

Rotor 53

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About

Rotor 53 is part of a research program to study fan stages suitable for use in engines for quiet powered lift aircraft. Experimental studies have been conducted on fan stages suitable for use in engines for quiet powered lift aircraft using the externally blown flap. The externally blown flap aircraft requires a large flow of low velocity air for effective lift and low noise during take-off and landing. To meet the low noise requirement, the fans will be required to have low tip speed and low-pressure ratio. The pressure ratios of interest in the program range from 1.15 to 1.4. Rotor 53 has a pressure ratio of 1.35.

- Original technical report ^[1]:

```
@TechReport{osborn1978design,
  author      = {Osborn, Walter M. and Moore, R. D. and Steinke,
Ronald J.},
  date        = {1978},
  institution = {NASA Lewis Research Center Cleveland, OH, United
States},
  title       = {Aerodynamic Performance of a 1.35-Pressure-Ratio
Axial-Flow Fan Stage},
  number      = {NASA-TP-1299},
  url         = {https://ntrs.nasa.gov/citations/19790001851},
}
```

- Picture :



Fig. 1 <https://catalog.archives.gov/id/17423389>

- @Misc{brown1974records,
author = {Brown, M.},
title = {Rotor 53 and stator 53. {R}ecords of the {N}ational
{A}eronautics and {S}pace {A}dministration, 1903 - 2006. {P}hotographs
relating to agency activities, facilities and personnel, 1973 - 2013},
year = 1974,
url = {<https://catalog.archives.gov/id/17466806>}}

Useful documents

- [downloadable models](#) (Git project)
 - NASA technical report
(.pdf)
 - geometrical parameters file
(.csv), usable as input of OpenMCAD^[2] to generate reference blade models.

Reference blade

The **reference blade** is defined with multiple-circular arc profiles^[3] given in the original NASA report^[1]. Corresponding models are computed with the open-source code OpenMCAD^[2].

Geometry

[The geometry of rotor 53 is described in the original NASA report](#) by the following tables. The length are in centimeters and the angles in degrees.

TABLE IV. - BLADE GEOMETRY FOR ROTOR 53

| RP | PERCENT RADII | | | BLADE ANGLES | | | DELTA INC | CONE ANGLE |
|-----|---------------|--------|--------|--------------|-------|--------|--------------|---------------|
| | SPAN | RI | RO | KIC | KTC | KOC | | |
| TIP | 0. | 25.235 | 24.498 | 57.67 | 48.68 | 39.79 | 3.67 | -12.422 |
| 1 | 5. | 24.422 | 23.781 | 55.43 | 46.98 | 38.52 | 3.70 | -10.420 |
| 2 | 10. | 23.568 | 23.064 | 53.48 | 45.16 | 36.85 | 3.79 | -7.939 |
| 3 | 15. | 22.737 | 22.348 | 52.00 | 43.36 | 34.72 | 3.93 | -5.957 |
| 4 | 30. | 20.285 | 20.197 | 47.02 | 37.48 | 27.95 | 4.60 | -1.242 |
| 5 | 50. | 17.170 | 17.329 | 40.30 | 28.51 | 16.72 | 5.70 | 2.014 |
| 6 | 70. | 14.231 | 14.461 | 33.67 | 18.58 | 3.50 | 6.64 | 2.712 |
| 7 | 85. | 12.144 | 12.311 | 28.86 | 10.59 | -7.69 | 7.04 | 1.891 |
| 8 | 90. | 11.473 | 11.594 | 27.30 | 8.05 | -11.21 | 7.09 | 1.364 |
| 9 | 95. | 10.814 | 10.877 | 25.75 | 5.55 | -14.65 | 7.12 | .710 |
| HUB | 100. | 10.160 | 10.160 | 24.22 | 3.08 | -18.08 | 7.14 | .057 |

| RP | BLADE THICKNESSES | | | AXIAL DIMENSIONS | | | |
|-----|-------------------|------|------|------------------|-------|-------|-------|
| | TI | TM | TO | ZI | ZMC | ZTC | ZO |
| TIP | .041 | .207 | .041 | .899 | 2.426 | 2.426 | 4.243 |
| 1 | .041 | .209 | .041 | .828 | 2.433 | 2.433 | 4.310 |
| 2 | .041 | .214 | .041 | .762 | 2.438 | 2.438 | 4.375 |
| 3 | .042 | .222 | .041 | .705 | 2.440 | 2.440 | 4.439 |
| 4 | .051 | .258 | .052 | .537 | 2.449 | 2.449 | 4.620 |
| 5 | .065 | .319 | .063 | .327 | 2.460 | 2.460 | 4.843 |
| 6 | .073 | .375 | .074 | .155 | 2.480 | 2.480 | 5.020 |
| 7 | .083 | .406 | .083 | .061 | 2.509 | 2.509 | 5.107 |
| 8 | .084 | .410 | .084 | .038 | 2.519 | 2.519 | 5.122 |
| 9 | .083 | .411 | .083 | .019 | 2.530 | 2.530 | 5.129 |
| HUB | .082 | .412 | .082 | .000 | 2.540 | 2.540 | 5.135 |

Aerodynamic design

| | unit | value |
|-----------------------------------|---------|-------|
| pressure ratio | [-] | 1.35 |
| mass flow | [kg/s] | 32.7 |
| tip speed | [m/s] | 302.8 |
| tip solidity | [-] | 1 |
| aspect ratio | [-] | 2.86 |
| number of blades | [-] | 30 |
| nominal rotation speed ω_n | [rad/s] | 1200 |

Material properties

The original material of the rotor 53 is not defined in the NASA report. A generic titanium Ti-6Al-4V is considered:

| | unit | value |
|-----------------|-------|-----------|
| alloy | [-] | Ti-6Al-4V |
| Young's modulus | [GPa] | 108 |

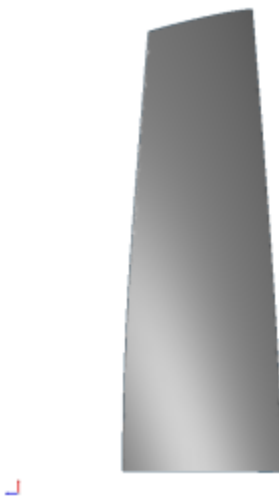
| | unit | value |
|------------------------|----------------------|--------------|
| density | [kg/m ³] | 4400 |
| Poisson's ratio | [-] | 0.34 |
| yield stress | [GPa] | 0.824 |

CAD model

The CAD model is computed with the open source code OpenMCAD^[2].



pressure side



suction side

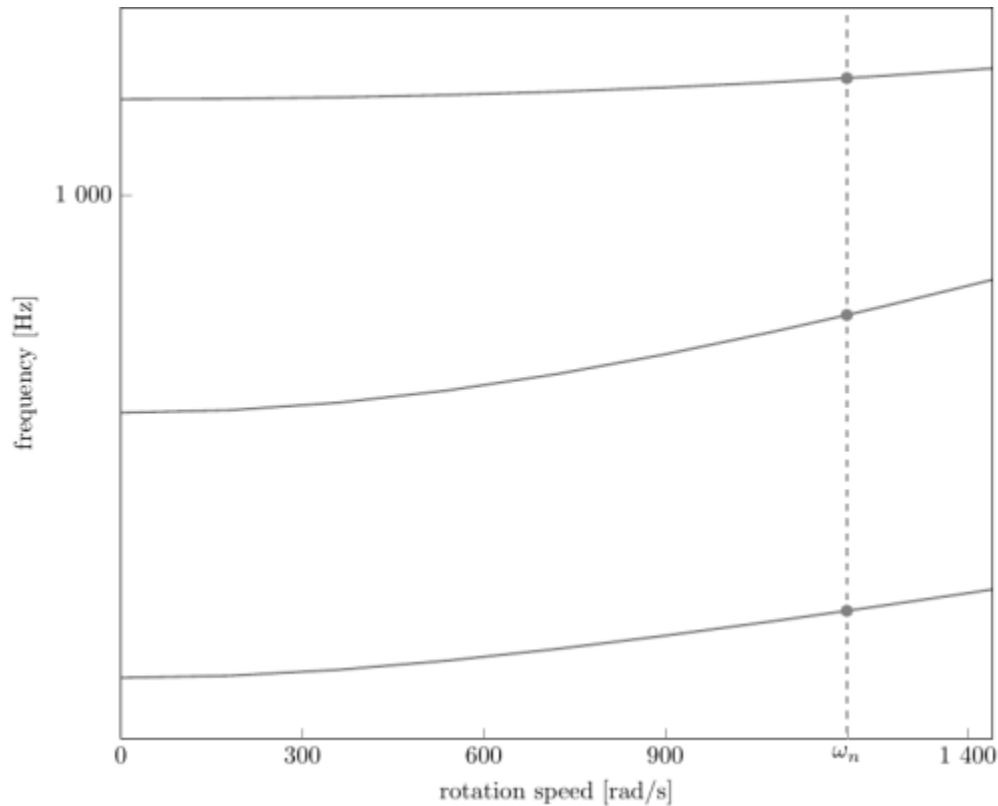
Natural frequencies

First three natural frequencies (with clamped root) for the mesh computed with OpenMCAD^[2]:

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|-------------|-------------|--|-------------------------------|
| 1 | 1B | 1205.30 | 191.83 |
| 2 | 2B | 3993 | 635.51 |
| 3 | 1T | 7291 | 1160.40 |

Campbell diagram

Evolution of the natural frequencies of the first 3 vibration modes, as a function of rotation speed, for the mesh computed with OpenMCAD^[2]:



Campbell diagram computed with a linear centrifugal preload, with clamped root (nominal rotation speed $\omega_n = 1\,200$ rad/s)

- graph (.pdf)
- Campbell data (.csv)

Initial blade

The **initial blade** is defined with in-house LAVA parameters^[4] computed from the reference blade CAD model. The initial blade is usually used as starting point for an optimization process. Its geometry is similar to the one of the reference blade.

Natural frequencies

First three natural frequencies (with clamped root)

- from the whole mesh:

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|------|------|-------------------------------------|------------------------|
| 1 | 1B | 1200 | 190.99 |
| 2 | 2B | 3979.52 | 633.36 |

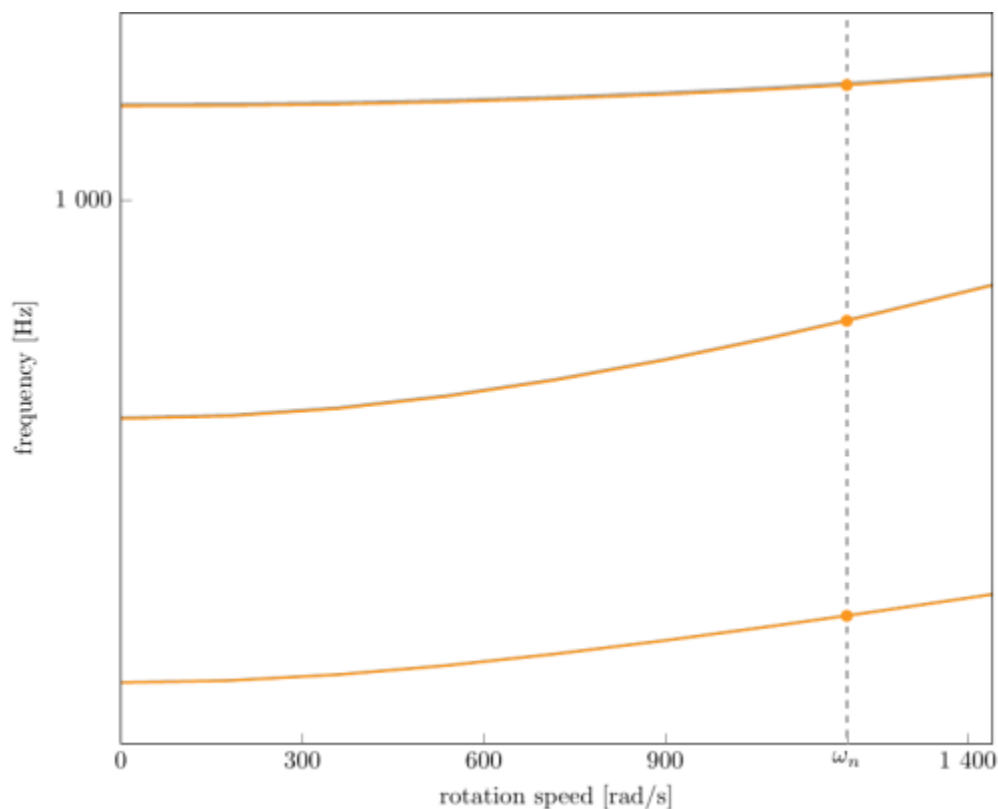
| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|------|------|-------------------------------------|------------------------|
| 3 | 1T | 7269.27 | 1156.94 |

- from the reduced order model:

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|------|------|-------------------------------------|------------------------|
| 1 | 1B | 1200.03 | 190.99 |
| 2 | 2B | 3980.44 | 633.51 |
| 3 | 1T | 7271.91 | 1157.36 |

Campbell diagram

Comparison of the evolution of the natural frequencies of the first 3 vibration modes, as a function of rotation speed for the initial and the reference blade:



Campbell diagram computed with a linear centrifugal preload, with clamped root (nominal speed $\omega_n = 1200$ rad/s),

initial blade (orange), reference blade (gray)

- graph (.pdf)
- Campbell data (.csv)

Fichiers téléchargeables

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Libre accès

[lien vers le projet Git](#)

À propos

Le rotor 53 fait partie d'un programme de recherche visant à étudier les étages de soufflante susceptibles d'être utilisés dans des moteurs d'avions plus silencieux. Des études expérimentales ont été menées sur des étages de soufflante utilisant un volet à soufflage externe. L'utilisation de tel volets nécessite un grand débit d'air à faible vitesse pour une portance efficace et un faible niveau de bruit au décollage et à l'atterrissage. Pour répondre à cette exigence de faible bruit, les soufflantes devront avoir une faible vitesse en tête et un faible taux de compression. Les taux de compression d'intérêt dans le programme varient de 1,15 à 1,4. Le rotor 53 possède un taux de compression de 1,35.

- Rapport technique original ^[1]:

```
@TechReport{osborn1978design,  
  author      = {Osborn, Walter M. and Moore, R. D. and Steinke,  
Ronald J.},  
  date        = {1978},  
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  number      = {NASA-TP-1299},  
  url         = {https://ntrs.nasa.gov/citations/19790001851},  
}
```

- Photographie :



Fig. <https://catalog.archives.gov/id/17423389>

- @Misc{brown1974records,
author = {Brown, M.},
title = {Rotor 53 and stator 53. {R}ecords of the {N}ational
{A}eronautics and {S}pace {A}dministration, 1903 - 2006. {P}hotographs
relating to agency activities, facilities and personnel, 1973 - 2013},
year = 1974,
url = {https://catalog.archives.gov/id/17466806}}

Documents utiles

- [modèles téléchargeables](#) (lien vers projet Git)
 - rapport technique original
de la NASA (.pdf)
 - fichier de paramètres géométriques
(.csv), utilisable en entrée de OpenMCAD^[2] pour générer l'aube de référence

Aube de référence

L'**aube de référence** est définie par des profils de type arcs circulaires multiples^[3], donnés dans le rapport technique original de la NASA^[1]. Les modèles associés sont obtenus avec le code en libre accès OpenMCAD^[2].

Géométrie

La géométrie du rotor 53 est décrite dans le [rapport d'origine de la NASA](#) par les tableaux suivants. Les grandeurs sont en centimètres et en degrés.

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| 1 | 5. | 24.422 | 23.781 | 55.43 | 46.98 | 38.52 | 3.70 | -10.420 |
| 2 | 10. | 23.568 | 23.064 | 53.48 | 45.16 | 36.85 | 3.79 | -7.939 |
| 3 | 15. | 22.737 | 22.348 | 52.00 | 43.36 | 34.72 | 3.93 | -5.957 |
| 4 | 30. | 20.285 | 20.197 | 47.02 | 37.48 | 27.95 | 4.60 | -1.242 |
| 5 | 50. | 17.170 | 17.329 | 40.30 | 28.51 | 16.72 | 5.70 | 2.014 |
| 6 | 70. | 14.231 | 14.461 | 33.67 | 18.58 | 3.50 | 6.64 | 2.712 |
| 7 | 85. | 12.144 | 12.311 | 28.86 | 10.59 | -7.69 | 7.04 | 1.891 |
| 8 | 90. | 11.473 | 11.594 | 27.30 | 8.05 | -11.21 | 7.09 | 1.364 |
| 9 | 95. | 10.814 | 10.877 | 25.75 | 5.55 | -14.65 | 7.12 | .710 |
| HUB | 100. | 10.160 | 10.160 | 24.22 | 3.08 | -18.08 | 7.14 | .057 |

| RP | BLADE THICKNESSES | | | AXIAL DIMENSIONS | | | |
|-----|-------------------|------|------|------------------|-------|-------|-------|
| | TI | TM | TO | ZI | ZMC | ZTC | ZO |
| TIP | .041 | .207 | .041 | .899 | 2.426 | 2.426 | 4.243 |
| 1 | .041 | .209 | .041 | .828 | 2.433 | 2.433 | 4.310 |
| 2 | .041 | .214 | .041 | .762 | 2.438 | 2.438 | 4.375 |
| 3 | .042 | .222 | .041 | .705 | 2.440 | 2.440 | 4.439 |
| 4 | .051 | .258 | .052 | .537 | 2.449 | 2.449 | 4.620 |
| 5 | .065 | .319 | .063 | .327 | 2.460 | 2.460 | 4.843 |
| 6 | .073 | .375 | .074 | .155 | 2.480 | 2.480 | 5.020 |
| 7 | .083 | .406 | .083 | .061 | 2.509 | 2.509 | 5.107 |
| 8 | .084 | .410 | .084 | .038 | 2.519 | 2.519 | 5.122 |
| 9 | .083 | .411 | .083 | .019 | 2.530 | 2.530 | 5.129 |
| HUB | .082 | .412 | .082 | .000 | 2.540 | 2.540 | 5.135 |

Caractéristiques aérodynamiques

| | unités | valeurs |
|---|---------|---------|
| taux de compression | [-] | 1,35 |
| débit massique | [kg/s] | 32,7 |
| vitesse en tête | [m/s] | 302,8 |
| solidité en tête | [-] | 1 |
| allongement | [-] | 2,86 |
| nombre d'aubes | [-] | 30 |
| vitesse de rotation nominale ω_n | [rad/s] | 1200 |

Propriétés matériau

Le matériau original du rotor 53 n'est pas défini dans le rapport de la NASA. Un alliage de titane Ti-6Al-4v est considéré :

| | unité | valeurs |
|----------------|-------|-----------|
| alliage | [-] | Ti-6Al-4v |
| module d'Young | [GPa] | 108 |

| | unité | valeurs |
|-------------------------------|----------------------|----------------|
| masse volumique | [kg/m ³] | 4400 |
| coefficient de Poisson | [-] | 0,34 |
| limite élastique | [GPa] | 0,824 |

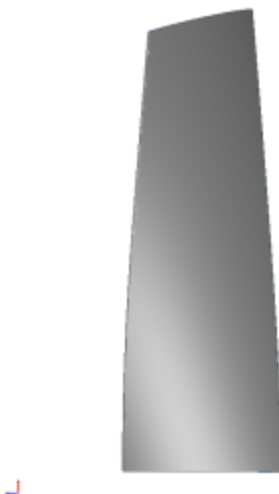
Modèle CAO

Le modèle CAO est obtenu avec OpenMCAD^[2].

intrados



extrados



Fréquences propres

Fréquences des trois premiers modes (noeuds du pied d'aube encastres) pour le maillage obtenu avec OpenMCAD^[2] :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|-------------|-------------|-----------------------------------|------------------------------|
| 1 | 1F | 1205,30 | 191,83 |
| 2 | 2F | 3993 | 635,51 |
| 3 | 1T | 7291 | 1160,40 |

Diagramme de Campbell

Évolution des fréquences propres des 3 premiers modes, en fonction de la vitesse de rotation, pour le maillage obtenu avec OpenMCAD^[2]:

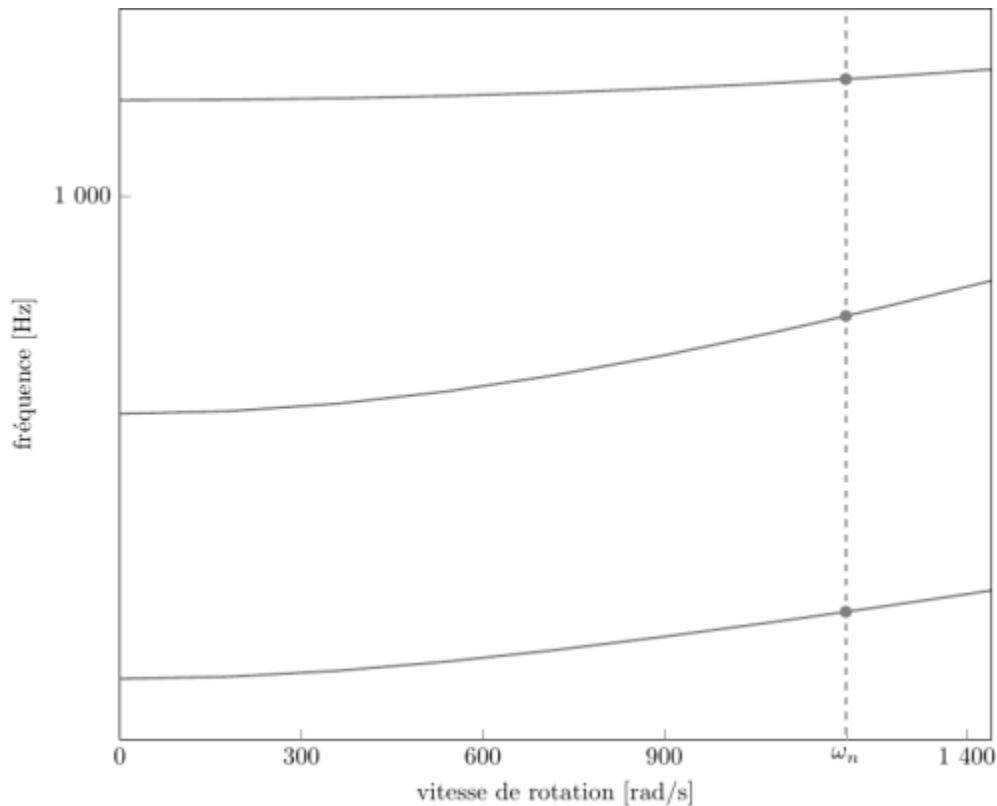


diagramme de Campbell calculé avec une précharge centrifuge linéaire, noeuds du pied d'aube encastres (vitesse nominale $\omega_n = 1\,200$ rad/s)

- graphique (.pdf)
- données du Campbell (.csv)

Aube initiale

L'**aube initiale** est définie par des paramètres spécifiques au LAVA^[4] obtenus à partir du modèle CAO de l'aube de référence. L'aube initiale est classiquement utilisée comme point de départ dans le cadre de procédures d'optimisation; sa géométrie est similaire à celle de l'aube de référence.

Fréquences propres

Fréquences des trois premiers modes (noeuds du pied d'aube encastres),

- pour le maillage complet :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|------|------|----------------------------|-----------------------|
| 1 | 1F | 1200 | 190,99 |
| 2 | 2F | 3979,52 | 633,36 |
| 3 | 1T | 7269,27 | 1156,94 |

- pour le modèle réduit :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|------|------|----------------------------|-----------------------|
| 1 | 1F | 1200,03 | 190,99 |
| 2 | 2F | 3980,44 | 633,51 |
| 3 | 1T | 7271,91 | 1157,36 |

Diagramme de Campbell

Comparaison de l'évolution des fréquences propres des 3 premiers modes, en fonction de la vitesse de rotation, pour l'aube initiale et de référence:

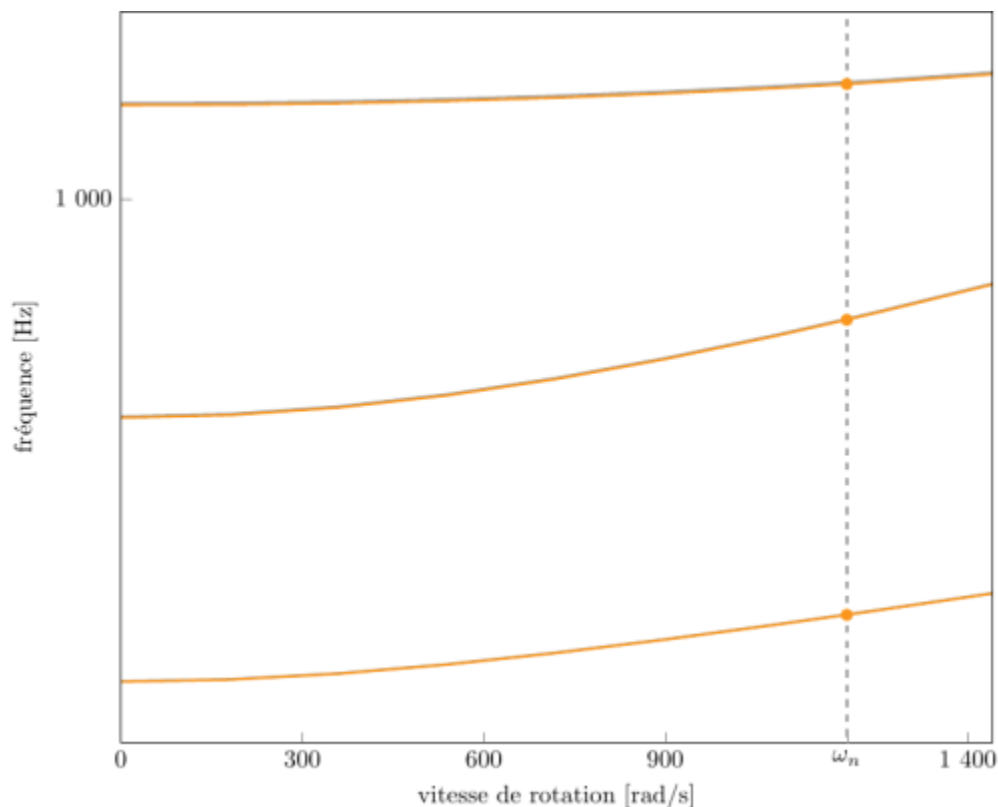


diagramme de Campbell calculé avec une précharge centrifuge linéaire, noeuds du pied d'aube encastrés (vitesse nominale $\omega_n = 1\,200$ rad/s),

aube initiale (orange), aube de référence (grise)

- graphique (.pdf)
- données du Campbell (.csv)

1. [a, b, c, d](#) Osborn *et al.* «Aerodynamic Performance of a 1.35-Pressure-Ratio Axial-Flow Fan Stage » 1978. [pdf](#)
2. [a, b, c, d, e, f, g, h, i, j](#) Kojtych S., Batailly A. «OpenMCAD, an open blade generator: from Multiple-Circular-Arc profiles to Computer-Aided Design model» 2022. [open source code](#)
3. [a, b](#) Crouse *et al.* «A computer program for composing compressor blading from simulated circular-arc

elements on conical surfaces » 1969. NASA-TN-D-5437. [pdf](#)

4. ^{a, b} Kojtych S. *et al.* «Methodology for the Redesign of Compressor Blades Undergoing Nonlinear Structural Interactions: Application to Blade-Tip/Casing Contacts » 2022. Journal of Engineering for Gas Turbines and Power, Vol. 145, No. 5. [pdf](#)

Document issu de la page wiki:

https://lava-wiki.meca.polymtl.ca/public/modeles/rotor_53/accueil

Dernière mise à jour: **2024/07/30 11:52**