Lightweighting Optimization of High-Performance Supercar Brake Caliper

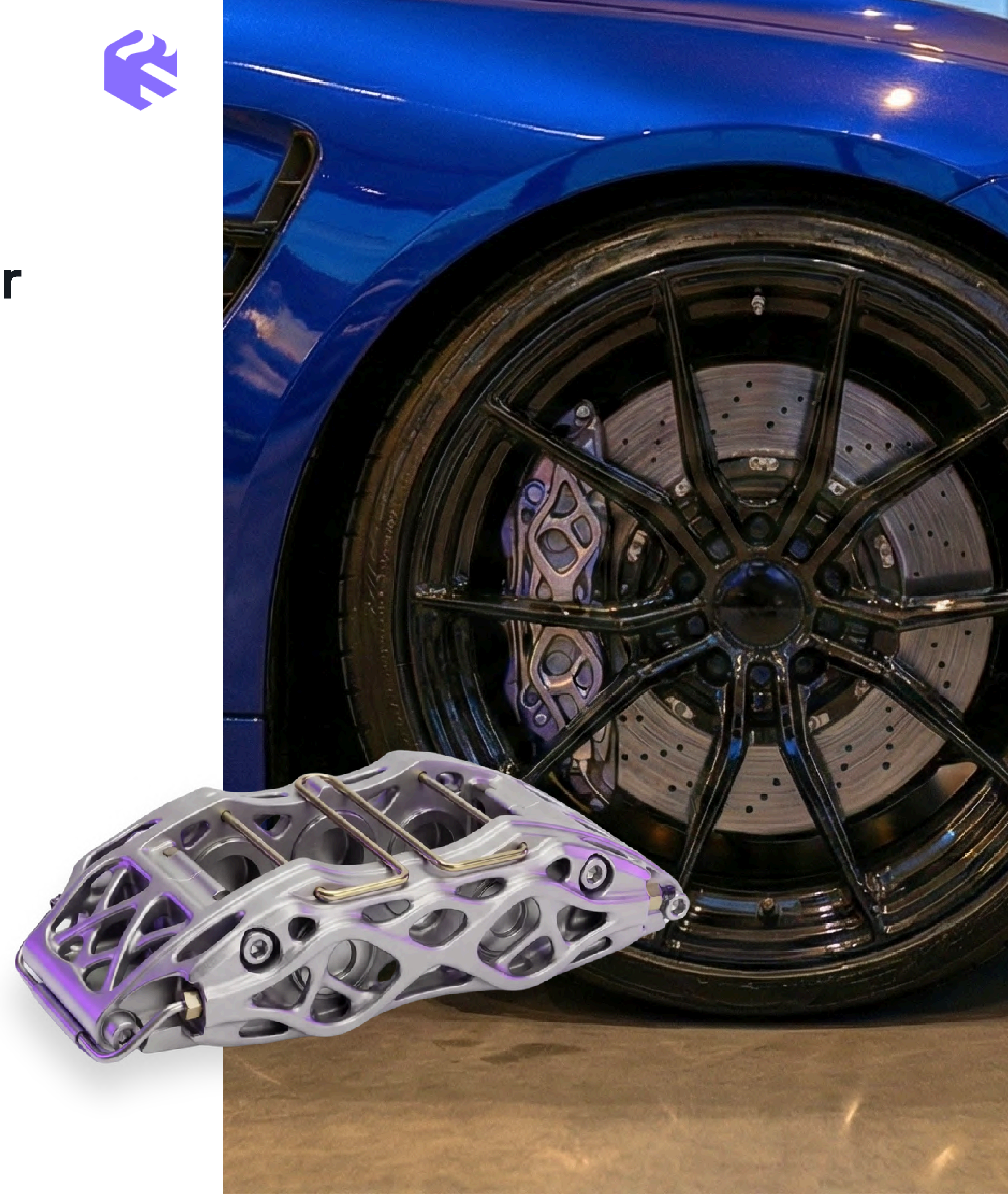
This case study details the engineering overhaul of a legacy automotive brake caliper intended for a limited-run supercar (300 units). By leveraging Cognitive Design's generative workflow, the team transitioned from a standard block-milled design to a high-performance, topology-optimized component.

The project successfully reduced unsprung mass by 42% while increasing stiffness-to-weight ratio, utilizing Titanium (Ti-6Al-4V) to withstand extreme thermal and mechanical loads.

Engineering Challenge

The client, a manufacturer of high-performance supercars, faces a critical conflict between vehicle dynamics and manufacturing constraints. Reduction of unsprung mass is paramount for handling and acceleration, but standard aluminum calipers (Al-6061) utilize bulk material to maintain stiffness, resulting in heavy components.

With a production run limited to 300 units, traditional high-pressure die casting tooling is cost-prohibitive, while standard 3-axis machining from billet limits geometric complexity. The caliper must also withstand **extreme braking temperatures** without deforming, necessitating a material and geometry capable of superior heat dissipation.



The Solution: Cognitive Design Workflow

1. DESIGN SPACE & LOAD CASES
We began by importing the legacy caliper assembly (piston bores, fluid channels, and mounting knuckles) into our Design Space environment.
- **Preservation Zones**: Defined critical interfaces (bolt holes, piston cylinders, brake pad slides) as non-design regions.
- **Load Cases**: Applied maximum braking torque (2.5g deceleration scenario), internal hydraulic pressure (200 bar), and thermal expansion loads.
- **Material Selection**: Evaluated Al-6061 (Base) vs. Ti-6Al-4V. Titanium was selected for the optimized route due to its superior strength-to-weight ratio and heat resistance, allowing for thinner, more aggressive structural trusses.

2. GENERATIVE EXPLORATION
We utilized Topology Optimization to explore three structural styles. Style A (**Machining**) used flat planes and cylindrical cuts for 3-axis CNC but remained heavier. Style B (**Die Casting**) applied split lines and draft angles, but tooling costs were prohibitive for 300 units. The selected Style C (**Topology Weaving**) created a bio-mimetic truss connecting piston housings with organic pathways, maximizing stiffness and surface area for air cooling.

3. PERFORMANCE & MANUFACTURABILITY (MDD & SDD)
To ensure the complex "Topology Weave" was manufacturable for the 300-unit run, we employed **Manufacturing-Driven Design (MDD)** constraints:
- AM Focus: Given the quantity and complexity, Metal AM (DMLS) was chosen. Constraints were set to minimize support structures (overhangs >45 degrees).
- Hybrid Finishing: The workflow incorporated machining allowances on the piston bores and mounting faces, ensuring the printed part could be post-processed to micron-level tolerances.
- Simulation-Driven Design (SDD): Meshless FEA was run in real-time during geometry generation. This allowed us to thicken struts in high-stress zones (near the mounting bolts) and thin them in low-stress zones (the bridge) instantly, without waiting for external validation.

4. VALIDATION
Final FEA confirmed the structural integrity of the Ti-6Al-4V organic design, maintaining a **safety factor of 2.5** under peak braking load. Caliper **deflection was reduced by 16%** compared to the original aluminum design, improving brake pedal feel, while the increased surface area improved **heat dissipation rates by 18%.**

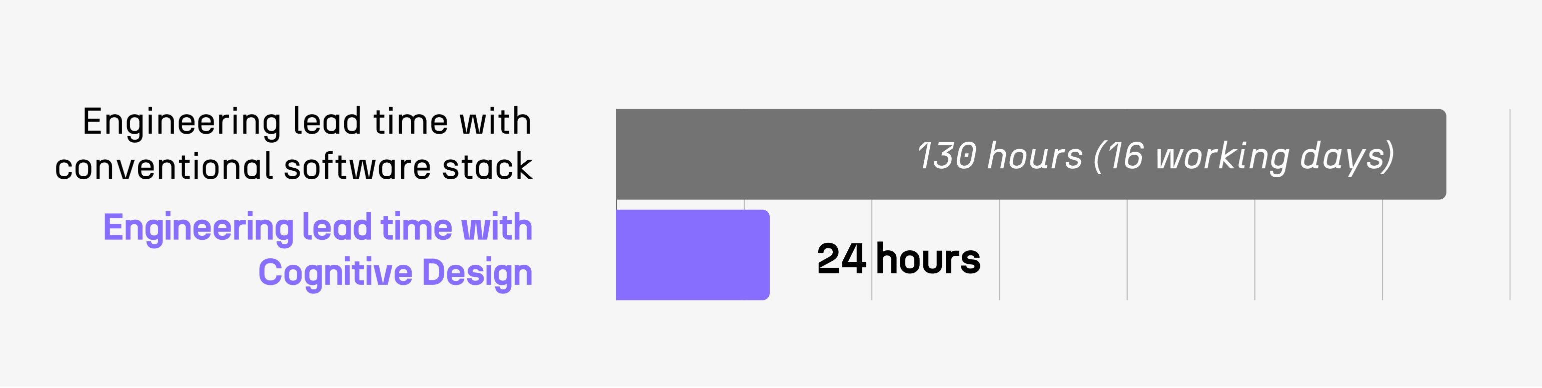

AM-optimized brake caliper


CNC-optimized brake caliper


Die Casting -optimized brake caliper

Key Metrics Comparison

Metric	CNC (Al-6061)	AM (Ti-6Al-4V)	Improvement
Mass	3.85 kg	2.23 kg	42% Reduction
Max Stress	120 MPa	450 MPa	Safe (Ti Yield >800 MPa)
Max Deflection	0.12 mm	0.10 mm	16% Stiffer
Heat Dissipation	Baseline	18%	From increased surface area



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