Lightweighting Optimization of High-Performance Supercar Brake Caliper

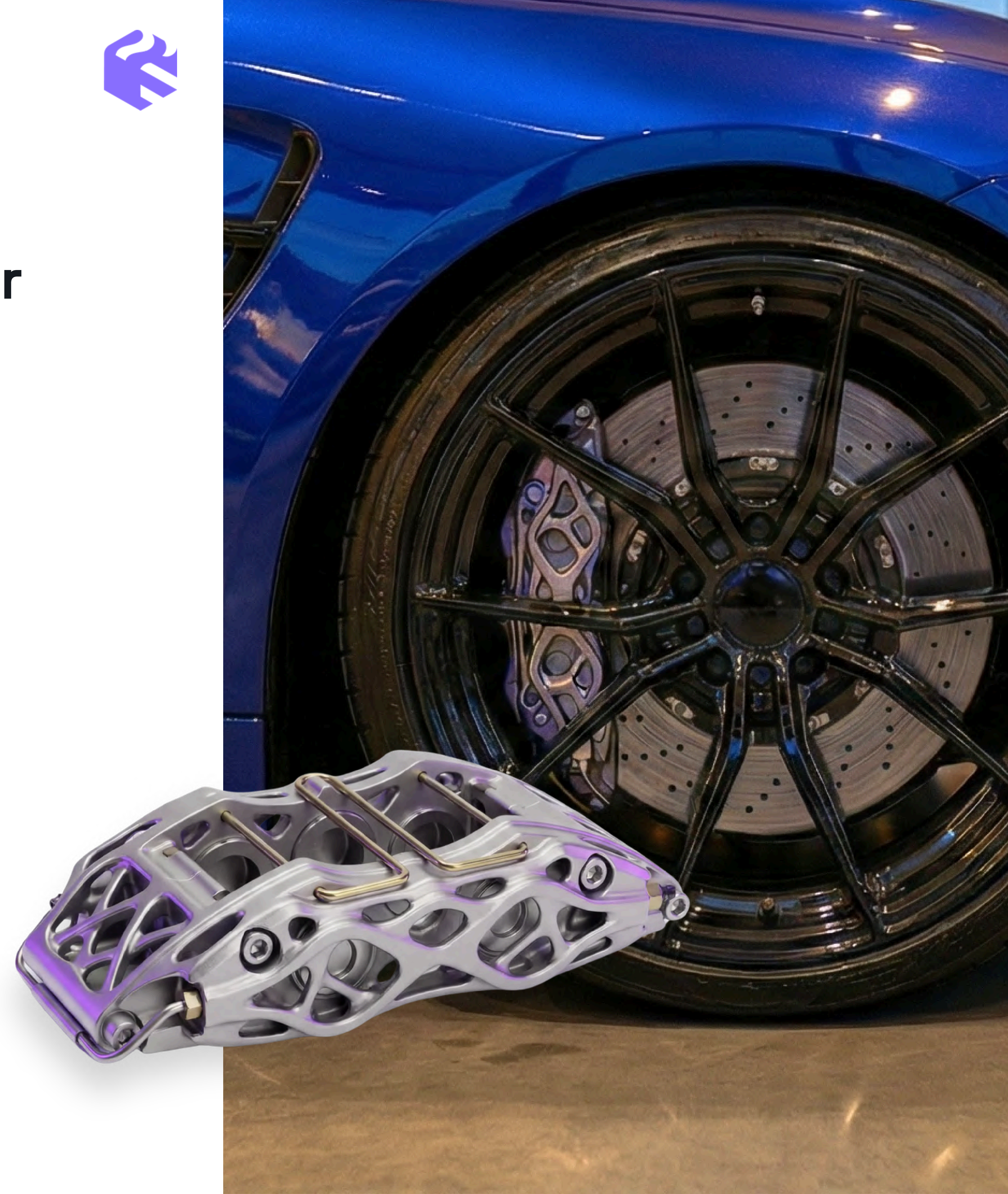
This case study details the engineering overhaul of a legacy automotive brake caliper intended for a limited-run supercar (300 units). By leveraging Cognitive Design's generative workflow, the team transitioned from a standard block-milled design to a high-performance, topology-optimized component.

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 were defined for critical interfaces (bolt holes, piston cylinders, brake pad slides) as non-design regions.

Load Cases: **maximum braking torque** (2.5g deceleration), **hydraulic pressure** (200 bar), and a **350°C thermal gradient** at the pad interface.

Material Selection evaluated Al-6061 vs. Ti-6Al-4V. **Titanium** was selected for its superior strength-to-weight ratio and low thermal conductivity (~7 W/m·K), passively protecting the hydraulic circuit from heat migration.

2. GENERATIVE EXPLORATION

Three structural styles were explored through **Topology Optimization**. 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 (**AM**) created a bio-mimetic truss connecting piston housings with organic pathways, maximizing stiffness while expanding external surface area by 5-10% for convective heat rejection.

3. PERFORMANCE & MANUFACTURABILITY (MDD & SDD)

To ensure the optimized model was manufacturable for the 300-unit run, **Manufacturing-Driven Design** (MDD) constraints were employed: AM Focus used Metal AM (DMLS) with overhangs constrained to >45 degrees.

Simulation-Driven Design (SDD) using **Meshless FEA** ran structural and thermal analyses in real-time, allowing the team to thicken struts in high-stress zones, thin them elsewhere, and confirm piston back temperature margins.

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%**, improving brake pedal feel. Thermal simulation confirmed piston back temperature at **~185°C versus 198°C** on the aluminum baseline, a 13°C gain in fluid safety margin over the DOT 5.1 wet boiling point.

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
Piston Back Temp.	198°C	~185°C	+13°C fluid margin