# Rotor 67

- Français
- English

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## About

To reduce fan noise, an advanced, two-stage, high-pressure-ratio fan having widely spaced blade rows was build and tested. Rotor 67 is the rotor of the first stage of this fan. But, the overall efficiency of this two-stage fan was approximately 5 percentage points less than its design value. Analysis of the test results indicated that the first-stage stator and the second stage had potential for good performance but were hampered mainly by the dampered first-stage rotor. The dampers were responsible for large radial gradients of total pressure and deviation angle across a large portion of the blade height, resulting in mismatches in later blade rows. To improve performance of the first stage as well as the stage matching, the original two-stage fan was reconfigured with a newly designed first-stage rotor. Lower-aspect-ratio blading was selected for the rotor to eliminate both the need for part span dampers and their associated penalties on aerodynamic performance.

- Original technical report [(cite:urasek1979design>Urasek D. C. *et al* «Performance of two-stage fan having low-aspect-ratio first-stage rotor blading » 1979. pdf)]:

```
@TechReport{urasek1979design,
  author           = {Urasek, D. C. and Gorrell, W. T. and Cunnan, W. S.},
  date             = {1979},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
States},
  title            = {Performance of two-stage fan having low-aspect-ratio
first-stage rotor blading},
  number           = {NASA-TP-1493},
  url              = {https://ntrs.nasa.gov/citations/19790018972},
}
```

- Picture :



Fig. 1 https://catalog.archives.gov/id/17500556

- ```
  @Misc{laity1980records,
  author   = {Laity, D.},
  title    = {Stage 67 rotor and stage 67 casing half stators mounted. {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     = {1980},
  url      = {https://catalog.archives.gov/id/17500556}}
  ```

**Useful documents**

- downloadable models (Git project)
  - NASA technical report (.pdf)
  - geometrical parameters file (.csv), usable as input of OpenMCAD[(cite:Kojtych_2022_gene_aubes>Kojtych S., Batailly A. «OpenMCAD, an open blade generator: from Multiple-Circular-Arc profiles to Computer-Aided Design model» 2022. open source code)] to generate reference blade models.

# Reference blade

The **reference blade** is defined with multiple-circular arc profiles[(cite:Crouse_1969_computer)] given in the original NASA report[(cite:urasek1979design)]. Corresponding models are computed with the open-source code OpenMCAD[(cite:Kojtych_2022_gene_aubes)].
  ```

## Geometry

The geometry of rotor 67 is described in the original NASA report by the following tables. The length are in centimeters and the angles in degrees.

TABLE III. - BLADE GEOMETRY

(a) First-stage rotor

| RP | PERCENT SPAN | RADII RI | RADII RO | BLADE ANGLES KIC | BLADE ANGLES KTC | BLADE ANGLES KOC | DELTA INC | CONE ANGLE |
|---|---|---|---|---|---|---|---|---|
| TIP | 0. | 25.530 | 24.773 | 66.61 | 64.83 | 54.06 | 2.30 | -10.639 |
| 1 | 5. | 24.880 | 24.125 | 64.56 | 62.39 | 53.15 | 2.36 | -9.797 |
| 2 | 10. | 24.178 | 23.478 | 62.83 | 60.14 | 52.50 | 2.42 | -8.542 |
| 3 | 20. | 22.753 | 22.184 | 60.85 | 56.86 | 51.60 | 2.58 | -6.433 |
| 4 | 30. | 21.294 | 20.889 | 59.01 | 53.98 | 48.25 | 2.74 | -4.239 |
| 5 | 40. | 19.810 | 19.595 | 56.81 | 50.88 | 43.24 | 3.13 | -2.073 |
| 6 | 50. | 18.291 | 18.301 | 54.27 | 47.40 | 36.70 | 3.79 | .086 |
| 7 | 60. | 16.723 | 17.006 | 51.40 | 43.47 | 29.05 | 4.56 | 2.299 |
| 8 | 70. | 15.081 | 15.712 | 47.44 | 39.04 | 19.53 | 6.24 | 4.679 |
| 9 | 80. | 13.349 | 14.418 | 43.79 | 34.97 | 7.60 | 7.28 | 7.330 |
| 10 | 90. | 11.493 | 13.123 | 41.40 | 31.81 | -6.39 | 6.56 | 10.521 |
| 11 | 95. | 10.503 | 12.476 | 40.30 | 30.59 | -13.82 | 5.93 | 12.427 |
| HUB | 100. | 9.583 | 11.829 | 39.35 | 29.60 | -21.38 | 5.24 | 13.854 |

| RP | BLADE THICKNESSES TI | BLADE THICKNESSES TM | BLADE THICKNESSES TO | AXIAL DIMENSIONS ZI | AXIAL DIMENSIONS ZMC | AXIAL DIMENSIONS ZTC | AXIAL DIMENSIONS ZO |
|---|---|---|---|---|---|---|---|
| TIP | .033 | .269 | .033 | 2.578 | 4.987 | 5.238 | 6.607 |
| 1 | .033 | .272 | .034 | 2.397 | 4.999 | 5.159 | 6.767 |
| 2 | .034 | .279 | .035 | 2.236 | 5.002 | 5.064 | 6.896 |
| 3 | .038 | .309 | .039 | 2.013 | 4.973 | 4.838 | 7.061 |
| 4 | .044 | .360 | .046 | 1.798 | 4.921 | 4.562 | 7.250 |
| 5 | .050 | .423 | .053 | 1.573 | 4.843 | 4.239 | 7.500 |
| 6 | .057 | .496 | .061 | 1.335 | 4.732 | 3.867 | 7.806 |
| 7 | .067 | .574 | .070 | 1.066 | 4.616 | 3.418 | 8.128 |
| 8 | .075 | .653 | .078 | .805 | 4.441 | 2.896 | 8.514 |
| 9 | .082 | .725 | .084 | .528 | 4.329 | 2.337 | 8.837 |
| 10 | .089 | .781 | .088 | .236 | 4.336 | 1.785 | 9.014 |
| 11 | .091 | .800 | .090 | .110 | 4.332 | 1.531 | 9.065 |
| HUB | .092 | .814 | .092 | -.000 | 4.329 | 1.305 | 9.104 |

## Aerodynamic design

| | unit | values |
|---|---|---|
| **pressure ratio** | [-] | 1.63 |
| **mass flow** | [kg/s] | 33.248 |
| **tip speed** | [m/s] | 427 |
| **tip solidity** | [-] | 1.288 |
| **aspect ratio** | [-] | 1.56 |
| **number of blades** | [-] | 22 |
| **nominal rotation speed $\omega_n$** | [rad/s] | 1680 |

## Material properties

The original material of the rotor 67 is not defined in the NASA report. A generic titanium Ti-6Al-4V is considered:

| | units | values |
|---|---|---|
| **alloy** | [-] | Ti-6Al-4V |
| **Young's modulus** | [GPa] | 108 |
| **density** | [kg/m3] | 4400 |
| **Poisson's ratio** | [-] | 0.34 |

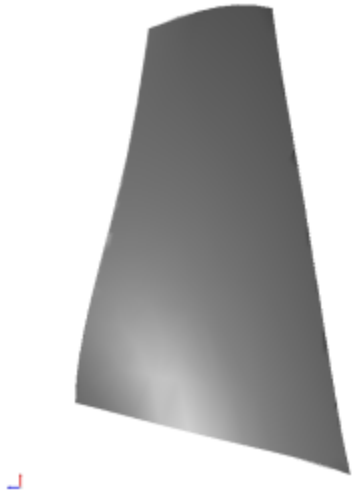
| | units | values |
|---|---|---|
| **yield stress** | [GPa] | 0.824 |

## CAD model

The CAD model is computed with the open source code OpenMCAD[(cite:Kojtych_2022_gene_aubes)].



pressure side



suction side

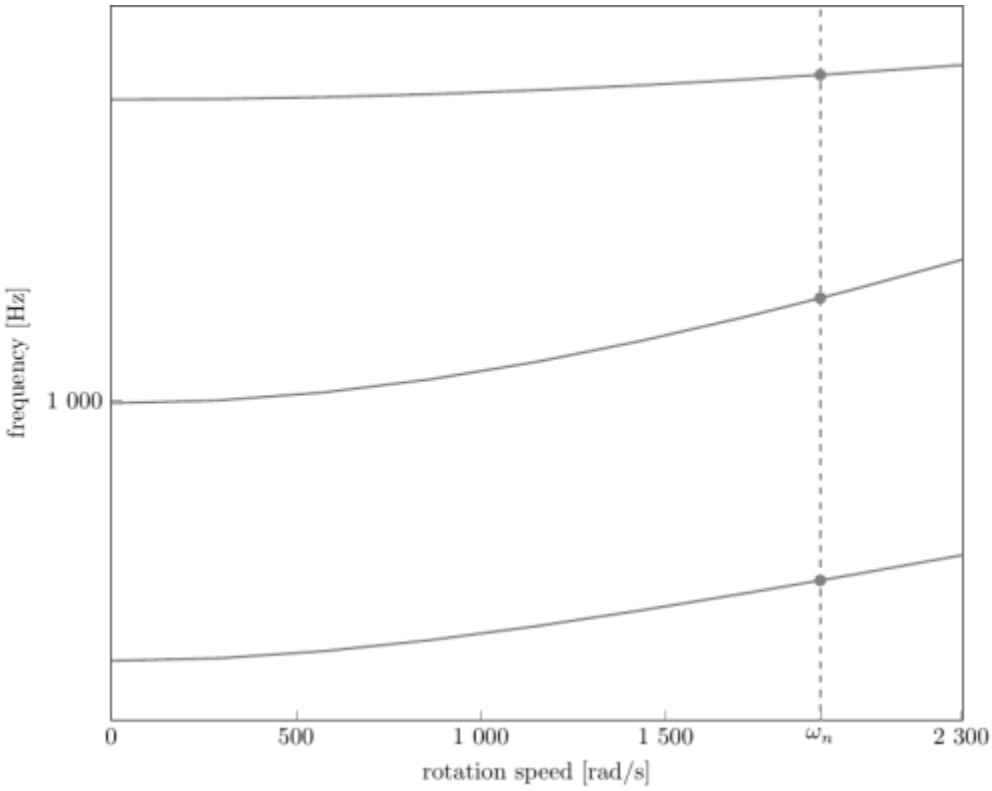
## Natural frequencies

First three natural frequencies (with clamped root) for the mesh computed with OpenMCAD[(cite:Kojtych_2022_gene_aubes)]:

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|---|---|---|---|
| 1 | 1B | 2318.54 | 369.01 |
| 2 | 2B | 6244.46 | 993.84 |
| 3 | 1T | 10871.29 | 1730.22 |

### 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[(cite:Kojtych_2022_gene_aubes)]:




Campbell diagram computed with a linear centrifugal preload, with clamped root (nominal rotation speed $\omega_n$ = 1 680 rad/s)

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

## Initial blade

The **initial blade** is defined with in-house LAVA parameters[(cite:Kojtych_2022_Methodology)] 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 | 2310.04 | 367.66 |
| 2 | 2B | 6215.77 | 989.27 |
| 3 | 1T | 10842.26 | 1725.60 |

- from the reduced order model:

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|---|---|---|---|
| 1 | 1B | 2310.36 | 367.71 |
| 2 | 2B | 6222.56 | 990.35 |
| 3 | 1T | 10866.01 | 1729.38 |

Fichiers téléchargeables
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**Libre accès**

**lien vers le projet Git**

# À propos

Pour réduire le bruit des soufflantes, une soufflante a deux étages a été construite et testée. Cette soufflante possède un grand taux de compression (2.4) et ses rangées d'aubes sont très espacées. Le rotor 67 est le rotor du premier étage de cette soufflante. Cependant, le rendement global de cette soufflante à deux étages était inférieur d'environ 5% au rendement prévu. L'analyse des résultats des essais a montré que le stator du premier étage et le deuxième étage avaient un potentiel de bonnes performances, mais qu'ils étaient entravés principalement par le rotor du premier étage qui était amorti. Les amortisseurs étaient responsables d'importants gradients de pression totale et d'angle de déviation sur une grande partie de la hauteur des aubes, ce qui a entraîné des déséquilibres dans les rangées d'aubes ultérieures. Pour améliorer les performances du premier étage ainsi que l'appariement des étages, le rotor du premier étage a été reconfiguré. Des aubes à faible allongement d'aspect ont été privilégiées.

- Rapport technique original [(cite:urasek1979design>)]:

```
@TechReport{urasek1979design,
  author           = {Urasek, D. C. and Gorrell, W. T. and Cunnan, W. S.},
  date             = {1979},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
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  title            = {Performance of two-stage fan having low-aspect-ratio
first-stage rotor blading},
  number           = {NASA-TP-1493},
  url              = {https://ntrs.nasa.gov/citations/19790018972},
}
```

- Photographie :



Fig1. https://catalog.archives.gov/id/17500556

- ```
  @Misc{laity1980records,
  author   = {Laity, D.},
  title    = {Stage 67 rotor and stage 67 casing half stators mounted.
  {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     = {1980},
  url      = {https://catalog.archives.gov/id/17500556}}
  ```

**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[(cite:Kojtych_2022_gene_aubes>)] pour générer l'aube de référence

# Aube de référence

L'**aube de référence** est définie par des profils de type arcs circulaires multiples[(cite:Crouse_1969_computer>Crouse *et al*. «A computer program for composing compressor blading from simulated circular-arc elements on conical surfaces » 1969. NASA-TN-D-5437. pdf)], donnés dans le rapport technique original de la NASA[(cite:urasek1979design)]. Les modèles associés sont obtenus avec le code en libre accès OpenMCAD[(cite:Kojtych_2022_gene_aubes)].
  ```

## Géométrie

La géométrie du rotor 67 est décrite dans le rapport d'origine de la NASA par les tableaux suivants. Les grandeurs sont en centimètres et en degrés.

TABLE III. - BLADE GEOMETRY

(a) First-stage rotor

| RP | PERCENT SPAN | RADII RI | RADII RO | BLADE ANGLES KIC | BLADE ANGLES KTC | BLADE ANGLES KOC | DELTA INC | CONE ANGLE |
|---|---|---|---|---|---|---|---|---|
| TIP | 0. | 25.530 | 24.773 | 66.61 | 64.83 | 54.06 | 2.30 | -10.639 |
| 1 | 5. | 24.880 | 24.125 | 64.56 | 62.39 | 53.15 | 2.36 | -9.797 |
| 2 | 10. | 24.178 | 23.478 | 62.83 | 60.14 | 52.50 | 2.42 | -8.542 |
| 3 | 20. | 22.753 | 22.184 | 60.85 | 56.86 | 51.60 | 2.58 | -6.433 |
| 4 | 30. | 21.294 | 20.889 | 59.01 | 53.98 | 48.25 | 2.74 | -4.239 |
| 5 | 40. | 19.810 | 19.595 | 56.81 | 50.88 | 43.24 | 3.13 | -2.073 |
| 6 | 50. | 18.291 | 18.301 | 54.27 | 47.40 | 36.70 | 3.79 | .086 |
| 7 | 60. | 16.723 | 17.006 | 51.40 | 43.47 | 29.05 | 4.56 | 2.299 |
| 8 | 70. | 15.081 | 15.712 | 47.44 | 39.04 | 19.53 | 6.24 | 4.679 |
| 9 | 80. | 13.349 | 14.418 | 43.79 | 34.97 | 7.60 | 7.28 | 7.330 |
| 10 | 90. | 11.493 | 13.123 | 41.40 | 31.81 | -6.39 | 6.56 | 10.521 |
| 11 | 95. | 10.503 | 12.476 | 40.30 | 30.59 | -13.82 | 5.93 | 12.427 |
| HUB | 100. | 9.583 | 11.829 | 39.35 | 29.60 | -21.38 | 5.24 | 13.854 |

| RP | BLADE THICKNESSES TI | BLADE THICKNESSES TM | BLADE THICKNESSES TO | AXIAL DIMENSIONS ZI | AXIAL DIMENSIONS ZMC | AXIAL DIMENSIONS ZTC | AXIAL DIMENSIONS ZO |
|---|---|---|---|---|---|---|---|
| TIP | .033 | .269 | .033 | 2.578 | 4.987 | 5.238 | 6.607 |
| 1 | .033 | .272 | .034 | 2.397 | 4.999 | 5.159 | 6.767 |
| 2 | .034 | .279 | .035 | 2.236 | 5.002 | 5.064 | 6.896 |
| 3 | .038 | .309 | .039 | 2.013 | 4.973 | 4.838 | 7.061 |
| 4 | .044 | .360 | .046 | 1.798 | 4.921 | 4.562 | 7.250 |
| 5 | .050 | .423 | .053 | 1.573 | 4.843 | 4.239 | 7.500 |
| 6 | .057 | .496 | .061 | 1.335 | 4.732 | 3.867 | 7.806 |
| 7 | .067 | .574 | .070 | 1.066 | 4.616 | 3.418 | 8.128 |
| 8 | .075 | .653 | .078 | .805 | 4.441 | 2.896 | 8.514 |
| 9 | .082 | .725 | .084 | .528 | 4.329 | 2.337 | 8.837 |
| 10 | .089 | .781 | .088 | .236 | 4.336 | 1.785 | 9.014 |
| 11 | .091 | .800 | .090 | .110 | 4.332 | 1.531 | 9.065 |
| HUB | .092 | .814 | .092 | -.000 | 4.329 | 1.305 | 9.104 |

## Caractéristiques aérodynamiques

| | unités | valeurs |
|---|---|---|
| **taux de compression** | [-] | 1,63 |
| **débit massique** | [kg/s] | 33,248 |
| **vitesse en tête** | [m/s] | 427 |
| **solidité en tête** | [-] | 1,288 |
| **allongement** | [-] | 1,56 |
| **nombre d'aubes** | [-] | 22 |
| **vitesse de rotation nominale $\omega_n$** | [rad/s] | 1680 |

## Propriétés matériau

Le matériau original du rotor 67 n'est pas défini dans le rapport de la NASA. Un alliage de titane Ti-6Al-4v est considéré :

| | unités | valeurs |
|---|---|---|
| **alliage** | [-] | Ti-6Al-4v |
| **module d'Young** | [GPa] | 108 |
| **masse volumique** | [kg/m3] | 4400 |

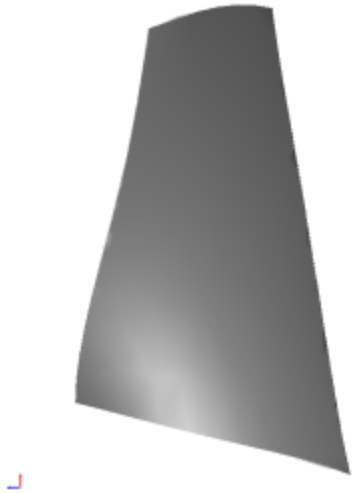
| | unités | valeurs |
|---|---|---|
| **coefficient de Poisson** | [-] | 0,34 |
| **limite élastique** | [GPa] | 0,824 |

## Modèle CAO

Le modèle CAO est obtenu avec OpenMCAD[(cite:Kojtych_2022_gene_aubes)].



intrados



extrados

## Fréquences propres

Fréquences des trois premiers modes (noeuds du pied d'aube encastrés) pour le maillage obtenu avec OpenMCAD[(cite:Kojtych_2022_gene_aubes)] :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|---|---|---|---|
| 1 | 1F | 2318,54 | 369,01 |
| 2 | 2F | 6244,46 | 993,84 |
| 3 | 1T | 10871,29 | 1730,22 |

### Diagramme de Campbell

Évolution des fréquences propres des 3 premiers modes, en fonction de la vitesse de rotation, pour le maillage obtenu avec OpenMCAD[(cite:Kojtych_2022_gene_aubes)]:

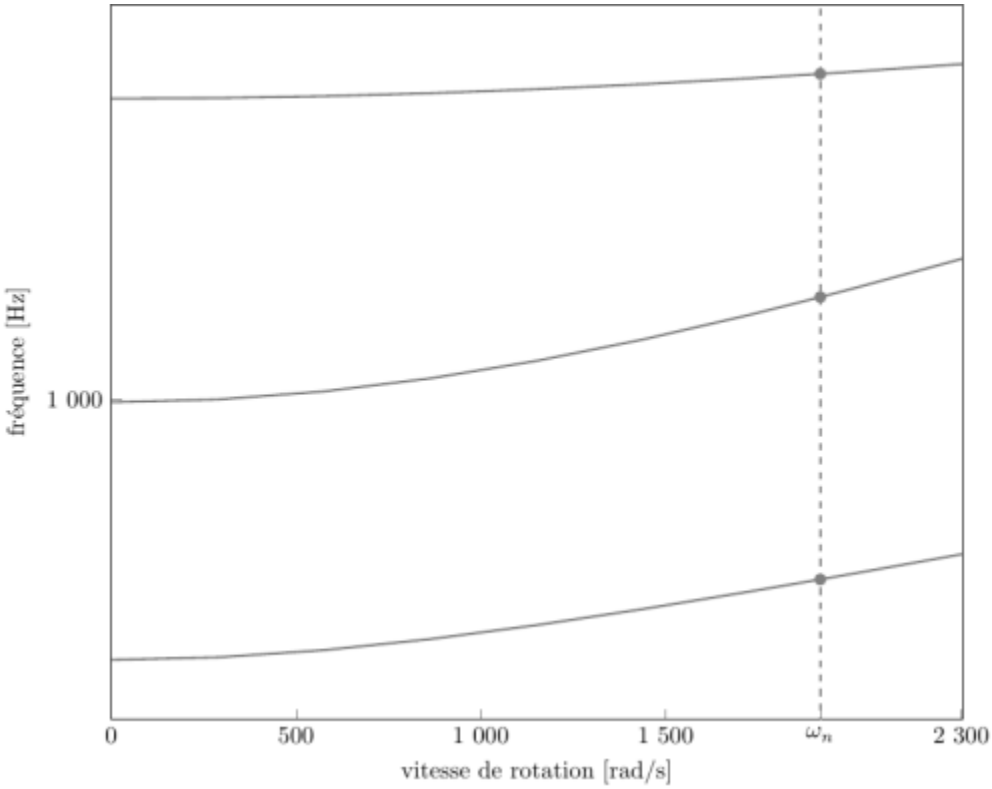



diagramme de Campbell calculé avec une précharge centrifuge linéaire, noeuds du pied d'aube encastrés (vitesse nominale $\omega_n$ = 1 680 rad/s)

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

# Aube initiale

L'**aube initiale** est définie par des paramètres spécifiques au LAVA[(cite:Kojtych_2022_Methodology>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)] 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 | 2310,04 | 367,66 |

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|---|---|---|---|
| 2 | 2F | 6215,77 | 989,27 |
| 3 | 1T | 10842,26 | 1725,60 |

- pour le modèle réduit :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|---|---|---|---|
| 1 | 1F | 2310,36 | 367,71 |
| 2 | 2F | 6222,56 | 990,35 |
| 3 | 1T | 10866,01 | 1729,38 |

## 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:

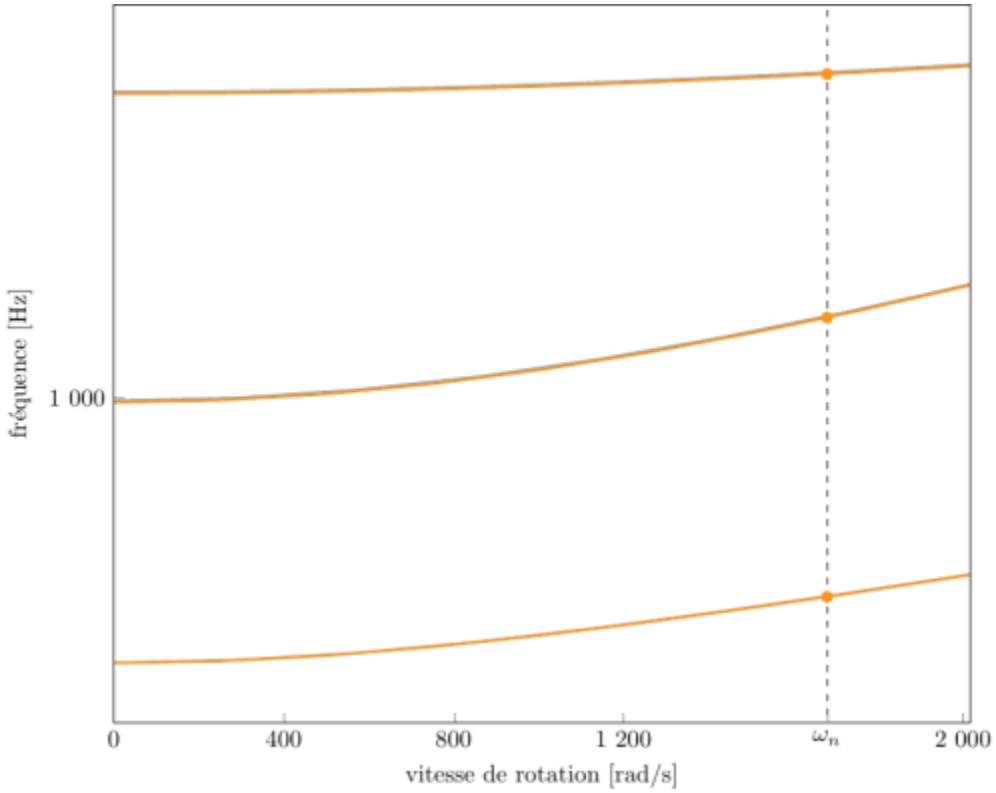



diagramme de Campbell calculé avec une précharge centrifuge linéaire, noeuds du pied d'aube encastrés (vitesse nominale $\omega_n$ = 1 680 rad/s),

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

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

Document issu de la page wiki:
**https://wiki.lava.polymtl.ca/public/modeles/rotor_67/accueil?rev=1722541154**

Dernière mise à jour: **2024/08/01 15:39**