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Thermal Management of Brake Systems

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1) Summary / Purpose

Analyze and model heat generation and dissipation in an automotive brake rotor under repeated braking events. Develop a parametric model for rotor geometry (diameter, thickness, ventilation pattern) and perform a thermal analysis to evaluate temperature rise, cooling effectiveness, and fade risk. Build a reusable analysis workflow that RES can extend to other thermal management problems.

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2) Objectives

- **O1 – Generator:** Build a parameterized CAD model of a ventilated brake rotor (diameter, thickness, vane geometry).
- **O2 – Variants:** Create ≥ 3 rotor variants (solid disc, simple vented, high-performance vented).
- **O3 – Analysis:** Estimate braking energy input, temperature rise, and cooldown rate using analytical heat transfer methods and simplified FEA.
- **O4 – Evidence:** Deliver an 8–10 page technical brief with assumptions, energy/temperature charts, and design recommendations.
- **O5 – Handoff:** Provide CAD files, drawings, and a structured Python/Excel workbook for repeatable analysis.

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3) Scope of Work

3.1 CAD (Parametric Generator)

- Define parameter set: rotor diameter, thickness, vane pattern, material properties.
- Create base model with configurable geometry and export variants.

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- Generate technical drawings (hub interface, vane geometry, key dims).

3.2 Thermal Analysis

- Compute braking energy input: scaled by duty cycle (single stop vs repeated).
- Estimate temperature rise via lumped capacity method
- Approximate heat dissipation: convective cooling correlations (forced vs natural convection).
- Optional: Simplified thermal FEA (Fusion 360 Simulation or ANSYS student license).

3.3 Packaging & Communication

- **Drawings:** Cross-sections showing vane design and hub interface.
- **Data Book:** Energy balance equations, assumptions, constants.
- **Report:** Methods, results, trade-offs, recommendations.
- **Repository:** Organized folder with CAD, scripts, reports.

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4) Deliverables

1. Parametric CAD model + step/iges export, 3+ variants.
2. Drawing set (PDF) with vane geometry and hub/assembly.
3. Analysis workbook (spreadsheet or Python) calculating ΔT, cooling rate, fade limits.
4. Technical brief (8–10 pages, PDF) with charts and recommendations.

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5. Readme file with instructions to re-run analysis.

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5) Tools & Stack

- **CAD:** Fusion 360 / SolidWorks
- **Analysis:** Python (NumPy, Matplotlib) or Excel
- **Thermal:** Lumped capacity equations + simplified FEA (optional)

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6) Assumptions & Constraints

- Steady-state heat transfer approximations acceptable.
- Use steel or cast iron properties from open literature.
- Ignore pad material effects (v1).
- No experimental brake dynamometer testing (analysis only).

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7) Out of Scope (v1)

- Full CFD/thermo-structural simulations.
- Acoustic/vibration (squeal) analysis.
- Vehicle-level integration (only component-level).

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8) Milestones & Timeline (example)

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- **M0 (Day 0–3):** Requirements + repo scaffold, material property research.
- **M1 (Week 1):** Parametric CAD rotor model complete; variant A baseline exported.
- **M2 (Week 2):** Analytical thermal model and energy balance complete.
- **M3 (Week 3):** Results and plots for A/B/C variants (ΔT vs stop cycles).
- **M4 (Week 4):** Drawings + report finished, final recommendations delivered.

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9) Quality Standards

- CAD: Fully constrained sketches; parameter-driven vane geometry.
- Analysis: Equations referenced, units tracked, sensitivity to duty cycle ±10%.
- Plots: Temperature vs time, ΔT vs rotor mass, cooling rate comparisons.
- Documentation: Readable by juniors, reproducible by handoff.

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10) Success Criteria / KPIs

- CAD model generates 3+ rotor variants without geometry errors.
- Thermal model outputs temperature vs time and cooling plots for each variant.
- Report presents trade-offs (mass vs cooling vs fade resistance).
- Repository passes reproducibility test by another junior engineer.