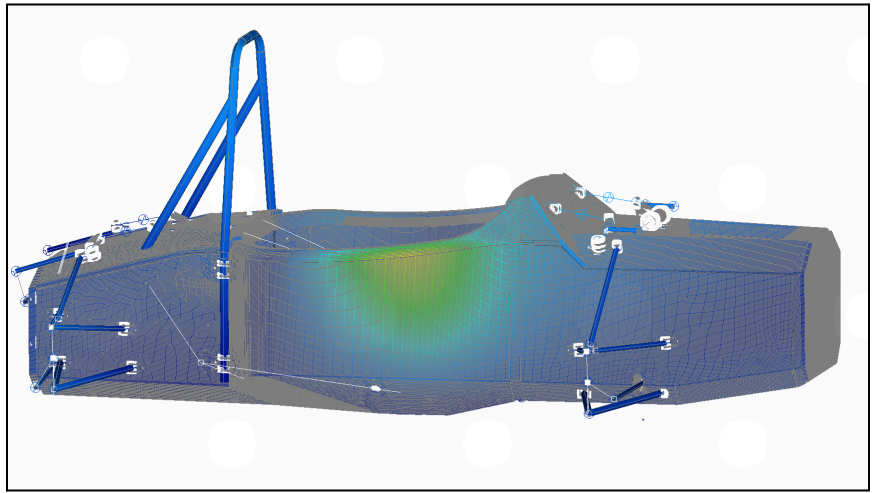
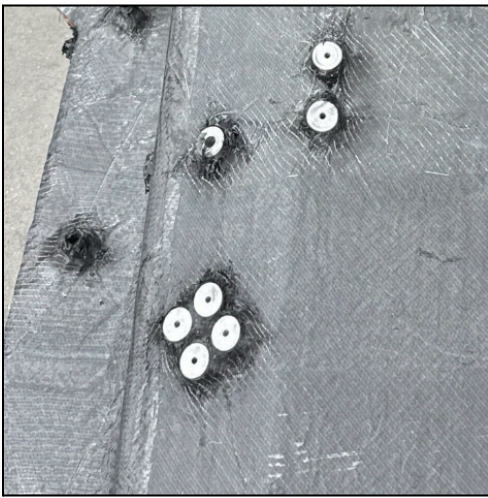


(ANSYS CFD. Velocity Field Section Cut Along the Vehicle Centerline for the Original Light Design)

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Redesign Formula SAE Monocoque-Chassis Mounting Attachments



Problem & Design Objective:

In race car design, every gram matters. Any weight we can remove without compromising structural integrity is free performance. Our car uses a carbon-fiber monocoque that attaches to the chassis through several embedded aluminum mounting blocks. These blocks experience high multi-axis stresses, but in their original form they were completely solid—adding 2.6 pounds to the total weight of the car.

To reduce this weight, I designed a new mounting bracket that:

1. Maintains the required factors of safety under combined axial, shear, torsional, bearing, pull-out, and delamination loads.
2. Remove as much material as possible to minimize weight.
3. Preserves the external geometry needed to interface with the existing monocoque.

Challenges:

The core challenges came from balancing physical manufacturability with the limitations of idealized FEA. Many of the lightest, most optimized geometries simply couldn't be produced on the 3-axis CNC machines available, forcing constant tradeoffs between theoretical performance and what was actually machineable. At the same time, the FEA results often diverged from real-world behavior, requiring us to sort out whether the discrepancies came from experimental variability or from genuine differences in material properties—especially in the carbon fiber layup, epoxy system, and 7075-T6 aluminum. To overcome this, we incorporated experimentally measured properties such as Young's modulus and tensile, compressive, and torsional strengths into the simulations, allowing us to align the digital model with reality and make informed design decisions.

Solution & Results:

The redesign focused on creating a lighter, more efficient aluminum-carbon attachment system while preserving the structural reliability required for suspension and powertrain load transfer. Using Simcenter NASTRAN FEA, I modeled multi-axis load cases—axial, shear, torsional, bearing, and pull-out—based on historical force data and

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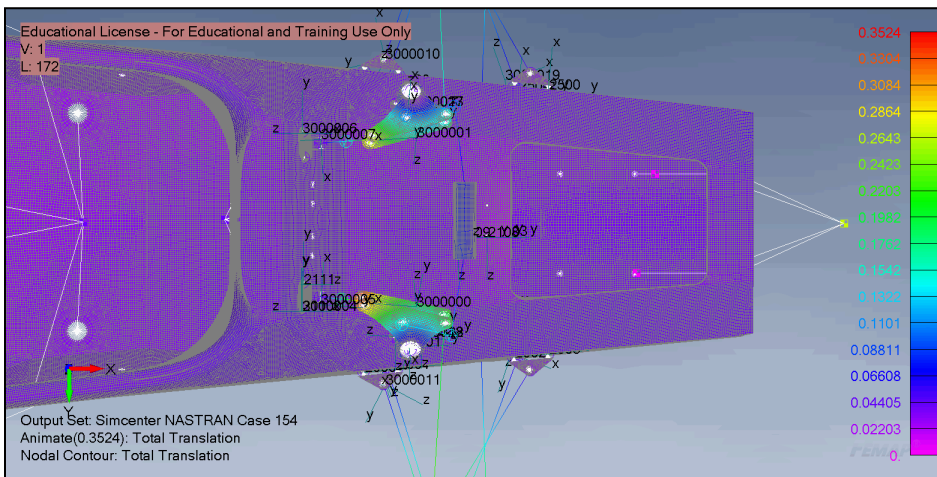
strain-gauge measurements from previous vehicle tests. The analysis examined principal stresses, strain gradients, and torsional stiffness across the bonded joint.

By identifying high- and low-stress regions within the blocks, I was able to strategically remove material through pocketing, rib thinning, and contour optimization without compromising safety factors or risking delamination at the carbon–aluminum interface. This enabled a lighter internal geometry while preserving all external surfaces needed to fit the existing monocoque cavities.

The final design, CNC-machined from 7075-T6 aluminum and bonded to the monocoque with Hysol EA 9396 epoxy, reduced mass by 38% (422 g) while maintaining torsional stiffness within 2% of the original assembly. Static torsion and deflection testing validated the FEA, with measured strains matching predictions within $\pm 7\%$ and stresses remaining well below yield. The result is a lighter, stiffer, and fully manufacturable attachment system that improves overall vehicle performance without sacrificing structural integrity.



(Post-cure monocoque mold with my mounting attachments exposed, prior to adding the steel honeycomb core, surface polishing, and final chassis integration)

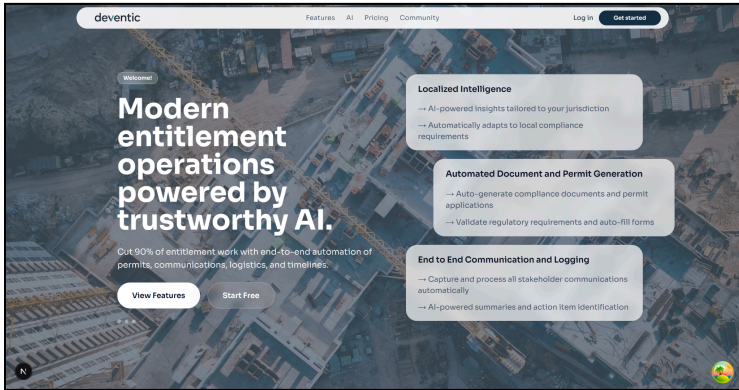


(Simcenter NASTRAN finite-element analysis showing the displacement response of the Formula SAE monocoque, including bonded chassis connection blocks and suspension hardpoints, under the applied front drop-test load case.)

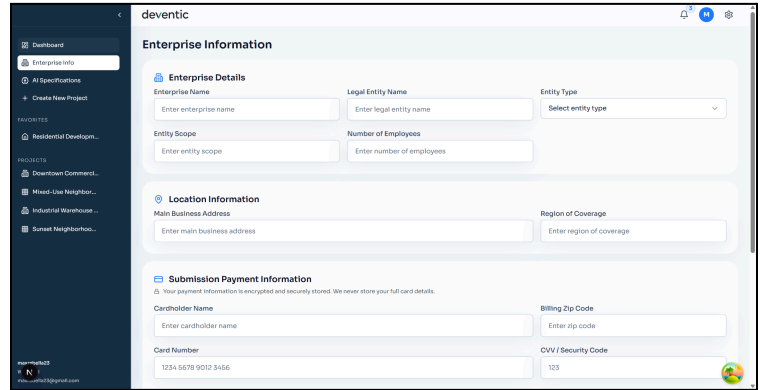
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Entitlement and Pre-Construction Regulatory Automation Software (www.deventic.ai)



(Website Landing Page)



(Platform Enterprise Info Page UI)

Problem & Design Objective:

Entitlement and pre-construction workflows are fragmented, slow, and heavily dependent on manual interpretation of zoning codes, municipal ordinances, permit requirements, and agency timelines. Developers, cities, and consultants waste significant time navigating inconsistent processes, tracking documents, and coordinating stakeholders. The objective was to build an end-to-end platform that fully automates location specific regulatory workflows using AI. To do this, the main requirements were

1. Include an easy to use interface for non-technical users.
2. Use a dynamic, multitenant, location-specific PostgreSQL/PostGIS database (Supabase) for zoning variables, logistics metrics, and document templates.
3. Perform web scraping for permit discovery and document acquisition.
4. Generate regulatory documents using Retrieval-Augmented Generation (RAG).
5. Communicate with HOAs, utility companies, and local governments via integrated email, SMS, and online intake forms.
6. Automatically build, track, and manage project logistics, metrics, and timelines as events occur.

Challenges:

Several technical challenges surfaced during development. Regulatory data was inconsistent across municipalities, so I built a custom ingestion pipeline with normalization, hierarchical chunking, and metadata tagging, enabling accurate RAG retrieval despite varying formats. Ensuring secure multi-tenant storage required a PostgreSQL/PostGIS schema with strict row-level security (RLS), role-based permissions, and spatial indexing to keep enterprises isolated while supporting fast geospatial queries.

Coordinating AI logic with backend workflows was another difficulty. I addressed this by building a FastAPI orchestration layer that handles vector search, OpenAI calls, document generation, and scheduled actions through a state-machine workflow, ensuring predictable outputs across complex tasks.

Municipal data acquisition was unreliable—many portals used irregular HTML, embedded PDFs, or scanned documents. I solved this with custom scrapers, OCR fallbacks, and a standard schema for all extracted data before embedding. Real-time

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communication and UI integration required stable pipes for user interaction. I implemented webhook-based email/SMS messaging and built a frontend that manages authentication, sessions, and live project-state updates while hiding system complexity from the user.

Solution & Results:

I built the platform as a fully integrated AI-driven web application, with the backend running on FastAPI and the frontend deployed through Vercel for fast global routing, edge caching, and continuous deployment. The frontend communicates with the backend through authenticated REST endpoints, providing users with real-time project updates, autogenerated regulatory documents, and a complete audit-ready timeline.

The core engine uses vector embeddings to map zoning codes, permit rules, and municipal requirements into a searchable semantic layer. This enables the system to automatically determine needed permits, generate location-specific documents, and provide regulation-based answers without manual lookup. All actions—document creation, communications, status changes, and workflow steps—are logged and synced to the database in real time.

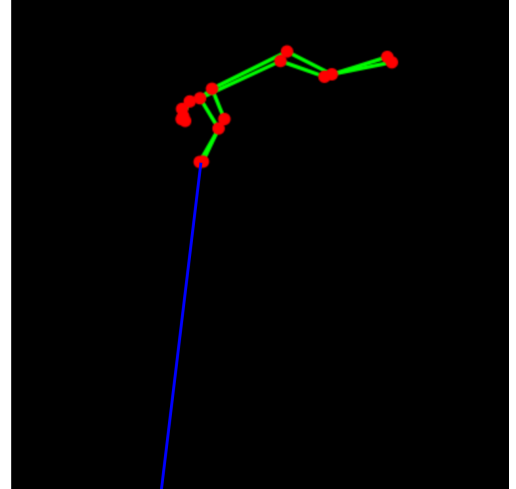
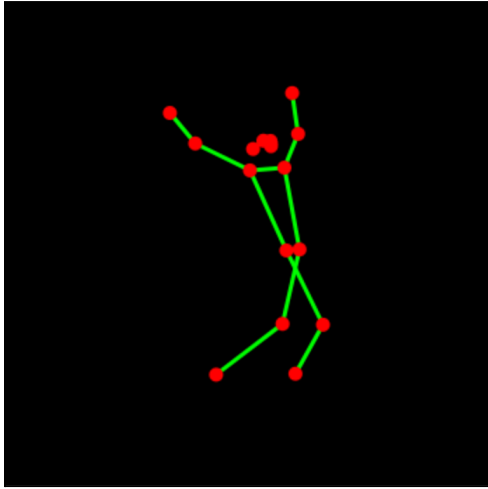
Structured project data is stored in a Supabase-hosted PostgreSQL/PostGIS instance, which handles authentication, row-level security (RLS), and spatial logic for parcels and zoning overlays. Automated email and SMS communication is triggered through backend webhooks, allowing the system to contact utilities, HOAs, and agencies without user intervention.

This was a 9-month long project that really helped build my knowledge of AI, RAG, databases, deployment and hosting operations, and how to write clean code so I don't get lost.

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Pole Vault Computer Vision Tracking Software



Problem & Design Objective:

As a collegiate pole vaulter, translating a fast, complex movement into clear technique adjustments is extremely difficult. To build experience in computer vision and neural networks—and to create a practical analysis tool—I developed a system designed to:

1. Track body joints and pole motion from a single 2D video
2. Extract biomechanical metrics such as angles, velocities, and pole behavior
3. Handle varied recording conditions (lighting, angle, frame rate)
4. Use YOLO-based models for pose and pole detection
5. Train a neural network on elite vaulter datasets to benchmark technique and provide feedback

Challenges

The biggest challenges were keeping the pole consistently detected as it bent, overlapped my body, or moved partially out of frame; dealing with widely varying camera angles and video quality; and making raw keypoints comparable to elite vaulters with different body sizes and vault speeds. I addressed these issues by training a small custom YOLO model on labeled vault clips and adding simple frame-to-frame matching so the system could maintain pole identity even when detections were imperfect. To reduce camera-related inconsistencies, I normalized keypoints using basic body-segment ratios and resampled all videos to a consistent frame rate. Finally, I converted raw coordinates into joint angles, scaled them by body size, and applied a lightweight time-alignment step, producing clean, comparable motion data for evaluating technique against elite movement patterns.

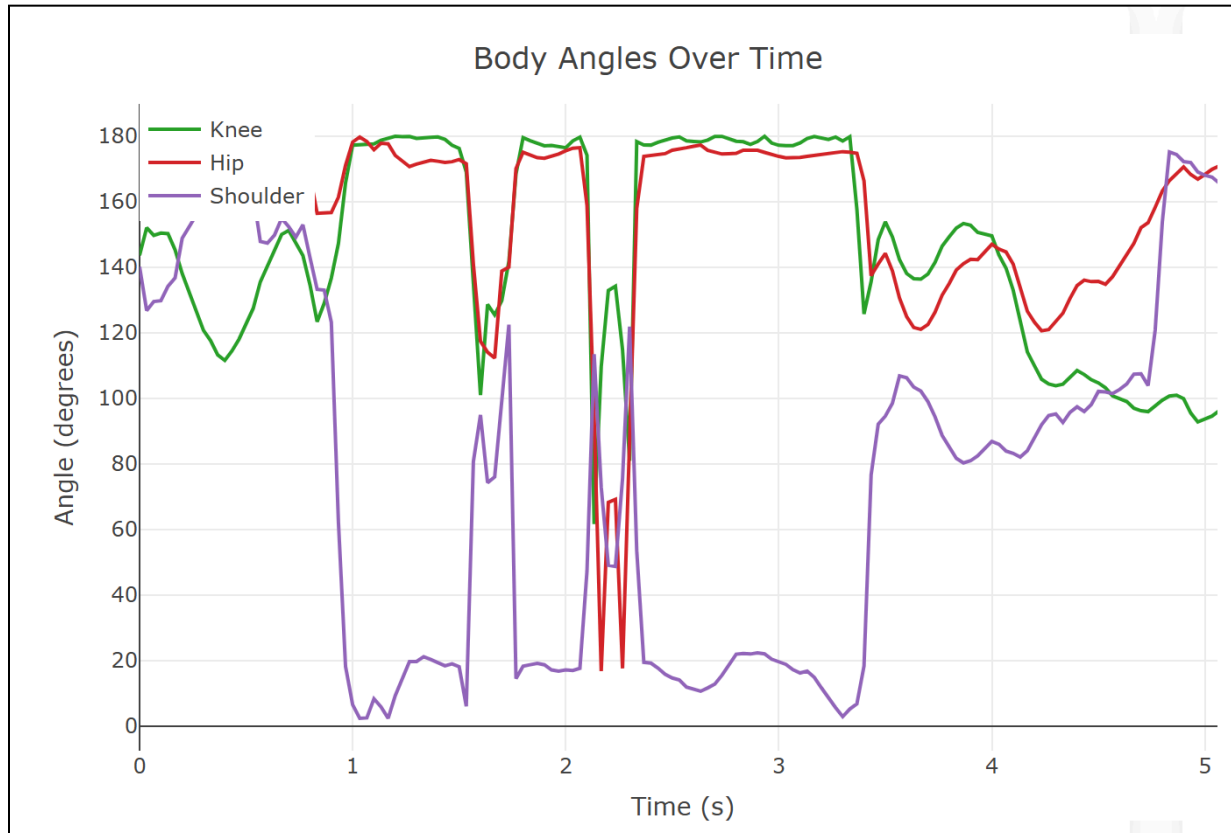
Solution & Results

The final system uses a custom-trained YOLO model to detect body joints and the pole from a single 2D video, generating frame-by-frame keypoints and a stable pole region even under imperfect recording conditions. From these detections, the pipeline computes joint angles, segment velocities, and pole-angle trajectories, all normalized with body-segment ratios and a consistent frame rate so measurements remain reliable across different cameras. A preprocessing module aligns each vault to a shared timeline and automatically identifies phases such as the plant,

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takeoff, swing, and extension. These standardized motion features are fed into a lightweight temporal neural network—implemented and trained in PyTorch—using a curated dataset of elite vaulter clips. The model learns characteristic high-level movement patterns and outputs phase-specific technique comparisons and feedback, allowing the system to evaluate an athlete's performance against elite benchmarks with consistent, interpretable metrics.



(Graph of body angles for an example pole vault over time converting frames to time.

Time 1.00-1.60: Planting of pole. Body in extended position. Still on ground.

Time 1.60-1.80 seconds: Initial Jump. Throwing shoulders, increasing angle.

Time 1.80-2.10: Swing. Long movement extended movements.

Time 2.10-2.35. Curled Position. Body position tight and hard angles.

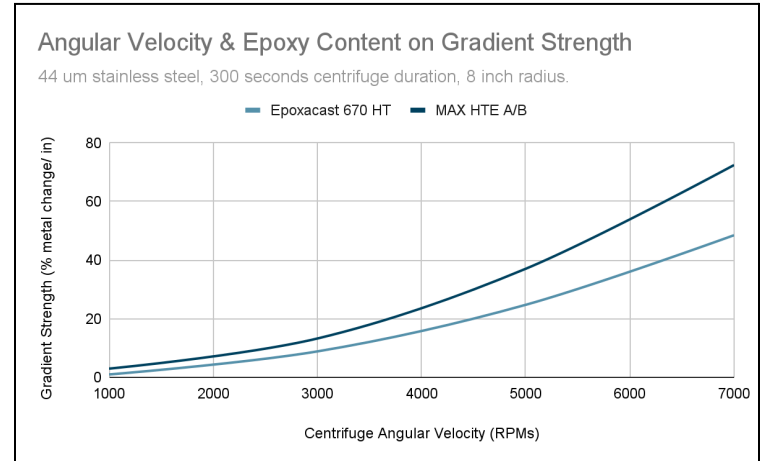
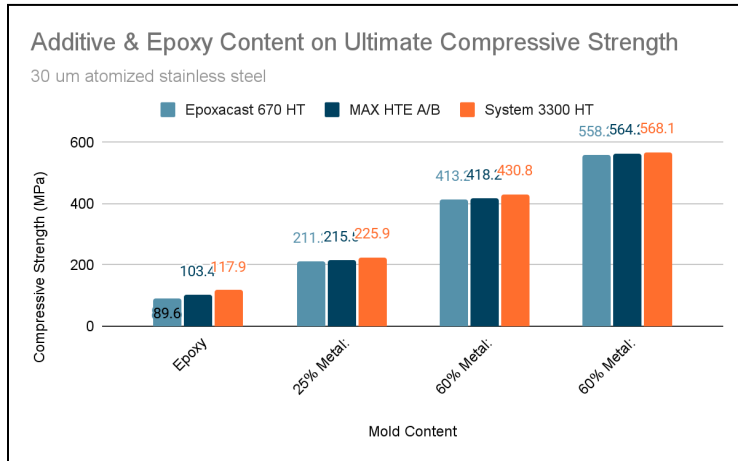
Time 2.35-3.3: Extension up the pole. Body back in extended position.

Time 3.30+: Curl over the pole, vault finished. Start of erratic movement.)

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Low-Cost High-Performance Injection Mold Manufacturing Process Using Targeted Atomized Metal Gradients In An Epoxy Matrix (utility patent pending)



Problem & Design Objective:

A substantial gap exists between inexpensive prototype molds and the costly, labor-intensive steel or aluminum tooling required for production-quality injection molding. While metal molds offer excellent durability and thermal stability, they are slow and expensive to machine, making them impractical for low-volume or iterative workflows. Low-cost alternatives such as SLA resins or carbon-fiber/epoxy composites cannot withstand the heat, pressure, and wear associated with repeated injection cycles.

The objective of this work was to develop and validate a new mold-manufacturing method capable of medium-volume production that:

1. Achieves a service life of up to 75,000 injection cycles
2. Is at least 5× cheaper than conventional metal tooling
3. Supports full 2-plate mold construction
4. Produces parts within medium tolerances consistent with standard injection-molding practices

Challenges:

The mechanical, thermal, and dimensional requirements for a medium-volume, manufacturable mold—combined with strict cost constraints—created several challenges throughout development. Composite molds were the only viable path at this price point, but even the highest-performing epoxies could not survive beyond roughly 10,000 cycles on their own. This drove the need to reinforce the epoxy binder with atomized metal, ceramic, and carbon-fiber additives to achieve the necessary strength, hardness, and thermal stability. However, these additives significantly increased material cost and were limited by the epoxy's structural capacity. To address both issues, I developed a method of concentrating the additives only in regions experiencing the highest mechanical and thermal loads—such as the cavity face—while keeping the remainder of the mold epoxy-dominant. This approach improved performance exactly where it was needed while reducing total additive usage, lowering cost, and enabling the mold to approach medium-volume durability.

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Solution & Results:

This work produced a low-cost mold manufacturing method using a reinforced metal–epoxy composite with centrifugally induced metal gradients cast inside a high-precision 3D-printed shell. Mechanical and thermal testing identified an optimal blend of epoxy, atomized stainless steel, ceramic additives, and carbon fiber that delivered the required stiffness, hardness, and heat resistance while remaining castable. A custom centrifuge concentrated metal near high-load regions—especially the cavity face—creating gradients ranging from under 5% to over 80% metal, improving wear resistance and thermal conduction exactly where needed while keeping material cost low. The SLA-printed mold framework provided 25–40 μm accuracy for the cavity, gates, ejector pin channels, and conformal cooling geometry, eliminating the need for CNC machining. After vacuum degassing and controlled curing, the sacrificial print was dissolved, leaving a finished mold requiring minimal polishing. The resulting molds held $\pm 0.1\text{--}0.2\text{ mm}$ tolerances, achieved up to $3\times$ the hardness and stiffness of unfilled epoxies, and matched aluminum’s thermal behavior in metal-rich regions. Material cost dropped by 60–85%, manufacturing time by roughly 70%, and the molds successfully produced ABS, PP, and medical-grade parts with no degradation across repeated cycles, fully compatible with standard two-plate injection systems.

	Mold Type				
Performance Metric	Best Balance	Higher Temp Plastic Use	Low Cost-Low Cycle	Aluminum 6061-T6	P20 Steel
Material & Conditions	20% MAX HTE 60% Atomized S. Steel, 44 μm 7% Powder Zirconia (ZrO_2), 50 μm 13% 1-3 mm Chopped CF 5000 RPM, 240 seconds (8in radius)	20% MAX HTE 45% Atomized S. Steel, 44 μm 20% Powder Zirconia (ZrO_2), 50 μm 15% 1-3 mm Chopped CF 4000 RPM, 300 seconds (8in radius)	52.5% MAX HTE 40% Atomized S. Steel, 44 μm 7.5% Powder Zirconia (ZrO_2), 50 μm 5000 RPM, 400 seconds (8in radius)	N/A	N/A
Cycle Life	100,000	80,000	15,000	50-100,000	300,000+
Gradient Strength (% change per in)	$\approx 33.4\%$	$\approx 22.5\%$	$\approx 41.4\%$	N/A	N/A
Hardness at Cavity Face (HRC)	≈ 44.3	≈ 36.8	≈ 35.0	≈ 17.0	≈ 32.5
Ultimate Compressive Strength (MPa)	572	528	295	≈ 310	≈ 1050
MAX Injection Temp ($^{\circ}\text{F}$)	475	575	425	≈ 800	≈ 1200
Dimensional Precision (μm)	40	40	35	≈ 25	≈ 15
Average Cost*	\$410	\$520	\$180	$\approx \$2,500$	$\approx \$5,000$

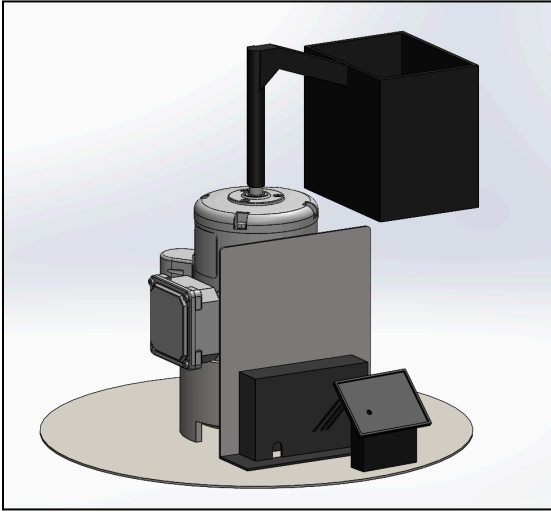
* $\approx$ Machine & Material Cost of a Simple 2 Plate (6inx6inx2.5in) Mold. Overall performance metrics of optimized mold content ratios.

$\approx$ Values are averages, cycle life is an estimation comparing performance specifications to standard molds.

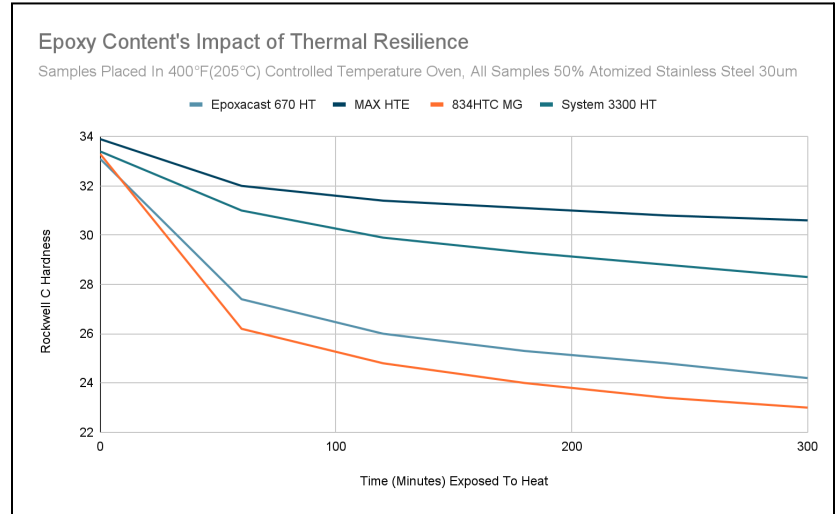
Figure 21. Overall performance metrics of optimized mold content ratios.

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(Design of the custom high-torque centrifuge used to induce material gradients)



(Example of more Validation data comparing epoxy formulations for thermal resilience)

Research Abstract:

Injection molding is an essential component to modern manufacturing, enabling large-scale production of plastic parts across industries ranging from automotive to consumer electronics. While traditional metal molds offer durability and precision, they are expensive, time-consuming to produce, and often limited in complexity. The high initial costs associated with steel and aluminum molds present a significant barrier for companies and individuals seeking scalable plastic manufacturing solutions. Lower-cost alternatives such as 3D printed and composite molds do exist; however, they typically lack the mechanical performance necessary for anything beyond prototyping. Existing research on composite materials for mold fabrication is well-documented, particularly in the study of epoxy additives to enhance mechanical and thermal properties while reducing costs. Despite this, composite molds are still largely limited to low-cycle applications in industry. This research builds upon these advancements to improve mold performance and expand their practical applications.

This research introduces a new mold manufacturing method using an epoxy-metal matrix with performance-enhancing additives to create a targeted gradient of metal within the material. The study is divided into two phases. In the first, the optimal ratio of metal, epoxy, and additives for a high-performing, cost-effective mold is experimentally determined, focusing on how mechanical properties like hardness relate to metal content. The second phase used centrifugal force to create material gradients within the epoxy, applying data from the first phase to track changes in strength and hardness throughout the gradient. This process enables the calculation of metal content at various points to determine the rate of change of the gradient. The mold is shaped by a high-resolution 3D-printed framework that includes advanced features like conformal cooling channels, which are typically expensive and difficult to implement in traditional molds. The results show that this method achieves structural integrity, dimensional accuracy, and thermal efficiency similar to traditional metal molds, while significantly reducing cost and production time. This approach offers a scalable, high-performance, and cost-effective alternative to conventional mold-making techniques, with the potential to disrupt the injection molding industry.