Headlamp Housing Lightweighting: Topology-Driven Ribbing for Injection-Molded Automotive Lighting

This case study documents the lightweighting of an automotive headlamp rear housing. The value Cognitive Design delivered here was not a single clever optimization; it was the ability to **generate and compare dozens of rib concepts quickly** and converge on the design that balanced mass, impact performance, and moldability. By running the same workflow first on a single governing load case and then across the full load case set, guided by simulation at each step, the team reached a **16% mass reduction** while improving the safety factor under impact loading.

Engineering Challenge

Headlamp housings sit inside a tight regulatory and multi-physics envelope: beam pattern (ECE R112) demands dimensional fidelity on the optical-facing surface, while the same part must survive under-hood thermal exposure, vibration fatigue, and low-speed impact on a glass-fiber-reinforced polymer. Legacy housings manage this by thickening walls uniformly, a safe but heavy approach.

1. **Anisotropic Fiber Shrinkage**: PA66-GF30 shrinks unevenly with fiber flow direction; warpage on the front face threatens beam alignment and lens sealing.
2. **Local Thermal Gradient**: the bulb or LED socket reaches roughly 120°C against a cooler housing body, so ribbing must absorb this gradient without new stress risers.
3. **Impact Retention Without Fragmentation**: low-speed impact and pedestrian-protection rules require no fragment shedding or detachment from BIW mounts, a harder constraint than staying under yield.
4. **Moldability Under Lightweighting**: draft angles, rib-to-wall ratios, and demoldability must be met by the same geometry carrying the structural and thermal loads above.

The Solution: Cognitive Design Workflow

1. Design Space & Load Cases

We imported the legacy housing geometry and defined Preservation Zones around the optical module cutouts, the body-in-white fixation bosses, and the connector bores for the wiring harness interface. Load cases included a vibration fatigue spectrum (3-5g), thermal cycling to approximately 120°C near the bulb socket, and a low-speed frontal impact case modeled in LS-Dyna. We retained PA66-GF30 for both legacy and optimized geometry, keeping the comparison **purely geometry-driven**.

2. Generative Exploration

Using the Design Explorer, **we generated more than 50 rib variants in parallel**, honeycomb and radial patterns with varying cell size, height, and base thickness, compared to the 2 to 3 concepts a conventional workflow allows. We evaluated each variant on mass, stress under the impact case, and manufacturability, and selected a honeycomb-based route for its balance of stiffness and moldability, while keeping flow-induced fiber orientation on the front face consistent with the legacy tool.

3. Performance & Manufacturability (MDD & SDD)

Manufacturing-Driven Design enforced a minimum draft angle of 1.5 degrees and kept rib-to-wall thickness below 60 percent of nominal to avoid sink marks, with a near-constant wall thickness derived from the midsurfaced geometry. **Simulation-Driven Design** used **meshless FEA** to steer rib height and density in real time, first against the single impact load case, then across the full load case set once the base concept was locked.

4. Validation / Final FEA

We validated the Phase 1 concept against the impact load case alone in LS-Dyna, then **reran the full workflow across all three load cases** together for Phase 2. This staged approach let us lock impact performance early, then confirm it held under the added vibration and thermal loads without reopening warpage risk on the front face. The final design confirmed a safety factor of 1.7 against the impact case, up from 1.4 on the legacy housing, with peak Von Mises stress reduced from 62 MPa to 52 MPa.

Key Metrics Comparison

Metric	Legacy (PA66-GF30)	Optimized (PA66-GF30)	Improvement
Mass	340 g	285 g	16% reduction
Max Von Mises Stress	62 MPa	52 MPa	16% lower
Safety Factor	1.4	1.7	21%
Concepts Explored per Part	2-3 (manual, sequential)	50+ variants (parallel DoE)	~20x more design options