

Modal Analysis of a PETG-CF Fan Housing

V5 orientation: base on the XY plane and height along $+Z$

Numerical study prepared in ETUDE_MODAL_PETGCF_COMPOSANTS_V5_SOCLE_XY_Z

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Abstract

This report documents the finite-element modal analysis of a fan housing intended to be manufactured in PETG-CF. The purpose is to identify the elastic natural frequencies of the housing and compare them with excitation frequencies associated with a blade rotational speed close to 2000 rpm. The final V5 model is oriented with the real base resting on the XY plane and the fan height along $+Z$. The mesh is a validated tetrahedral mesh with 95,358 nodes and 312,777 TETRA4 elements. The housing is modelled as PETG-CF, while the motor and electronics are represented as localized equivalent masses. The first elastic mode is found at 49.214 Hz. The rotation frequency at 2000 rpm is 33.333 Hz, and the five-blade passing frequency is 166.667 Hz. The first mode is not directly coincident with the 1X rotation line, and no computed mode is directly coincident with the five-blade passing line. The third mode, however, is close to the 4X rotational harmonic and should be monitored in later design iterations.

1 Objective

The study objective is to evaluate whether the fan housing has natural frequencies close to the main operating excitations. For a nominal rotational speed $N = 2000$ rpm,

$$f_{\text{rot}} = \frac{N}{60} = 33.333 \text{ Hz.} \quad (1)$$

For five blades, the blade passing frequency is

$$f_{\text{BPF}} = 5f_{\text{rot}} = 166.667 \text{ Hz.} \quad (2)$$

The relevant comparison therefore includes the 1X rotational line, its harmonics, and the blade passing frequency.

2 Geometry Preparation

The original CAD was geometrically valid but poorly suited for a robust tetrahedral mesh. It contained many small faces and short edges, especially on the arms. The final mesh-preparation geometry replaced highly detailed arms by simpler prismatic ribs, removed small non-structural faces, and avoided a small feature that introduced sliver faces during boolean operations.

Table 1: Topology reduction produced by the mesh-preparation step.

Geometry	Faces	Edges	Edges < 0.1 mm	Faces < 5 mm ²
Original CAD	1450	4135	2299	1175
Mesh-prepared CAD	274	622	5	18

The final V5 orientation was produced after the modal model was validated. The real support base was identified and placed on the XY plane, with the fan height along $+Z$. This rigid transformation does not change the modal physics, but it makes the results easier to inspect and communicate.

3 Mesh and Material Model

The mesh was generated with the NETGEN tetrahedral algorithm through SALOME/SMESH [1]. The chosen mesh was retained because it computed robustly and provided a reasonable model size for repeated Code_Aster runs.

Table 2: Mesh characteristics.

Quantity	Value
Element type	TETRA4
Nodes	95,358
Volume elements	312,777
Mechanical degrees of freedom	286,074
Mesh volume	704 189.190 mm ³

The housing material is an equivalent isotropic PETG-CF. This is an engineering approximation: a printed PETG-CF part is expected to be anisotropic, and its actual stiffness depends on print orientation, wall count, infill, temperature, and inter-layer bonding.

Table 3: Equivalent PETG-CF material properties used in the modal model.

Property	Symbol	Value
Young's modulus	E	6000 MPa
Poisson ratio	ν	0.35
Density	ρ	1.30×10^{-9} tonne/mm ³

4 Embedded Masses

The motor and electronics are not modelled as detailed CAD parts. Instead, their mass is distributed over two local mesh regions. The stiffness in these regions remains PETG-CF; only the equivalent density is increased.

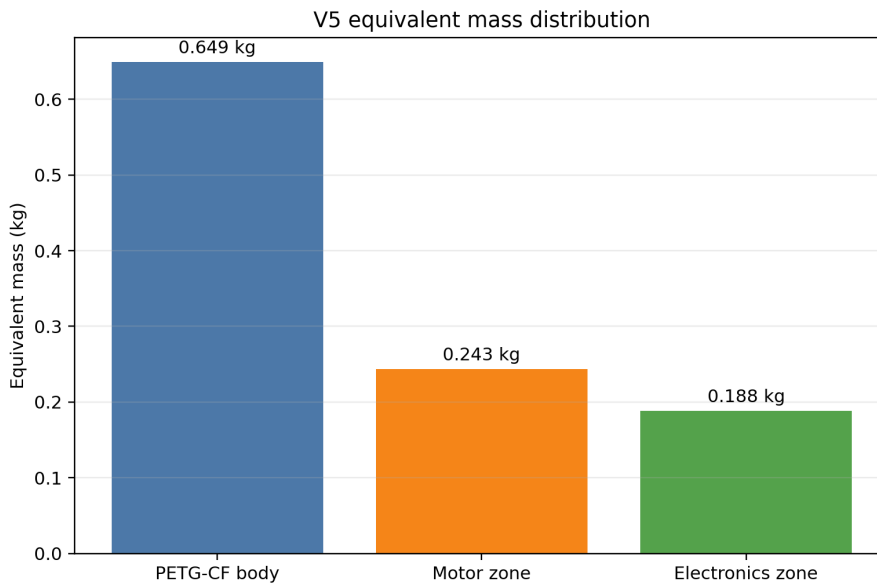


Figure 1: Equivalent mass distribution used in the V5 model.

Table 4: Equivalent mass distribution.

Zone	Elements	Volume (mm ³)	Mass (kg)
PETG-CF housing region	278,034	499,125.546	0.648863
Motor region	23,127	117,900.693	0.243271
Electronics base region	11,616	87,162.950	0.188312
Total	312,777	704,189.190	1.080446

5 Modal Solver Setup

The modal problem is solved in Code_Aster [2] using a linear 3D mechanical model in free-free conditions. The stiffness and mass matrices are assembled and the generalized eigenvalue problem is solved:

$$K\phi_i = \omega_i^2 M\phi_i. \quad (3)$$

The search band is 1 Hz to 1500 Hz. The six rigid-body modes near 0 Hz are not listed because the frequency band starts at 1 Hz. The Code_Aster run ended with diagnostic OK.

6 Modal Results

Table 5: Computed elastic natural frequencies.

Elastic mode	Aster mode number	Frequency (Hz)
1	7	49.214
2	8	73.181
3	9	131.946
4	10	250.576
5	11	289.925
6	12	339.059
7	13	377.305
8	14	450.782
9	15	492.777
10	16	522.370
11	17	584.026
12	18	622.931
13	19	643.105
14	20	748.567
15	21	925.806
16	22	1042.368
17	23	1137.910
18	24	1217.084
19	25	1277.192
20	26	1393.306
21	27	1459.501

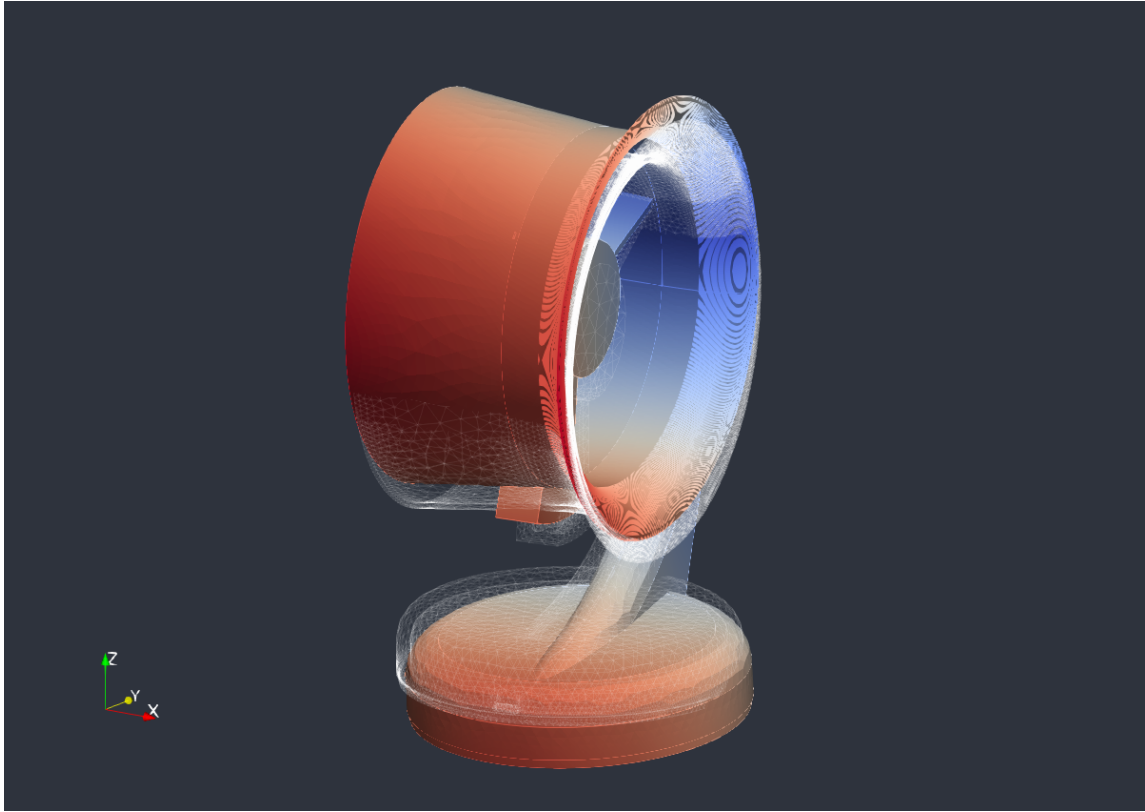


Figure 2: First elastic mode at 49.214 Hz. The deformation is visually amplified and is not a physical displacement amplitude.

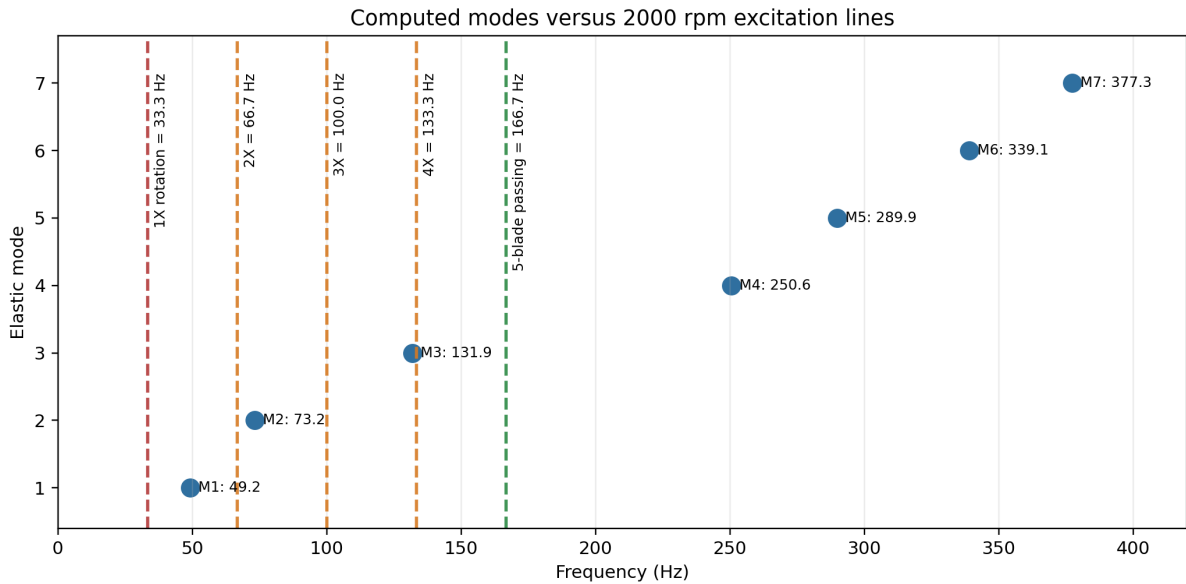


Figure 3: Computed modes compared with excitation lines for 2000 rpm.

The first mode is above the 1X rotation line. The third mode at 131.946 Hz is close to the 4X rotational harmonic at 133.333 Hz; this is the main frequency proximity observed in the current free-free model. The five-blade passing frequency at 166.667 Hz is not directly coincident with a computed natural frequency.

7 Mass-Only Estimate for Adding Five Blades

The blades are not yet included in the finite-element model. A first-order estimate can be made by assuming that the five blades only add mass and do not change the structural stiffness:

$$f_{\text{new}} \approx f_0 \sqrt{\frac{M_0}{M_0 + \Delta M}}, \quad (4)$$

where $f_0 = 49.214$ Hz, $M_0 = 1.080\,446$ kg, and ΔM is the total blade mass.

Table 6: Mass-only estimate for adding five blades.

Mass per blade (g)	Five blades (kg)	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)
5	0.025	48.654	72.349	130.445
10	0.050	48.113	71.544	128.995
15	0.075	47.590	70.766	127.592
20	0.100	47.083	70.013	126.234
25	0.125	46.593	69.283	124.918
30	0.150	46.117	68.575	123.642

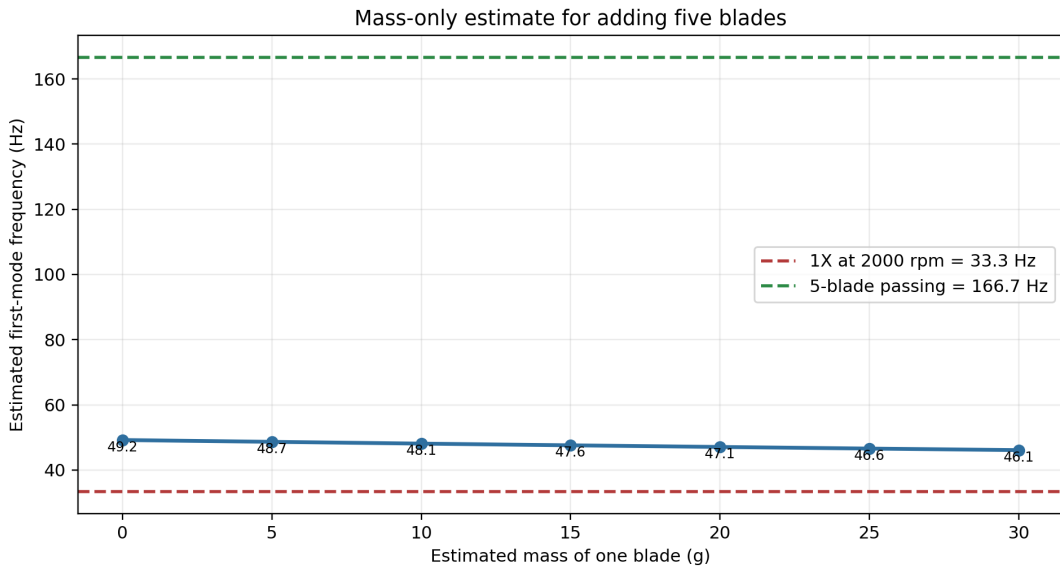


Figure 4: Estimated shift of the first mode when five blades are added as mass only.

8 Effect of a Circular Gasket Under the Base

Adding a circular gasket under the base is relevant, but it must be represented by the right physical mechanism. In the present free-free modal model, adding a gasket without any support condition would have little meaning unless its mass is included. The important effect of a gasket is usually not its mass but its compliance and damping at the interface between the fan and the table/support.

Three levels of modelling are possible:

1. add the gasket mass only: useful if the gasket is heavy, but usually a small effect on frequencies;
2. model the gasket as distributed elastic supports under the base: appropriate for studying how support stiffness shifts the modes;

3. model a real rubber layer or contact interface: needed for more realistic damping and shock behaviour, but requires rubber properties and contact assumptions.

For modal analysis, the most useful next step is a supported modal model with vertical and lateral stiffnesses under the circular base. The expected outcome is that rigid-body modes disappear, low-frequency supported modes appear, and some housing modes may shift depending on gasket stiffness. A very soft gasket can isolate vibration but may introduce low-frequency rocking modes; a very stiff gasket behaves almost like a hard support.

9 Drop or Shock Analysis Feasibility

A table drop is a different problem from a modal analysis. Modal analysis gives natural frequencies and mode shapes; a drop requires transient dynamics, contact, and possibly nonlinear material behaviour.

The impact velocity for a drop height h is approximately

$$v_0 = \sqrt{2gh}. \quad (5)$$

For example, a 0.8 m table drop gives $v_0 \approx 3.96$ m/s. The most important unknown is not only the velocity, but the stopping distance or contact duration. A short stopping distance produces a high deceleration and therefore high stresses.

There are two practical modelling routes:

1. simplified shock load: impose an equivalent acceleration pulse or deceleration level and run a transient or quasi-static check;
2. nonlinear drop model: include the floor/contact, gasket/contact compliance, transient dynamics, and possibly nonlinear PETG-CF behaviour.

The simplified shock model is a good first engineering step. The nonlinear drop model is more realistic but requires additional data: drop height, impact orientation, floor stiffness, gasket properties, blade and motor mass/inertia, and PETG-CF failure criteria.

10 Limitations

The present model is a useful design-level modal study, but it is not an experimental validation. The main limitations are:

- PETG-CF is treated as isotropic;
- the model is free-free and does not include real mounting stiffness;
- blades are not explicitly meshed;
- damping is not estimated;
- the motor and electronics are represented as distributed equivalent masses;
- no contact or nonlinear impact behaviour is included.

11 Recommended Next Work

The most useful next simulations are:

1. supported modal analysis with a circular gasket stiffness under the base;

2. sensitivity study versus gasket stiffness and gasket thickness;
3. mass and inertia representation of the five blades;
4. simplified shock analysis using an acceleration pulse for a table drop;
5. experimental tap test or microphone/accelerometer measurement to compare real frequencies with the model.

12 Reproducibility

The main files are:

- Code_Aster command file: 03_CODE_ASTER/carter_modal_petgcf_composants_v5_socle_xy_z.comm;
- oriented mesh: 02_MAILLAGE/ventilateur_1_meshprep_socle_xy_z_netgen.med;
- modal result: 04_RESULTATS_PARAVIS/carter_modal_petgcf_composants_v5_socle_xy_z_modes.rmed;
- ParaViS state: 04_RESULTATS_PARAVIS/visualisation_modes_v5_socle_xy_z.pvsm;
- vibration GIF: 04_RESULTATS_PARAVIS/mode_001_49p214Hz_vibration_socle_xy_z.gif.

References

- [1] *SALOME Platform*. CEA and EDF, 2026. URL <https://www.salome-platform.org/>. Used for MED mesh handling and post-processing workflows.
- [2] *Code_Aster: Structures and Thermomechanics Analysis for Studies and Research*. EDF, 2026. URL <https://www.code-aster.org/>. Local version used: 16.9.