

Rotor 35

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Original model

Rotor 35 is part of a research program to study a advanced-core compressor design with a high compression ratio (20:1). It is therefore the first stage rotor of this eight stage transonic compressor. Of these eight stages, the first four have been designed and tested : rotors 35, 36, 37 and 38. For more information, here is a link to [a report from NASA](#).

- Original technical report ^[1]:

```
@TechReport{reid1982design,  
  author      = {Reid, L. and Moore, R. D.},  
  date        = {1982},  
  institution  = {NASA Lewis Research Center Cleveland, OH, United  
States},  
  title       = {Performance of single-stage axial-flow transonic  
compressor with rotor and stator aspect ratios of 1.63 and 1.78, respectively,  
and with design pressure ratio of 1.82},  
  number      = {NASA-TP-1974},  
  url         = {https://ntrs.nasa.gov/citations/19820011348},  
}
```

- Picture :



Fig. 1 <https://catalog.archives.gov/id/17466807>

- `@Misc{brown1977records, author = {Brown, M.}, title = {Rotor 35 - Rotor 35 - Stator 35 in casing. {R}ecords of the {N}ational {A}eronautics and {S}pace {A}dministration, 1903 - 2006. {P}hotographs relating to agency activities, facilities and personnel, 1977 - 2013}, url = {https://catalog.archives.gov/id/17466807}}`

Useful documents

- [downloadable models](#) (Git project)
- PDF of the NASA report :
rotor35.pdf
- CSV file of the blade geometry :
rotor35_original.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 35 is described in the original NASA report by the following tables. The length are in centimeters and the angles in degrees.

(a) For rotor 35

RP	PERCENT		RADII		BLADE ANGLES			DELTA	CONE
	SPAN	RI	RO	KIC	KTC	KOC	INC	ANGLE	
TIP	0.	25.248	24.511	62.55	62.99	53.21	2.09	-15.764	
1	5.	24.916	24.221	61.52	61.84	52.53	2.41	-14.327	
2	10.	24.571	23.931	60.55	60.74	51.87	2.72	-12.780	
3	15.	24.224	23.642	59.80	59.85	51.23	2.96	-11.326	
4	30.	23.163	22.772	58.34	57.74	48.54	3.41	-7.137	
5	50.	21.726	21.613	56.16	54.31	44.26	4.21	-1.890	
6	70.	20.221	20.454	53.70	49.53	39.16	5.51	3.545	
7	85.	19.019	19.584	52.28	47.30	33.31	6.56	8.150	
8	90.	18.596	19.294	52.00	46.85	30.96	6.86	9.887	
9	95.	18.158	19.005	51.82	46.50	28.36	7.18	11.763	
HUB	100.	17.780	18.715	51.69	46.24	25.70	7.46	12.787	

RP	BLADE THICKNESSES			AXIAL DIMENSIONS			
	TI	TM	TO	ZI	ZMC	ZTC	ZO
TIP	.025	.175	.025	.698	2.410	2.379	3.308
1	.027	.187	.027	.635	2.331	2.345	3.354
2	.028	.199	.028	.576	2.313	2.301	3.398
3	.029	.212	.029	.529	2.269	2.242	3.438
4	.032	.252	.032	.417	2.188	2.051	3.542
5	.037	.305	.038	.280	2.133	1.896	3.701
6	.042	.361	.043	.129	2.045	1.749	3.884
7	.047	.408	.047	.058	1.992	1.715	4.007
8	.048	.425	.049	.037	1.967	1.646	4.046
9	.050	.443	.050	.017	1.940	1.579	4.082
HUB	.051	.458	.051	.000	1.915	1.520	4.118

Aerodynamic design

	unit	values
pressure ratio	[-]	1.82
mass flow	[kg/s]	20.2
tip speed	[m/s]	455
tip solidity	[-]	1.3
aspect ratio	[-]	1.19
number of blades	[-]	36
nominal rotation speed ω_n	[rad/s]	1800

Material properties

Rotor 35 is made of a 200-grade maraging steel^[4], but the exact material properties are not provided in the NASA report. The following properties are considered :

	unité	valeurs
alloy	[-]	18-Ni-200-maraging
Young's modulus	[GPa]	180
density	[kg/m ³]	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].



pressure side



suction side

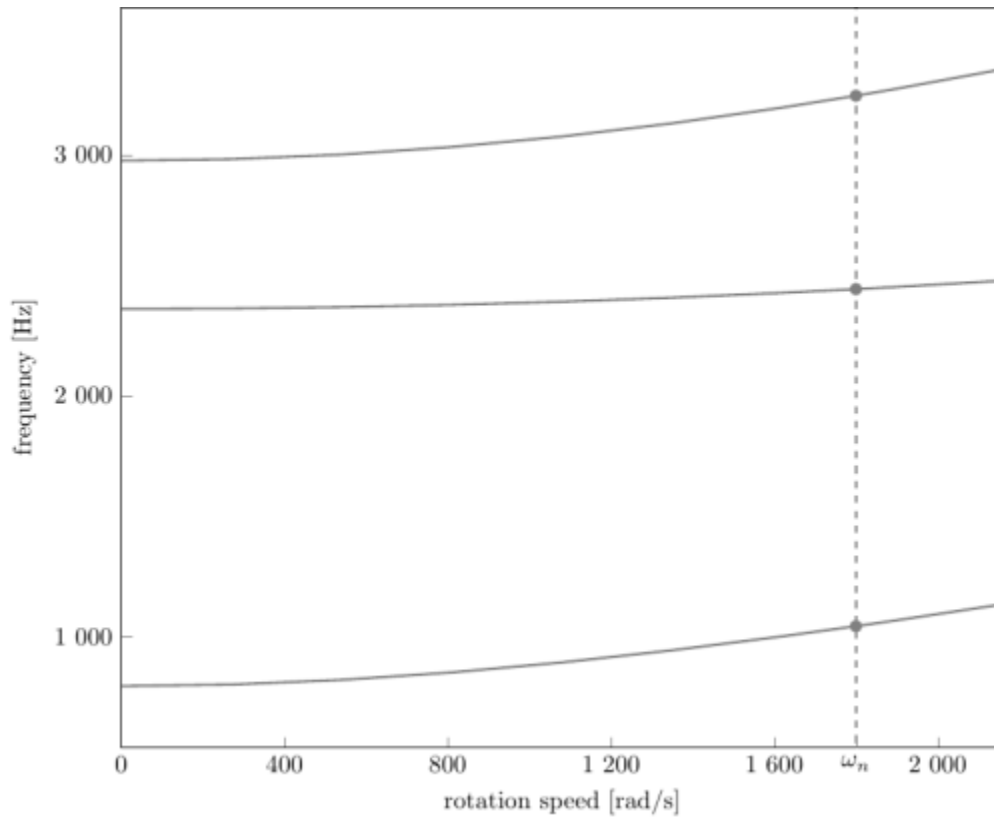
Natural frequencies

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	5000.55	795.86
2	1T	14833.91	2360.89
3	2B	18699.83	2976.17

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 $\omega_n = 1\,800$ 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	5037.31	801.71
2	1T	14910.06	2373.01
3	2B	18900.76	3008.15

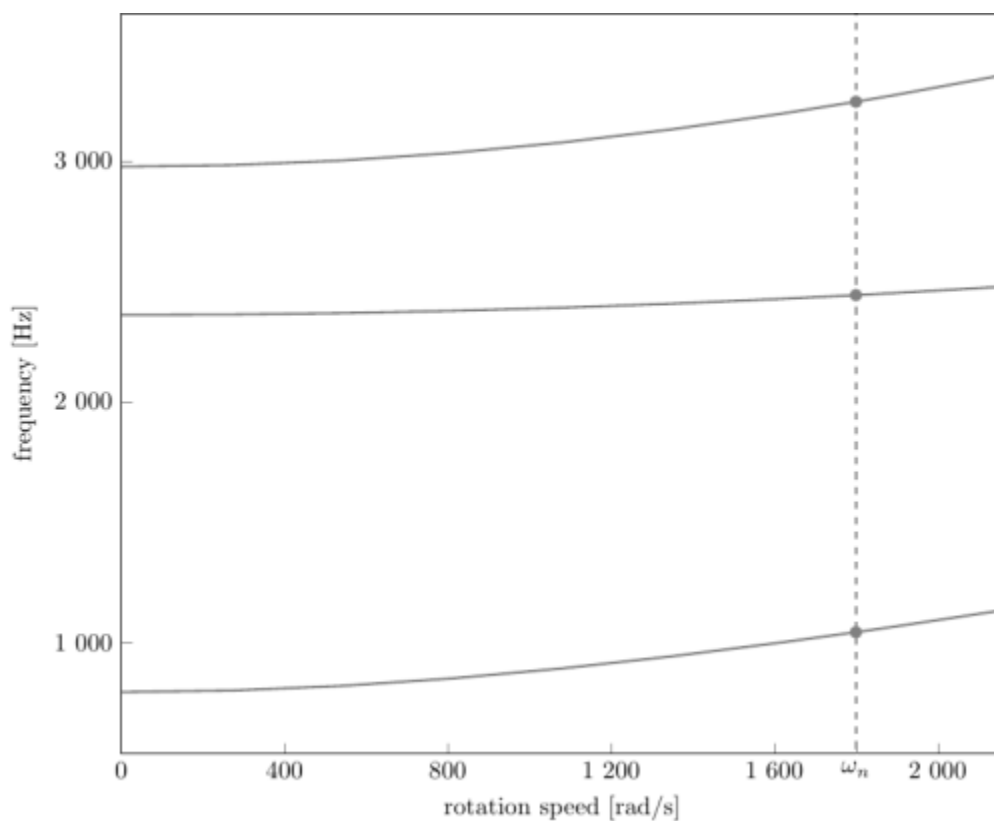
- from the reduced order model:

Mode	Type	Natural angular frequency (rad/sec)	Natural frequency (Hz)
1	1B	5037.84	801.80

Mode	Type	Natural angular frequency (rad/sec)	Natural frequency (Hz)
2	1T	14917.41	2374.18
3	2B	18926.96	3012.32

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 $\omega_n = 1800$ 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](#)

Modèle original

Le rotor 35 appartient à un programme de recherche visant à étudier une conception de compresseur possédant un grand taux de compression (20:1). Il est donc le rotor du premier étage de ce compresseur transsonique de huit étages. Parmi ces huit étages, les quatre premiers ont été conçus et testés, ils correspondent aux rotors 35, 36, 37 et 38. Pour plus d'information, voici un lien vers [un rapport de la NASA](#).

- Rapport technique original ^[6]:

```
@TechReport{reid1982design,  
  author      = {Reid, L. and Moore, R. D.},  
  date        = {1982},  
  institution = {NASA Lewis Research Center Cleveland, OH, United  
States},  
  title       = {Performance of single-stage axial-flow transonic  
compressor with rotor and stator aspect ratios of 1.63 and 1.78,  
respectively, and with design pressure ratio of 1.82},  
  number      = {NASA-TP-1974},  
  url         = {https://ntrs.nasa.gov/citations/19820011348},  
}
```

- Photographie :



Fig. 1 <https://catalog.archives.gov/id/17466807>

- ```
@Misc{brown1977records,
author = {Brown, M.},
title = {Rotor 35 - Rotor 35 - Stator 35 in casing. {R}ecords of the
{N}ational {A}eronautics and {S}pace {A}dministration, 1903 - 2006.
{P}hotographs relating to agency activities, facilities and personnel,
1977 - 2013},
url = {https://catalog.archives.gov/id/17466807}}
```

### Documents utiles

- [modèles téléchargeables](#) (lien vers projet Git)
- PDF du rapport de la NASA :  
[rotor35.pdf](#)
- Fichier CSV de la géométrie :  
[rotor35\\_original.csv](#)  
, utilisable en entrée de OpenMCAD<sup>[2]</sup> pour générer l'aube de référence

## Aube de référence

L'**aube de référence** est définie par des profils de type arcs circulaires multiples<sup>[3]</sup>, donnés dans le rapport technique original de la NASA<sup>[6]</sup>. Les modèles associés sont obtenus avec le code en libre accès OpenMCAD<sup>[2]</sup>.

## Géométrie

La géométrie du rotor 35 est décrite dans le [rapport d'origine de la NASA](#) par les tableaux suivants. Les grandeurs sont en centimètres et en degrés.

## (a) For rotor 35

| RP  | PERCENT |        |        | RADII |       |       | BLADE ANGLES |         |  | DELTA<br>INC | CONE<br>ANGLE |
|-----|---------|--------|--------|-------|-------|-------|--------------|---------|--|--------------|---------------|
|     | SPAN    | RI     | RG     | KIC   | KTC   | KOC   | INC          | ANGLE   |  |              |               |
| TIP | 0.      | 25.248 | 24.511 | 62.55 | 62.99 | 53.21 | 2.09         | -15.764 |  |              |               |
| 1   | 5.      | 24.916 | 24.221 | 61.52 | 61.84 | 52.53 | 2.41         | -14.327 |  |              |               |
| 2   | 10.     | 24.571 | 23.931 | 60.55 | 60.74 | 51.87 | 2.72         | -12.780 |  |              |               |
| 3   | 15.     | 24.224 | 23.642 | 59.80 | 59.85 | 51.23 | 2.96         | -11.326 |  |              |               |
| 4   | 30.     | 23.163 | 22.772 | 58.34 | 57.74 | 48.54 | 3.41         | -7.137  |  |              |               |
| 5   | 50.     | 21.726 | 21.613 | 56.16 | 54.31 | 44.26 | 4.21         | -1.890  |  |              |               |
| 6   | 70.     | 20.221 | 20.454 | 53.70 | 49.53 | 39.16 | 5.51         | 3.545   |  |              |               |
| 7   | 85.     | 19.019 | 19.584 | 52.28 | 47.30 | 33.31 | 6.56         | 8.150   |  |              |               |
| 8   | 90.     | 18.596 | 19.294 | 52.00 | 46.85 | 30.96 | 6.86         | 9.887   |  |              |               |
| 9   | 95.     | 18.158 | 19.005 | 51.82 | 46.50 | 28.36 | 7.18         | 11.763  |  |              |               |
| HUB | 100.    | 17.780 | 18.715 | 51.69 | 46.24 | 25.70 | 7.46         | 12.787  |  |              |               |

| RP  | BLADE THICKNESSES |      |      | AXIAL DIMENSIONS |       |       |       |
|-----|-------------------|------|------|------------------|-------|-------|-------|
|     | TI                | TH   | TO   | ZI               | ZMC   | ZTC   | ZO    |
| TIP | .025              | .175 | .025 | .698             | 2.410 | 2.379 | 3.308 |
| 1   | .027              | .187 | .027 | .635             | 2.531 | 2.345 | 3.354 |
| 2   | .028              | .199 | .028 | .576             | 2.313 | 2.301 | 3.398 |
| 3   | .029              | .212 | .029 | .529             | 2.269 | 2.242 | 3.438 |
| 4   | .032              | .252 | .032 | .417             | 2.188 | 2.051 | 3.542 |
| 5   | .037              | .305 | .038 | .280             | 2.133 | 1.896 | 3.701 |
| 6   | .042              | .361 | .043 | .129             | 2.045 | 1.749 | 3.884 |
| 7   | .047              | .408 | .047 | .058             | 1.992 | 1.715 | 4.007 |
| 8   | .048              | .425 | .049 | .037             | 1.967 | 1.646 | 4.046 |
| 9   | .050              | .443 | .050 | .017             | 1.940 | 1.579 | 4.082 |
| HUB | .051              | .458 | .051 | .000             | 1.915 | 1.520 | 4.118 |

## Caractéristiques aérodynamiques

|                                         | unités  | valeurs |
|-----------------------------------------|---------|---------|
| taux de compression                     | [-]     | 1,82    |
| débit massique                          | [kg/s]  | 20,2    |
| vitesse en tête                         | [m/s]   | 455     |
| solidité en tête                        | [-]     | 1,3     |
| allongement                             | [-]     | 1,19    |
| nombre d'aubes                          | [-]     | 36      |
| vitesse de rotation nominale $\omega_n$ | [rad/s] | 1800    |

## Propriétés matériau

Le matériau du rotor 35 est un alliage à base de nickel : un acier maraging de grade 200<sup>[4]</sup>, mais ses caractéristiques ne sont pas fournies dans le rapport de la NASA. Les propriétés considérées sont :

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

## Modèle CAO

Le modèle CAO est obtenu avec OpenMCAD<sup>[2]</sup>.



intrados



extrados

## Fréquences propres

Fréquences des trois premiers modes (noeuds du pied d'aube encastés) pour le maillage obtenu avec OpenMCAD<sup>[2]</sup> :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|------|------|----------------------------|-----------------------|
| 1    | 1B   | 5000,55                    | 795,86                |
| 2    | 1T   | 14833,91                   | 2360,89               |
| 3    | 2B   | 18699,83                   | 2976,17               |

## Diagramme de Campbell

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

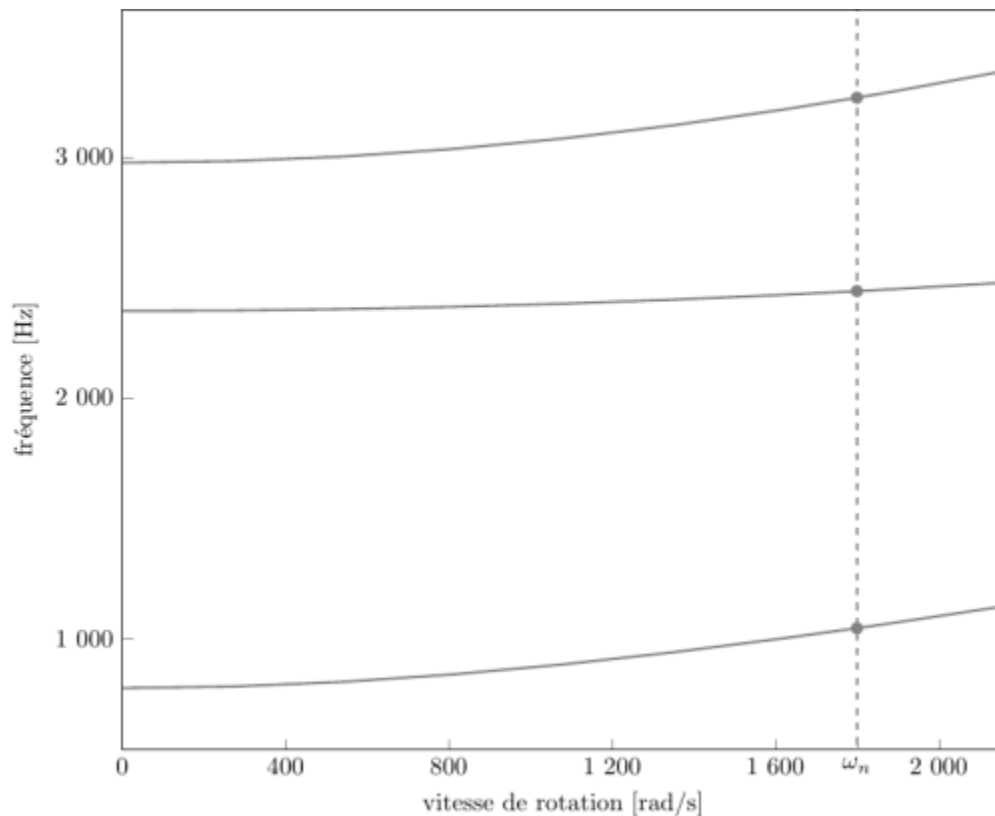


diagramme de Campbell calculé avec une précharge centrifuge linéaire, noeuds du pied d'aube encastrés (vitesse nominale  $\omega_n = 1800$  rad/s)

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

## Aube initiale

L'**aube initiale** est définie par des paramètres spécifiques au LAVA<sup>[5]</sup> 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    | 1B   | 5037,31                    | 801,71                |
| 2    | 1T   | 14910,06                   | 2373,01               |
| 3    | 2B   | 18900,76                   | 3008,15               |

- pour le modèle réduit :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|------|------|----------------------------|-----------------------|
| 1    | 1B   | 5037,84                    | 801,80                |

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|------|------|----------------------------|-----------------------|
| 2    | 1T   | 14917,41                   | 2374,18               |
| 3    | 2B   | 18926,96                   | 3012,32               |

## 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:

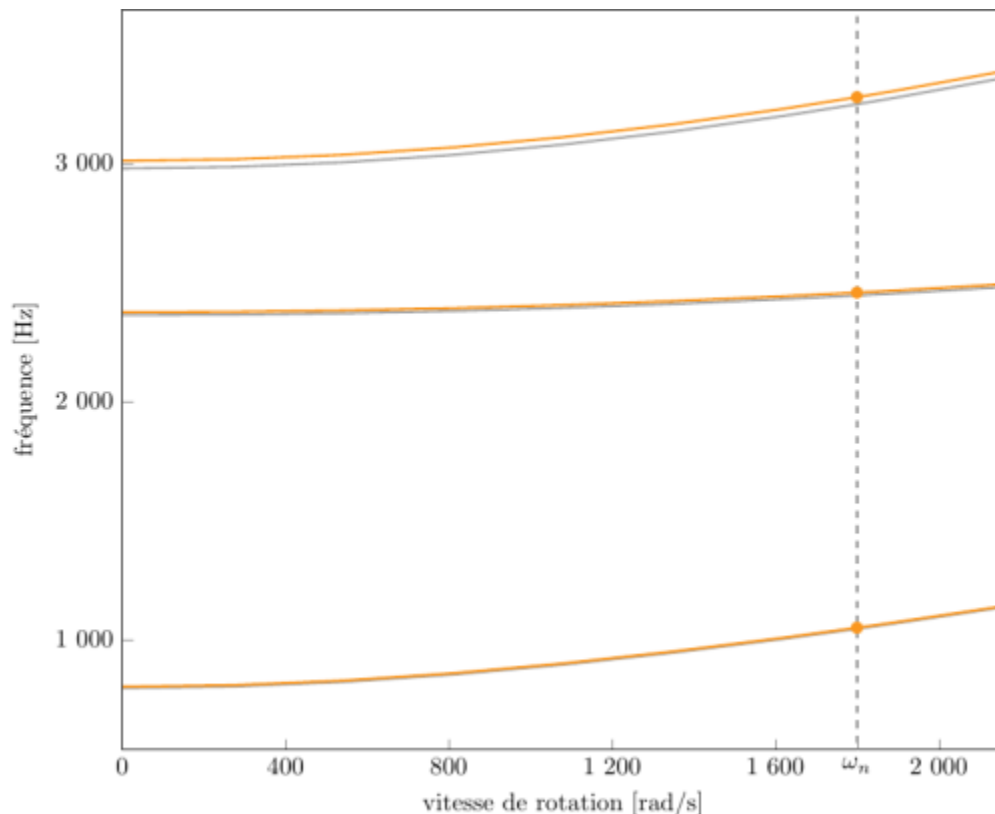


diagramme de Campbell calculé avec une précharge centrifuge linéaire, noeuds du pied d'aube encastrés (vitesse nominale  $\omega_n = 1800$  rad/s),

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

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

- <sup>a, b</sup> Reid L., Moore R. D. «Performance of Single-Stage Axial-Flow Transonic Compressor With Rotor and Stator Aspect Ratios of 1.19 and 1.26, Respectively, and With Design Pressure Ratio of 1.82 » 1978. [pdf](#)
- <sup>a, b, c, d, e, f, g, h, i, j</sup> Kojtych S., Batailly A. «OpenMCAD, an open blade generator: from Multiple-Circular-Arc profiles to Computer-Aided Design model» 2022. [open source code](#)
- <sup>a, b</sup> Crouse *et al.* «A computer program for composing compressor blading from simulated circular-arc elements on conical surfaces » 1969. NASA-TN-D-5437. [pdf](#)
- <sup>a, b</sup> Reid *et al.* «Design and overall performance of four highly loaded, high-speed inlet stages for and

advanced high-pressure-ratio core compressor» 1978. [pdf](#)

5. <sup>a, b</sup> 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\\_35/accueil](https://wiki.lava.polymtl.ca/public/modeles/rotor_35/accueil)

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