ENGINEERING BRIEF

Rugged Robotics

Forging the Path from Prototype to Production

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Rugged Robotics Forging the Path from Prototype to Production

Contents

Taking robotics to the extreme

When it comes to robotics design and development, the challenges are many. With increasing customer demand for maximum functionality, smaller form factors with reduced weight, improved reliability, lower costs, and the use of the latest technologies as typical requirements—it's imperative that the engineering processes be as forward-thinking and efficient as the products that are being developed.

Embracing the challenges

RoboteX—a Silicon Valley-based company that provides portable robotic rovers for first responders and paramilitary customers—engaged the Acorn team to redesign its original Avatar prototype robot. The original machined aluminum prototype performed well; however, it weighed 35 pounds, was expensive to produce, was not fully functional, and was not as reliable as it needed to be.

The goal was to reduce weight, lower costs, and improve performance. To ensure rapid deployment, ruggedness, performance in extreme conditions, and operator ease-of-use, an optimal balance of weight, battery life, vehicle speed, and package size had to be achieved.

Overall Goals	Performance Requirements	Durability Requirements
Reduce weight	Deploy rapidly	Operate in all types of weather
Lower costs	Operate easily	Endure rugged conditions
Improve performance	Excel in urban and rural locations	Withstand impact when thrown

RoboteX also needed assistance with BOM (bill of material) cost reduction (minimum of 50%), manufacturing planning, worldwide parts sourcing, and ongoing service for a product life cycle of four to five years.

Design goals

With the requirements in hand, we assessed the main engineering and manufacturing challenges. We developed a detailed and realistic set of design goals that encompassed reliability, strength, battery life, and the need to achieve them at the lowest cost possible.

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Concept development

After the high-level goals were agreed to, we began concept development—goals were defined more thoroughly and the initial engineering analysis began. In addition to the primary requirements, we analyzed the chassis, internal components, and drive train, and explored ways of sealing the portable robot to ensure it thrived in harsh conditions. Design for manufacturability and assembly (DFMA)—including worldwide sources for dependable and affordable parts—were also factored into our initial concept analysis and design.

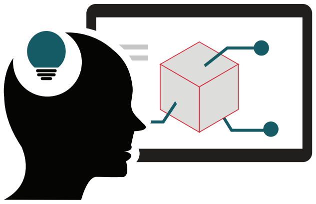
Optimizing weight

For a portable robotics platform, mass is a critical factor. The robot's weight impacts its strength, how rugged the design is to be able to withstand impacts such as five-foot drops, how fast it will move, and its battery life—all factors that are all directly proportional to the system's mass.

To succeed in the field, the Avatar had to weigh less than 25 pounds. Considering the estimated weight of its mandatory components—batteries, motors, electronics, and resilient enclosure—the target weight presented a significant challenge. To reduce weight, we had to think outside the box. For example, metal is the de facto standard for strength; however, we explored innovative plastic-based concepts that saved weight without compromising durability.

Assessing influential factors

Category	Operation Goals
Environmental protection	IP65-rated enclosure
Temperature	Temperature of -21° Celsius to +49° Celsius
Climbing	Front-wheel and rear-wheel drive, CG, traction, and balance requirements; required custom treads using custom molding
Power	Optimum use and preservation of power for speed and ability
Communication	Dependable high-speed video image transfer in harsh environments
Modular payload	PTZ camera, robotic arm, chemical detection and detonation packages
Interface	Simple user interface to minimize learning curve for operation



RoboteX Avatar Tactical Robot
CONCEPT DEVELOPMENT

- Goals and requirements
- Breadboard development
- Component selection
- Packaging options
- Drivetrain analysis
- Thermal modeling
- Materials, process capability, tooling approach
- Manufacturing plan
- Cost analysis
- Down-selection of concepts, layouts, performance metrics

Early and continual analysis

At Acorn, concept analyses and simulations are conducted early and frequently, yielding a wealth of actionable information—data that enables us to continually improve the concept prior to prototyping. As a result, we're able to reduce the number of prototype spins and bring products to market faster.

Conducting analysis early and often

To determine the viability of each concept, we ran rough order of magnitude (ROM) analyses on a series of parameters: gear strength, motor strength, power requirements, weight, vehicle flipping mechanism, heat sinking, power allocation, and heat dissipation. The results enabled us to eliminate concepts that had little—if any—chance of meeting the requirements.

First-order models were developed to quickly evaluate different layouts and component selections. Several thermal models were developed in parallel, enabling expedient decisions to be made on vehicle layout, safe touch-temperature for plastic components (below 60º Celsius), and methods to minimize the 600-watt-per-square-meter effects of the sun in the target desert environment, and survival in harsh ambient conditions. By conducting analyses at multiple levels, we were able to analyze risk-reward trade-offs in detail. Our upfront analysis revealed that 250 watts of power would need to be dissipated inside the IP65-rated enclosure, balanced by heat-sink size and air movers to ensure the robot performed well in rugged environments.

For critical components—such as motors and heat pipes—simplified CFD models were analyzed at the subassembly level to more accurately factor their performance into the overall system model. A matrix of results enabled the team to assess trade-offs and finalize decisions on system architecture (Figure 1.0).

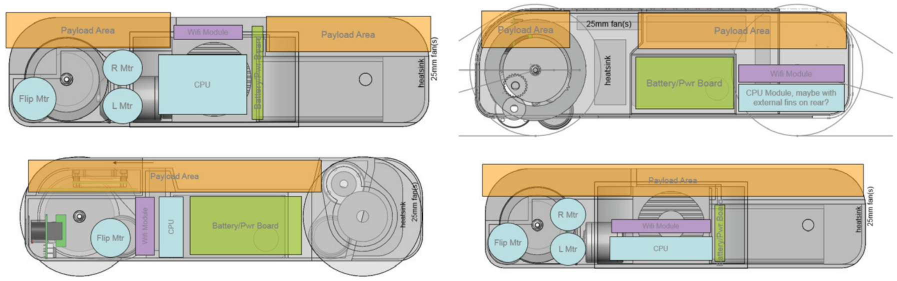


Figure 1.0 Concept Generation Phase: Layout Alternatives

Evaluated different layouts; assessed thermal solutions, solar load, internal power dissipation, payload capability, climbing performance, and cost

Evaluating materials

A good alternative to an expensive, CNC-machined, relatively heavy, aluminum chassis was required. We evaluated several high volume production processes, including die casting, thixomolding, sheet metal stamping, and plastic injection molding, and analyzed the trade-offs of each.

Material	Processes	Pros	Cons
Aluminum, magnesium	Die casting	High strength; rigidity	Thin walls not possible; expensive tooling; many secondary operations required
Magnesium	Thixomolding	Lighter than aluminum; stronger than plastic	Proprietary process; small supplier base, expensive tooling
Aluminum	Sheet metal stamping	Low cost tooling for moderate production	Requires multiple parts; difficult to seal; limited geometry options
Plastic	Injection molded	Minimum weight; lowest cost; accommodates complex, feature-rich designs	Weaker; strict supply-chain management required to meet structural and tolerance goals

Injection molding was ultimately selected based on its low cost and light weight—once our engineering analysis showed that meeting the performance requirements was possible. This required researching suitable plastic compounds (a PC/PET blend was ultimately selected), and conducting structural analyses coupled with mold-flow studies. Our internal studies, combined with vendor data cross-checking, also enabled our team to verify gates and molding processes, and analyze potential issues, such as heat dissipation and air traps.

Planning for rugged use

The rover's drop requirements and cantilevered loads presented a number of design challenges that required trade-offs to be made. The drive train and internal components required ultra-reliable parts that bolt-in-place, were well-sealed, easy to assemble, and met fit, performance, and payload-support goals. Several concept iterations were developed in order to find the best solution that would allow the rover to survive drops in extremely cold temperatures.

Refining the concepts

After the concepts were narrowed, increasingly rigorous analyses were performed. Spreadsheets, engineering calculations, resistance diagrams, and network flow models were created. Using computational fluid dynamics (CFD) simulation, we ran thermal models on specific areas of risk, and gathered critical information: total system air flow, specific air channel flows, air temperatures, rough component and outer surface temperatures, and the system's largest pressure drops.

In parallel, we continued to evaluate key factors: electrical requirements, environmental factors, parts costs, development budget, and expected time to market. While running simulations and assessing trade-offs in performance, space, weight, and costs, the team narrowed down concepts further, merged the best features of each, and ultimately arrived at a concept that would meet the functional and financial criteria most effectively.

Detailed design and prototype development

Designing for performance and manufacturability

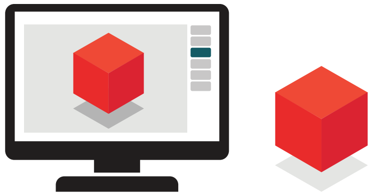
Part dimensions, thickness and shape, ribs and draft, finishing, ease-of-service, and attachment schemes were designed. Parts and assemblies were continually simulated, refined, and simulated again to assess performance. At the same time, components were analyzed for manufacturability and ease of assembly. As a result of in-depth modeling and proactive interaction with suppliers throughout the design phase, prototype spins were dramatically reduced.

Conducting tolerance analysis

Tolerance analysis is a critical part of the design process—it ensures a product will meet specifications and requirements after it's built on a manufacturing line. To garner good results in a timely manner, it's important to choose the right method of analysis. For the Avatar, we chose the direct linearization method of tolerance analysis for its balance of speed and accuracy. This approach uses a statistical summation to generate a predictive tolerance based on the selected manufacturing processes. With these results, we were able to tune the performance of key design elements to perform when produced in volume.

Optimizing the chassis

The centerpiece of the redesign effort was the chassis, and featured a common, single-molded, plastic solution. We simulated the performance of the chassis under stress conditions while working with vendors on what could be molded and what the costs would be via an RFQ process. The model was continually refined to optimize strength and overall performance, and enabled us to balance performance, cost, and manufacturability effectively—all before prototyping began.

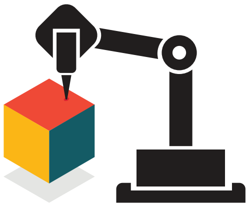


RoboteX Avatar Tactical Robot
DETAILED DESIGN
PROTOTYPE DEVELOPMENT

- CAD design
- Updated analysis: thermal, structural, tolerance
- Manufacturing qualification; sourcing plan
- DFM integration from supply base
- Prototype build

Checks and balances

All Acorn designs undergo CAD checks by Acorn engineers who are not working on the project. This step provides a fresh, unbiased opinion of the work. In addition, each project is overseen by a project director, a senior engineering manager who monitors progress. Our experience has shown that peer review and management oversight consistently saves time and money.



RoboteX Avatar Tactical Robot

VALIDATION AND PRODUCTION DESIGN

- Validate analysis and simulation results by the performance of the physical design
- Production design and analysis updates
- Vendor management
- Tool reviews, mold-flow, first article inspection
- Qualification
- CM build support

Managing heat

Building on the thermal analysis work initiated during concept development, we produced CFD models to analyze the heat generated by individual components and by the system as a whole. The models enabled us to analyze potential hot spots and to evaluate overall system thermal performance (Figures 2.1 and 2.2).

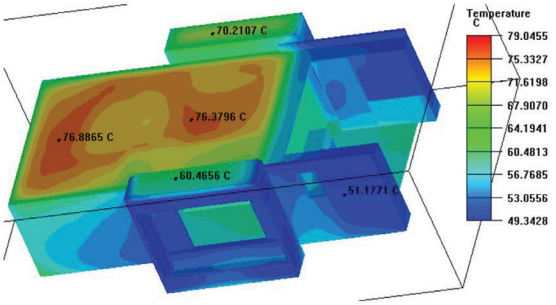


Figure 2.1 System-Level CFD Model

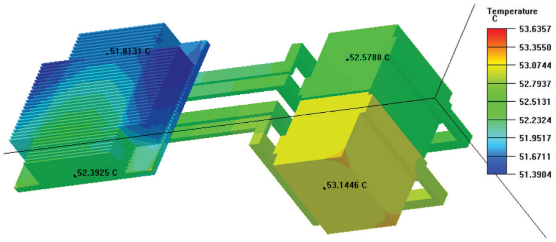


Figure 2.2 Verification of Motor Peak Temperatures

Forging the treads

To ensure the Avatar could traverse challenging terrain with precision, we designed a unique hybrid tread. We molded two different materials together to create a tread that delivered better traction and performance—especially in wet conditions. To ensure the new tread could be manufactured to spec cost effectively, we worked with suppliers to develop the design and tooling process required to manufacture the part.

Producing the prototype

Finally, a prototype was fabricated and assembled. Measured temperatures of specific components from the physical system validated the earlier predicted values from the initial analysis to within 15% of the measured data.

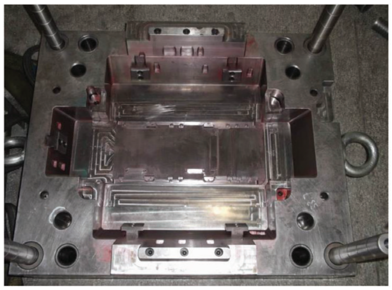


Figure 3.1 Tooling for large molded chassis

B-plate in process

Figure 3.2 Tooling

Slide in process

Working worldwide

Many crucial parts, including the chassis (which had to be completed in less than eight weeks), required overseas sourcing to reduce costs. Our engineers—in both the U.S. and China—were actively engaged in concept analysis, parts evaluation, detailed design, engineering, prototyping, and manufacturing. Throughout the entire process, the Acorn Design Center in China worked directly with suppliers in both China and Korea. This effort made the transition from concept development to design and production smooth, and it ensured the design could be manufactured on time and on budget.

Results

Through an ongoing, layered strategy of iterative detailed design, simulation, and analysis prior to building a prototype, RoboteX achieved an optimized production design within a highly accelerated development schedule. Weight was reduced by more than 10 pounds, and cost, ruggedness and durability goals were exceeded, while payload support more than doubled. With its remarkable durability and reliable performance, Avatar resulted in significant growth for RoboteX.

Item	Project Onset	End Result
Weight	35+ pounds	Reduced weight by more than 10 lb
Payload	Less than required	Increased by 100%
Durability	Not yet durable	Passed ruggedness and durability tests
Build of materials (BOM) costs	$10,000s per unit	$100s per unit
Parts		3 Die-cast/thixomolding 25 Injection molding 7 CNC 19 Sheet metal 2 Extrusion

Conclusion

Analyzing early and often

As a result of extensive analysis and modeling—conducted throughout the entire design process—we uncovered and resolved many architectural and manufacturability issues prior to concept selection, finalization, and detailed design. This virtual prototyping and simulation approach reduced physical prototype spins, compressed the overall development time, and increased the likelihood that performance goals and cost requirements would be met.

By collaborating with suppliers and manufacturers very early on, manufacturability—and the costs associated with it—were analyzed and vetted before the operations team began its work, reducing risks and accelerating the manufacturing schedule.

Looking to the future

As companies continue to make robots more powerful and complex—and form factors increasingly smaller—innovative design and manufacturing methods will be crucial to the success of these products. By employing both analysis-driven design principals and supply-chain collaboration early in the process, robot prototypes that work in the laboratory today can become manufacturable products.

> "You guys have made a superior product. We purchased a different robot a few years back, and we recently received the RoboteX AVATAR—wow, what a difference. It's a very easy robot to operate, and it's very easy to set up. It literally took me 5 minutes to set it up and get it running. A few minutes of driving it around the office and I felt like a pro. Officers are easily trained on it, so you don't have to have someone "specially" trained as a robot operator. Anyone can operate it. All this, and it was 1/6 of the cost of other robots."

Michael R. Moody

Metro SWAT/STAR Unit
Des Moines Police Department
Des Moines, Iowa

About the author

Jon Appleby
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Based in our Boston Office, Jon has more than 15 years of product development experience across many disciplines and applications. He earned a BS in mechanical engineering from the Massachusetts Institute of Technology and holds four U.S. patents.

About Acorn

Founded in 1993, Acorn Product Development is based in Silicon Valley with design centers in Boston, Atlanta, and China. We provide comprehensive product engineering services—from turnkey product development, subassembly development, and engineering analysis to materials cost analysis and manufacturing cost reduction—for leading companies around the globe.

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Contact us today and learn how our team can help you turn your concept into a product that delivers the performance and manufacturability you envision.

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