

Rotor 3

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About

Rotor 3 is part of a research program to study the effects of blade solidity on efficiency and stall margin of an axial-flow compressor rotor. It is one of a series of rotors designed with varying blade solidity achieved by changing the blade chord length : rotor 3 with a tip solidity of 1.3, rotor 4 with a tip solidity of 1.1 and rotor 5 with a tip solidity of 1.5.

Results show that the pressure ratio, temperature ratio and efficiency of this rotor are higher than design predicted values because of the actual losses being generally lower than those assumed in the design.

- Original NASA technical report ^[1]:

```
@TechReport{hager1972performance,
  author      = {Hager, Roy D and Janetzke, David C and Reid,
Lonnie},
  date       = {1972},
  institution = {NASA Lewis Research Center Cleveland, OH, United
States},
  title      = {Performance of a 1380-foot-per-second-tip-speed
axial-flow compressor rotor with a blade tip solidity of 1.3},
  number     = {NASA-TM X-2448},
  url       = {https://ntrs.nasa.gov/citations/19720012341},
}
```

- Pictures :



Fig1. <https://ntrs.nasa.gov/citations/19720012341> p.66



Fig2. <https://ntrs.nasa.gov/citations/19720012341> p.67

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^[4]. Corresponding models are computed with the open-source code OpenMCAD^[2].

Geometry

The geometry of rotor 3 is described in the [original NASA report](#) by the following table. The lengths are in inches and the angles in degrees.

TABLE III. - BLADE GEOMETRY FOR ROTOR 3

| RP | PERCENT RADII | | | BLADE ANGLES | | | DELTA INC |
|-----|---------------|-------|-------|--------------|-------|-------|--------------|
| | SPAN | RI | RO | KIC | KTC | KOC | |
| TIP | 0. | 9.885 | 9.769 | 62.50 | 58.45 | 47.30 | 2.10 |
| 1 | 5. | 9.729 | 9.578 | 61.80 | 57.37 | 46.80 | 2.26 |
| 2 | 10. | 9.510 | 9.386 | 60.62 | 55.92 | 46.30 | 2.57 |
| 3 | 30. | 8.598 | 8.620 | 55.62 | 50.08 | 44.42 | 4.11 |
| 4 | 40. | 8.127 | 8.237 | 53.20 | 47.11 | 41.00 | 4.90 |
| 5 | 42. | 8.020 | 8.142 | 52.60 | 46.43 | 40.03 | 5.04 |
| 6 | 45. | 7.893 | 8.046 | 52.00 | 45.63 | 39.13 | 5.17 |
| 7 | 48. | 7.772 | 7.950 | 51.44 | 44.85 | 38.03 | 5.34 |
| 8 | 50. | 7.652 | 7.854 | 50.90 | 44.07 | 37.03 | 5.47 |
| 9 | 70. | 6.665 | 7.089 | 46.70 | 37.25 | 27.45 | 6.54 |
| 10 | 90. | 5.558 | 6.323 | 44.20 | 29.54 | 14.55 | 7.31 |
| 11 | 95. | 5.240 | 6.131 | 44.10 | 27.26 | 10.82 | 7.42 |
| HUB | 100. | 5.000 | 5.940 | 44.00 | 25.51 | 6.10 | 7.47 |

| RP | BLADE THICKNESSES | | | AXIAL DIMENSIONS | | | CONE ANGLE |
|-----|-------------------|-------|-------|------------------|-------|-------|---------------|
| | TI | TM | TO | ZMC | ZTC | ZOC | |
| TIP | 0.020 | 0.061 | 0.020 | 0.563 | 0.563 | 0.894 | -6.300 |
| 1 | 0.020 | 0.064 | 0.020 | 0.564 | 0.564 | 0.927 | -5.800 |
| 2 | 0.020 | 0.068 | 0.020 | 0.565 | 0.565 | 0.962 | -4.700 |
| 3 | 0.020 | 0.085 | 0.020 | 0.552 | 0.552 | 1.109 | 0.900 |
| 4 | 0.020 | 0.094 | 0.020 | 0.551 | 0.551 | 1.183 | 4.100 |
| 5 | 0.020 | 0.096 | 0.020 | 0.561 | 0.561 | 1.200 | 5.000 |
| 6 | 0.020 | 0.098 | 0.020 | 0.573 | 0.573 | 1.217 | 5.800 |
| 7 | 0.020 | 0.101 | 0.020 | 0.581 | 0.581 | 1.234 | 6.700 |
| 8 | 0.020 | 0.103 | 0.020 | 0.589 | 0.589 | 1.252 | 7.600 |
| 9 | 0.020 | 0.122 | 0.020 | 0.650 | 0.650 | 1.390 | 15.600 |
| 10 | 0.020 | 0.143 | 0.020 | 0.689 | 0.689 | 1.486 | 26.800 |
| 11 | 0.020 | 0.149 | 0.020 | 0.688 | 0.688 | 1.488 | 30.400 |
| HUB | 0.020 | 0.154 | 0.020 | 0.685 | 0.685 | 1.486 | 32.600 |

Aerodynamic design

| | unit | value |
|-----------------------------------|---------|---------|
| pressure ratio | [-] | 1.801 |
| mass flow | [kg/s] | 29 |
| tip speed | [m/s] | 420.6 |
| tip solidity | [-] | 1.3 |
| aspect ratio | [-] | 2.53 |
| nominal rotation speed ω_n | [rad/s] | 1675.52 |

Material properties

Rotor 3 is made of a 200-grade maraging steel, but the exact material properties are not provided in the NASA report. The following properties are considered :

| | unit | value |
|-------|------|--------------------|
| alloy | [-] | 18-Ni-200-maraging |

| | unit | value |
|------------------------|-------------|--------------|
| Young's modulus | [GPa] | 180 |
| density | [kg/m3] | 8000 |
| Poisson's ratio | [-] | 0.3 |
| yield stress | [GPa] | 1.38 |

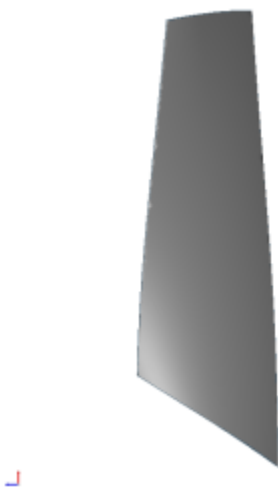
CAD model

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

intrados



extrados



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 | 1722.54 | 274.15 |
| 2 | 2B | 6548.96 | 1042.3 |

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|------|------|-------------------------------------|------------------------|
| 3 | 1T | 8224.31 | 1308.94 |

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 $\omega_n = 1\,675.52$ rad/s)

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

Initial blade

The **initial blade** is defined with in-house LAVA parameters^[5] 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)

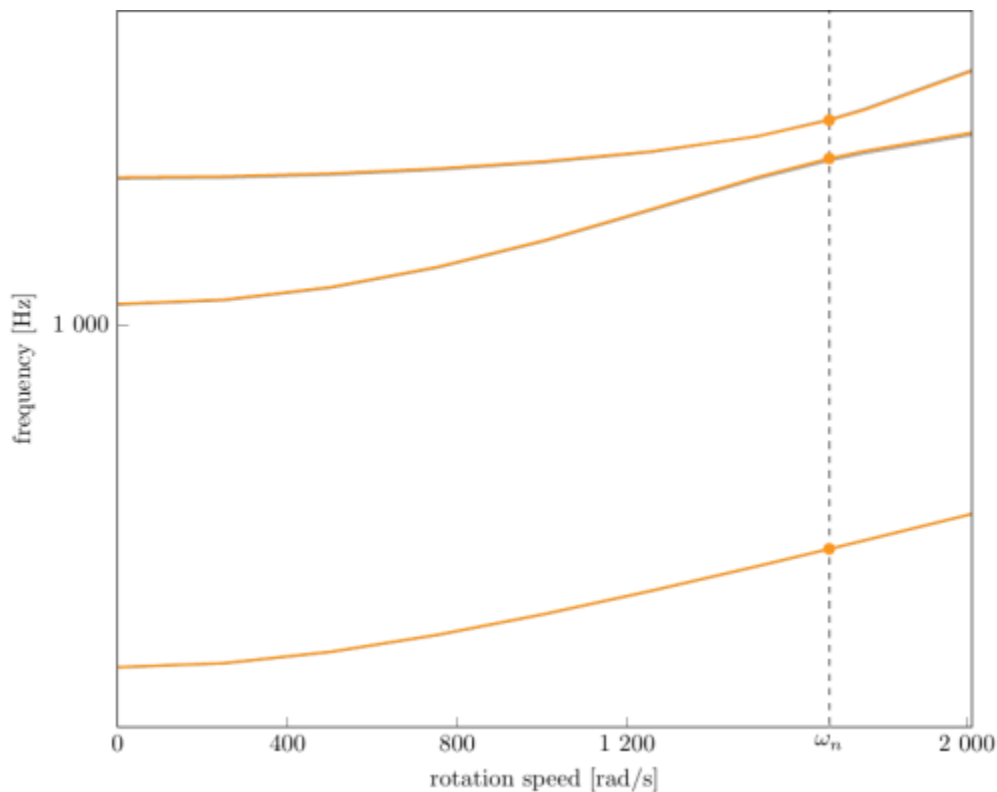
- from the whole mesh:

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|------|------|-------------------------------------|------------------------|
| 1 | 1B | 1728.06 | 275.029 |
| 2 | 2B | 6559.27 | 1043.94 |
| 3 | 1T | 8243.04 | 1311.92 |

- from the reduced order model:

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|------|------|-------------------------------------|------------------------|
| 1 | 1B | 1728.11 | 275.038 |
| 2 | 2B | 6561.34 | 1044.27 |
| 3 | 1T | 8245.298 | 1312.28 |

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 $\omega_n = 1675,52$ rad/s),

initial blade (orange), reference blade (gray)

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

Modèles téléchargeables

x

Libre accès

[lien vers le projet Git](#)

À propos

Le rotor 3 fait partie d'un programme de recherche pour étudier les effets de la solidité des pales sur le rendement et la marge de décrochage d'un compresseur à flux axial. Il fait partie d'une série de rotors conçus avec une solidité d'aube variable obtenue en modifiant la longueur de la corde de l'aube : le rotor 3 possède une solidité en tête de 1.3, le rotor 4 possède une solidité en tête de 1.1 et le rotor 5 possède une solidité en tête de 1.5.

Les résultats montrent que le taux de compression, le ratio de température et le rendement du rotor 3 sont plus élevés que ceux prévus lors de la conception car les pertes effectives sont inférieures à celles estimées lors de la conception.

- Rapport technique original ^[1]:

```
@TechReport{hager1972performance,
  author      = {Hager, Roy D and Janetzke, David C and Reid,
Lonnie},
  year       = {1972},
  institution = {NASA Lewis Research Center Cleveland, OH, United
States},
  title      = {Performance of a 1380-foot-per-second-tip-speed
axial-flow compressor rotor with a blade tip solidity of 1.3},
  number     = {NASA-TM X-2448},
  url       = {https://ntrs.nasa.gov/citations/19720012341},
}
```

- Photographies :

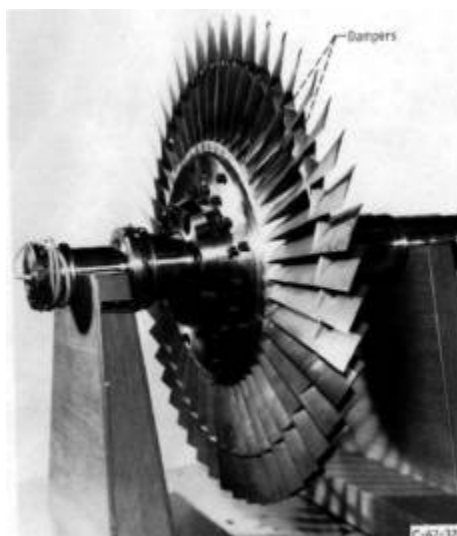


Fig1. <https://ntrs.nasa.gov/citations/19720012341> p.66

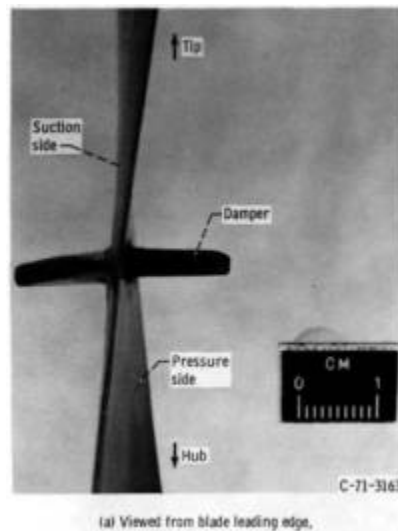


Fig2. <https://ntrs.nasa.gov/citations/19720012341> p.67

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^[4]. Les modèles associés sont obtenus avec le code en libre accès OpenMCAD^[2].

Géométrie

La géométrie du rotor 3 est décrite dans le [rapport d'origine de la NASA](#) par les tableaux suivants. Les grandeurs sont en pouces et en degrés.

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| RP | PERCENT RADII | | | BLADE ANGLES | | | DELTA INC |
|-----|---------------|-------|-------|--------------|-------|-------|-----------|
| | SPAN | RI | RO | KIC | KTC | KOC | |
| TIP | 0. | 9.885 | 9.769 | 62.50 | 58.45 | 47.30 | 2.10 |
| 1 | 5. | 9.729 | 9.578 | 61.80 | 57.37 | 46.80 | 2.26 |
| 2 | 10. | 9.510 | 9.386 | 60.62 | 55.92 | 46.30 | 2.57 |
| 3 | 30. | 8.598 | 8.620 | 55.62 | 50.08 | 44.42 | 4.11 |
| 4 | 40. | 8.127 | 8.237 | 53.20 | 47.11 | 41.00 | 4.90 |
| 5 | 42. | 8.020 | 8.142 | 52.60 | 46.43 | 40.03 | 5.04 |
| 6 | 45. | 7.893 | 8.046 | 52.00 | 45.63 | 39.13 | 5.17 |
| 7 | 48. | 7.772 | 7.950 | 51.44 | 44.85 | 38.03 | 5.34 |
| 8 | 50. | 7.652 | 7.854 | 50.90 | 44.07 | 37.03 | 5.47 |
| 9 | 70. | 6.665 | 7.089 | 46.70 | 37.25 | 27.45 | 6.54 |
| 10 | 90. | 5.558 | 6.323 | 44.20 | 29.54 | 14.55 | 7.31 |
| 11 | 95. | 5.240 | 6.131 | 44.10 | 27.26 | 10.82 | 7.42 |
| HUB | 100. | 5.000 | 5.940 | 44.00 | 25.51 | 6.10 | 7.47 |

| RP | BLADE THICKNESSES | | | AXIAL DIMENSIONS | | | CONE ANGLE |
|-----|-------------------|-------|-------|------------------|-------|-------|------------|
| | TJ | TM | TO | ZMC | ZTC | ZOC | |
| TIP | 0.020 | 0.061 | 0.020 | 0.563 | 0.563 | 0.894 | -6.300 |
| 1 | 0.020 | 0.064 | 0.020 | 0.564 | 0.564 | 0.927 | -5.800 |
| 2 | 0.020 | 0.068 | 0.020 | 0.565 | 0.565 | 0.962 | -4.700 |
| 3 | 0.020 | 0.085 | 0.020 | 0.552 | 0.552 | 1.109 | 0.900 |
| 4 | 0.020 | 0.094 | 0.020 | 0.551 | 0.551 | 1.183 | 4.100 |
| 5 | 0.020 | 0.096 | 0.020 | 0.561 | 0.561 | 1.200 | 5.000 |
| 6 | 0.020 | 0.098 | 0.020 | 0.573 | 0.573 | 1.217 | 5.800 |
| 7 | 0.020 | 0.101 | 0.020 | 0.581 | 0.581 | 1.234 | 6.700 |
| 8 | 0.020 | 0.103 | 0.020 | 0.589 | 0.589 | 1.252 | 7.600 |
| 9 | 0.020 | 0.122 | 0.020 | 0.650 | 0.650 | 1.390 | 15.600 |
| 10 | 0.020 | 0.143 | 0.020 | 0.689 | 0.689 | 1.486 | 26.800 |
| 11 | 0.020 | 0.149 | 0.020 | 0.688 | 0.688 | 1.488 | 30.400 |
| HUB | 0.020 | 0.154 | 0.020 | 0.685 | 0.685 | 1.486 | 32.600 |

Caractéristiques aérodynamiques

| | unités | valeurs |
|---|---------|---------|
| taux de compression | [-] | 1.801 |
| débit massique | [kg/s] | 29 |
| vitesse en tête | [m/s] | 420.6 |
| solidité en tête | [-] | 1.3 |
| allongement | [-] | 2.53 |
| vitesse de rotation nominale ω_n | [rad/s] | 1675.52 |

Propriétés matériau

Le matériau du rotor 3 est un alliage à base de nickel : un acier maraging de grade 200, mais ses caractéristiques ne sont pas fournies. Les propriétés considérées sont :

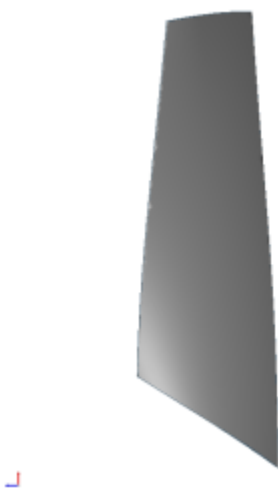
| | unité | valeurs |
|------------------------|----------------------|--------------------|
| alliage | [-] | 18-Ni-200-maraging |
| module d'Young | [GPa] | 180 |
| masse volumique | [kg/m ³] | 8000 |
| coefficient de Poisson | [-] | 0,3 |
| limite élastique | [GPa] | 1,38 |

Modèle CAO

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



intrados



extrados

Fréquences propres

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

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|------|------|----------------------------|-----------------------|
| 1 | 1F | 1722,54 | 274,15 |
| 2 | 2F | 6548,96 | 1042,3 |
| 3 | 1T | 8224,31 | 1308,94 |

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]:

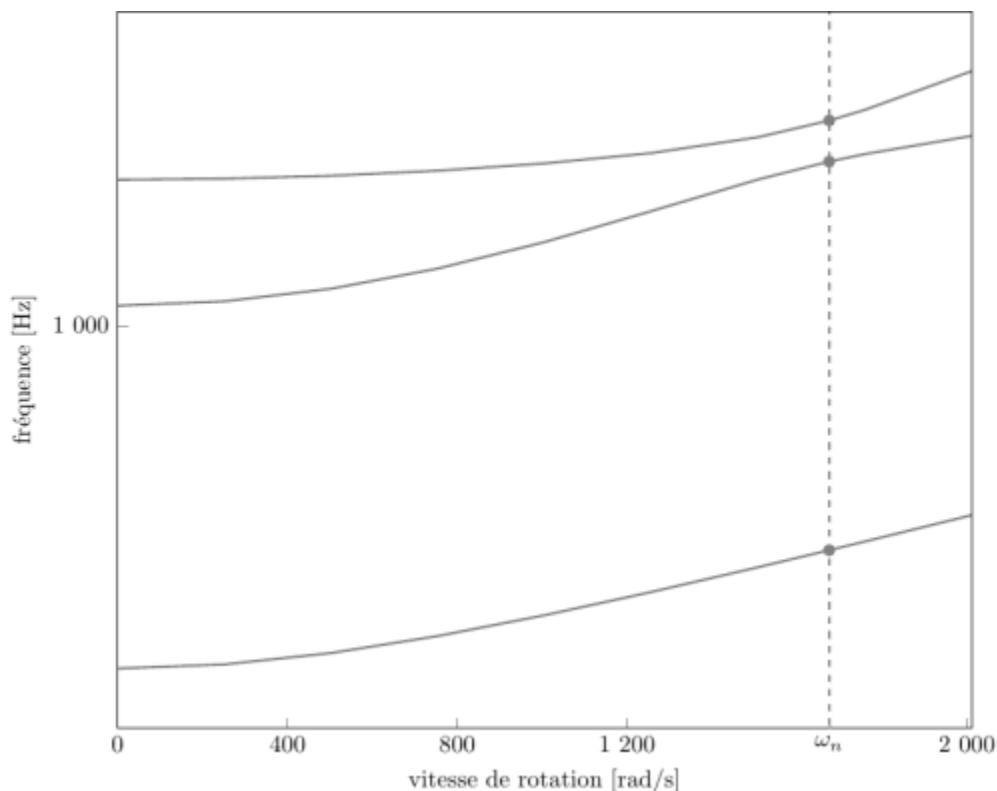


diagramme de Campbell calculé avec une précharge centrifuge linéaire, noeuds du pied d'aube encastrés (vitesse nominale $\omega_n = 1\,675,52$ rad/s)

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

Aube initiale

L'**aube initiale** est définie par des paramètres spécifiques au LAVA^[5] 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 encastrés),

- pour le maillage complet :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|------|------|----------------------------|-----------------------|
| 1 | 1F | 1728,06 | 275,029 |
| 2 | 2F | 6559,27 | 1043,94 |
| 3 | 1T | 8243,04 | 1311,92 |

- pour le modèle réduit :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|------|------|----------------------------|-----------------------|
| 1 | 1F | 1728,11 | 275,038 |
| 2 | 2F | 6561,34 | 1044,27 |
| 3 | 1T | 8245,298 | 1312,28 |

</tabs>

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:

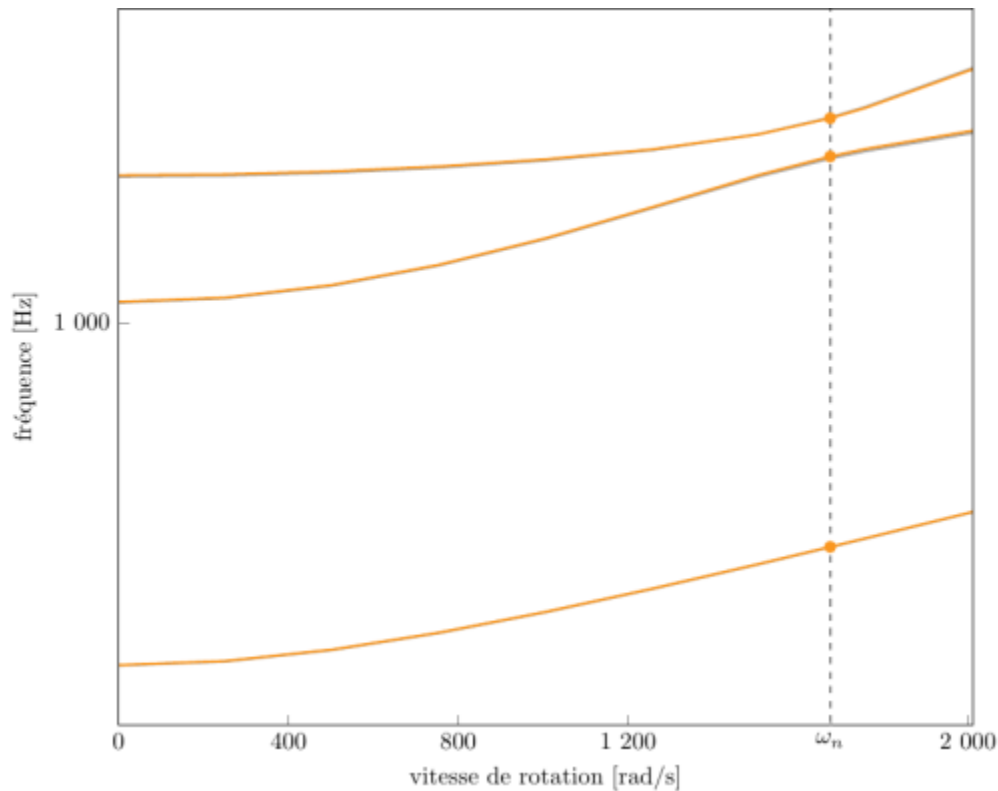


diagramme de Campbell calculé avec une précharge centrifuge linéaire, noeuds du pied d'aube encastrés (vitesse nominale $\omega_n = 1\,675,52$ rad/s),

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

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

1. ^{a, b} Hager. «Performance of a 1380-foot-per-second-tip-speed axial-flow compressor rotor with a blade tip solidity of 1.3 » 2013. [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. [code en libre accès](#)
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](#)

5. ^{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://wiki.lava.polymtl.ca/public/modeles/rotor_03/accueil?rev=1721854481

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