Rotor 66

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About

Rotor 66 is part of a 51 centimeter-diameter, five-stage compressor having a design weight flow of 29.7 kilograms per second with a pressure ratio of 9.27. Performance data obtained from tests indicated that the first stage was not meeting its design performance.

- Original technical report [(cite:urasek1976design>Urasek D. C. *et at* «Performance of inlet stage of transonic compressor» 1976 pdf)]:

```
@TechReport{urasek1976design,
  author           = {Urasek, Donald C. and Steinke, Ronald J. and Lewis,
George W.},
  date             = {1976},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
States},
  title            = {Performance of inlet stage of transonic compressor},
  number           = {NASA-TM X-3345},
  url              = {https://ntrs.nasa.gov/citations/19760009935},
  }
```

- Picture :



Fig. 1 https://catalog.archives.gov/id/17423368

- ```
  @Misc{brown1974records,
  author   = {Brown, M.},
  title    = {First stage rotor wheel from 5 stage compressor. {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/17423368}}
  ```

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:urasek1976design)]. Corresponding models are computed with the open-source code OpenMCAD[(cite:Kojtych_2022_gene_aubes)].
  ```

Geometry

The geometry of rotor 66 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 66

RP	PERCENT SPAN	RADII RI	RADII RO	BLADE ANGLES KIC	BLADE ANGLES KTC	BLADE ANGLES KOC	DELTA INC	CONE ANGLE
TIP	0.	25.324	25.222	62.51	63.11	58.81	2.68	-3.238
1	5.	24.794	24.657	61.59	62.04	57.92	2.93	-4.225
2	10.	24.216	24.092	60.60	60.87	57.03	3.20	-3.688
3	20.	23.041	22.962	58.61	58.47	55.18	3.75	-2.213
4	30.	21.841	21.831	56.67	55.94	52.98	4.27	-0.268
5	38.	20.866	20.927	55.14	53.75	50.75	4.69	1.522
6	46.	19.878	20.023	53.63	51.48	48.06	5.07	3.444
7	50.	19.378	19.571	52.87	50.29	46.46	5.26	4.458
8	70.	16.811	17.310	48.96	44.21	35.52	6.08	10.070
9	80.	15.470	16.180	46.91	40.93	27.52	6.39	13.261
10	90.	14.079	15.049	44.75	37.49	17.34	6.59	16.722
11	95.	13.361	14.484	43.60	35.80	11.47	6.65	18.571
HUB	100.	12.700	13.919	42.52	34.26	5.34	6.68	19.462

RP	BLADE THICKNESSES TI	BLADE THICKNESSES TM	BLADE THICKNESSES TO	AXIAL DIMENSIONS ZIC	AXIAL DIMENSIONS ZMC	AXIAL DIMENSIONS ZTC	AXIAL DIMENSIONS ZOC
TIP	0.025	0.115	0.025	0.808	1.689	1.936	2.604
1	0.028	0.126	0.028	0.778	1.688	1.910	2.636
2	0.030	0.138	0.030	0.746	1.687	1.879	2.667
3	0.035	0.161	0.035	0.681	1.684	1.809	2.730
4	0.041	0.184	0.041	0.615	1.680	1.726	2.795
5	0.044	0.202	0.044	0.561	1.677	1.650	2.852
6	0.048	0.218	0.048	0.505	1.672	1.565	2.913
7	0.050	0.227	0.050	0.476	1.670	1.518	2.946
8	0.059	0.265	0.059	0.320	1.650	1.244	3.130
9	0.062	0.282	0.062	0.226	1.635	1.075	3.237
10	0.066	0.298	0.066	0.117	1.616	0.879	3.347
11	0.068	0.305	0.068	0.057	1.606	0.772	3.399
HUB	0.069	0.312	0.069	0.000	1.596	0.672	3.450

Aerodynamic design

	unit	values
pressure ratio	[-]	1.61
mass flow	[kg/s]	29.7
tip speed	[m/s]	426
tip solidity	[-]	1.4
aspect ratio	[-]	3.1
number of blades	[-]	57
nominal rotation speed ω_n	[rad/s]	1679.94

Material properties

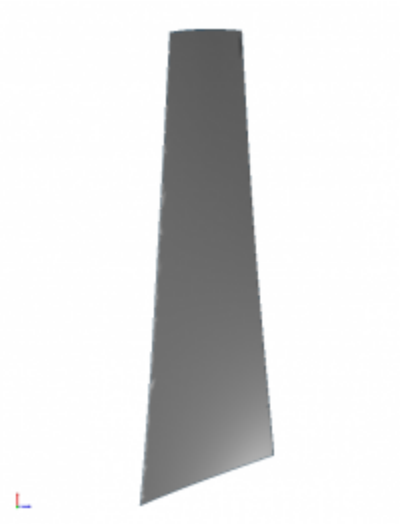
The original material of the rotor 66 is not defined in the NASA report. A generic titanium Ti-6Al-4V is considered:

	unité	valeurs
alloy	[-]	Ti-6Al-4V
Young's modulus	[GPa]	108

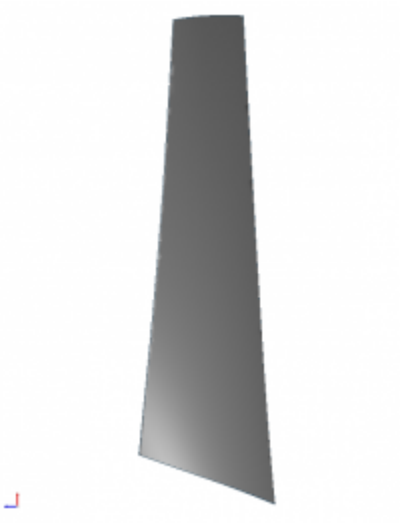
	unité	valeurs
density	[kg/m3]	4400
Poisson's ratio	[-]	0.34
yield stress	[GPa]	0.824

CAD model

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



pressure side



suction side

Natural frequencies

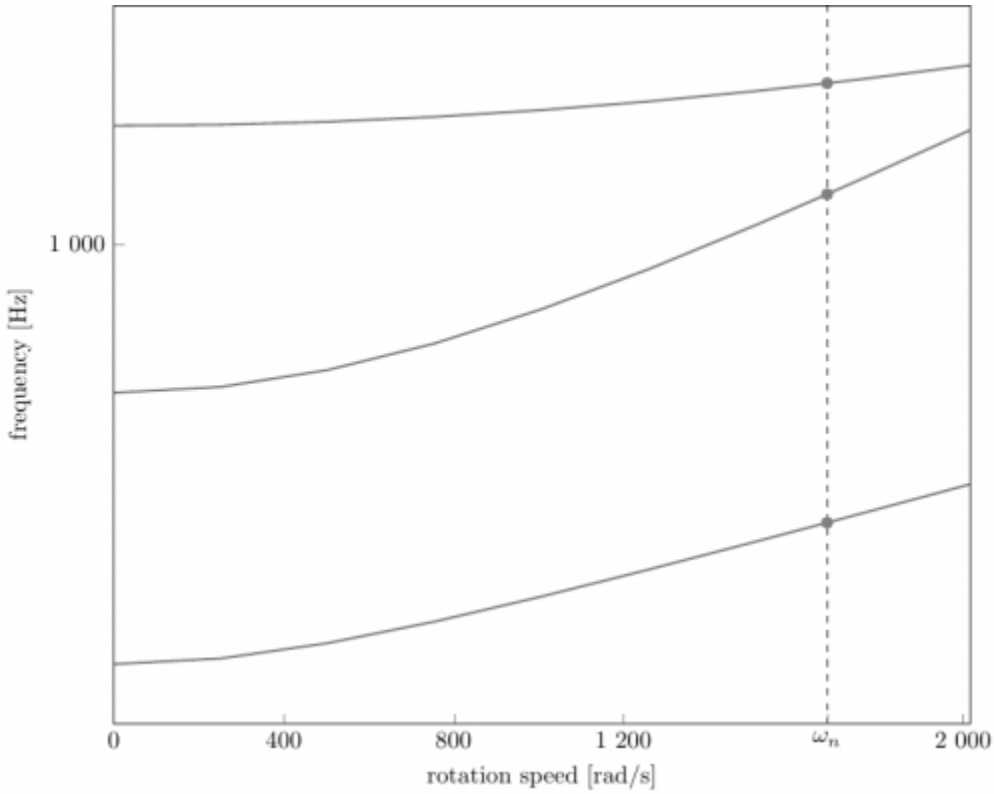
First three natural frequencies (with clamped root) for the mesh computed with OpenMCAD[(cite:Kojtych_2022_gene_aubes)]:

Mode	Type	Natural angular frequency (rad/sec)	Natural frequency (Hz)
1	1B	1249.77	198.91
2	2B	4502.58	716.61

Mode	Type	Natural angular frequency (rad/sec)	Natural frequency (Hz)
3	1T	7703.69	1226.08

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 ω_n = 1 679.94 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:

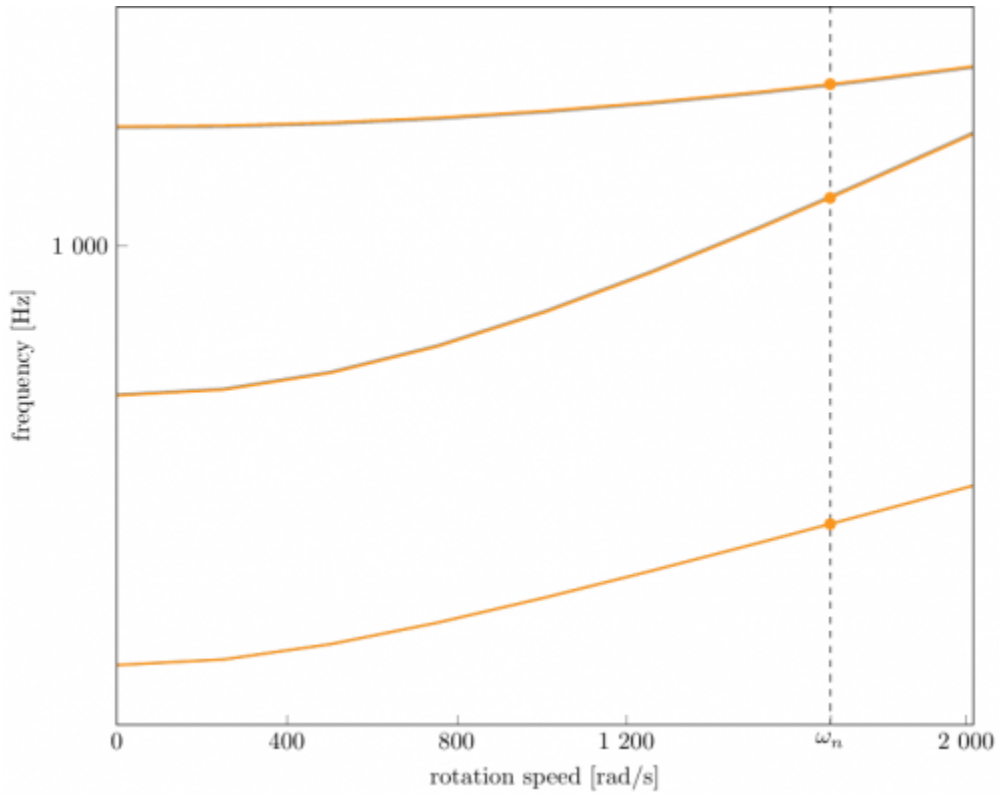
Mode	Type	Natural angular frequency (rad/sec)	Natural frequency (Hz)
1	1B	1248.51	198.71
2	2B	4487.89	714.27
3	1T	7721.85	1228.97

- from the reduced order model:

Mode	Type	Natural angular frequency (rad/sec)	Natural frequency (Hz)
1	1B	1248.53	198.71
2	2B	4488.92	714.43
3	1T	7723.73	1229.27

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 ω_n = 1 679.94 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 66 fait partie d'un compresseur à cinq étages de 51 centimètres de diamètre ayant un débit nominal de 29,7 kilogrammes par seconde et un taux de compression de 9,27. Les données de performance obtenues lors de tests ont indiqué que le premier étage n'atteignait pas ses performances de conception.

- Rapport technique original [(cite:urasek1976design>)]:

```
@TechReport{urasek1976design,
  author           = {Urasek, Donald C. and Steinke, Ronald J. and Lewis,
George W.},
  date             = {1976},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
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  url              = {https://ntrs.nasa.gov/citations/19760009935},
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- Photographie :



Fig. 1 https://catalog.archives.gov/id/17423368

- ```
  @Misc{brown1974records,
  author   = {Brown, M.},
  title    = {First stage rotor wheel from 5 stage compressor. {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/17423368}}
  ```

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:urasek1976design)]. Les modèles associés sont obtenus avec le code en libre accès OpenMCAD[(cite:Kojtych_2022_gene_aubes)].

Géométrie

La géométrie du rotor 66 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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3	20.	23.041	22.962	58.61	58.47	55.18	3.75	-2.213
4	30.	21.841	21.831	56.67	55.94	52.98	4.27	-0.268
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11	95.	13.361	14.484	43.60	35.80	11.47	6.65	18.571
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RP	BLADE THICKNESSES TI	BLADE THICKNESSES TM	BLADE THICKNESSES TO	AXIAL DIMENSIONS ZIC	AXIAL DIMENSIONS ZMC	AXIAL DIMENSIONS ZTC	AXIAL DIMENSIONS ZOC
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1	0.028	0.126	0.028	0.778	1.688	1.910	2.636
2	0.030	0.138	0.030	0.746	1.687	1.879	2.667
3	0.035	0.161	0.035	0.681	1.684	1.809	2.730
4	0.041	0.184	0.041	0.615	1.680	1.726	2.795
5	0.044	0.202	0.044	0.561	1.677	1.650	2.852
6	0.048	0.218	0.048	0.505	1.672	1.565	2.913
7	0.050	0.227	0.050	0.476	1.670	1.518	2.946
8	0.059	0.265	0.059	0.320	1.650	1.244	3.130
9	0.062	0.282	0.062	0.226	1.635	1.075	3.237
10	0.066	0.298	0.066	0.117	1.616	0.879	3.347
11	0.068	0.305	0.068	0.057	1.606	0.772	3.399
HUB	0.069	0.312	0.069	0.000	1.596	0.672	3.450

Caractéristiques aérodynamiques

	unités	**valeurs**
taux de compression	[-]	1,61
débit massique	[kg/s]	29,7
vitesse en tête	[m/s]	426
solidité en tête	[-]	1,4
allongement	[-]	3,1
nombre d'aubes	[-]	57
vitesse de rotation nominale ω_n	[rad/s]	1679,94

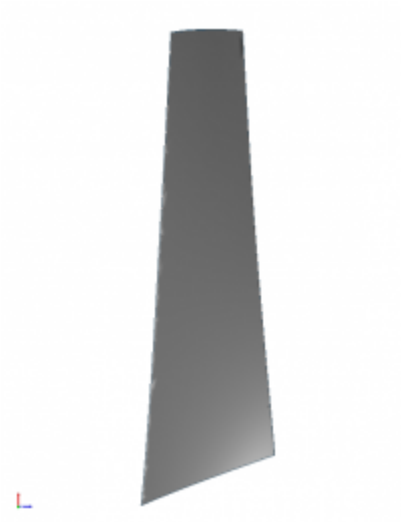
Propriétés matériau

Le matériau original du rotor 66 n'est pas défini dans le rapport de la NASA. Un alliage de titane Ti-6Al-4v est considéré :

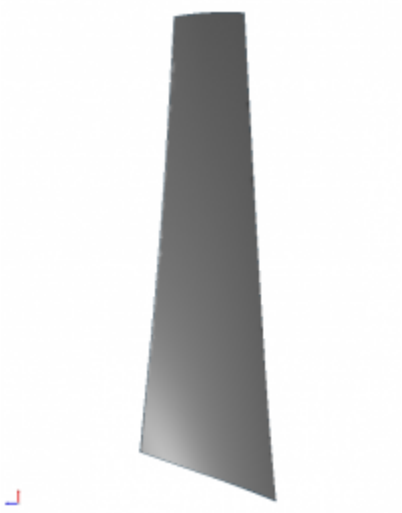
	unité	**valeurs**
alliage	[-]	Ti-6Al-4v
module d'Young	[GPa]	108
masse volumique	[kg/m3]	4400
coefficient de Poisson	[-]	0,34
limite élastique	[GPa]	0,824

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	1249,77	198,907
2	2F	4502,58	716,609
3	1T	7703,69	1226,08

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)]:

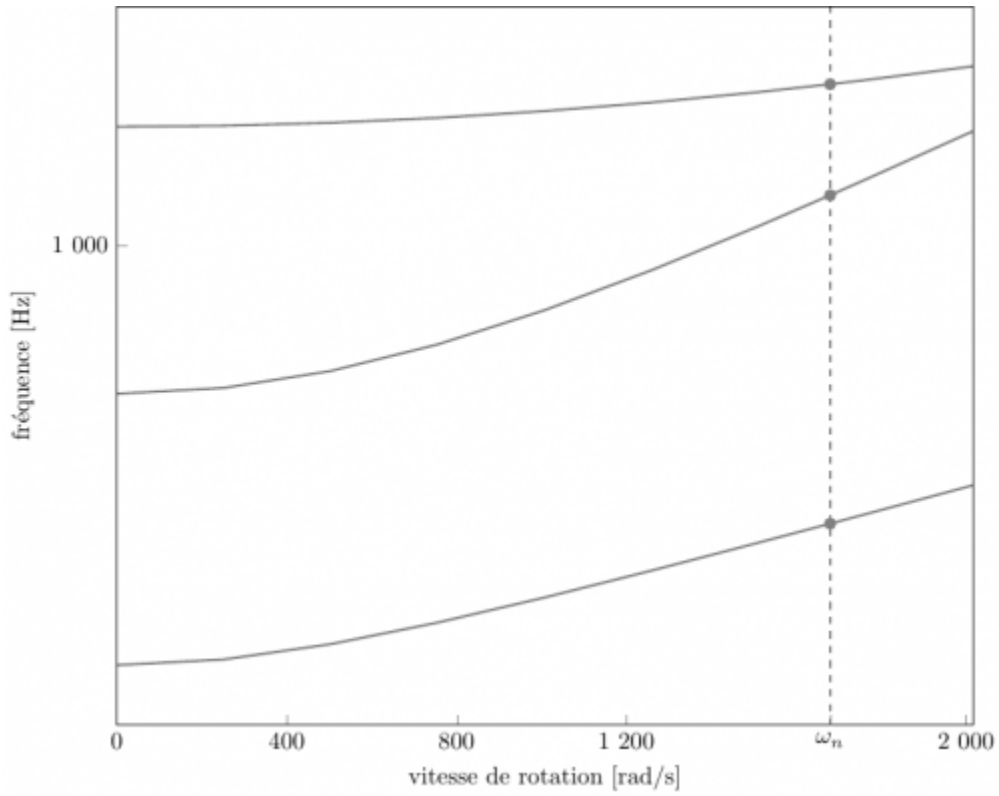


diagramme de Campbell calculé avec une précharge centrifuge linéaire, noeuds du pied d'aube encastrés (vitesse nominale ω_n = 1 679,94 rad/s)

- 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	1248,51	198,706
2	2F	4487,89	714,27
3	1T	7721,85	1228,97

- pour le modèle réduit :

Mode	Type	Pulsation propre (rad/sec)	Fréquence propre (Hz)
1	1F	1248,525	198,709
2	2F	4488,921	714,434
3	1T	7723,73	1229,27

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:

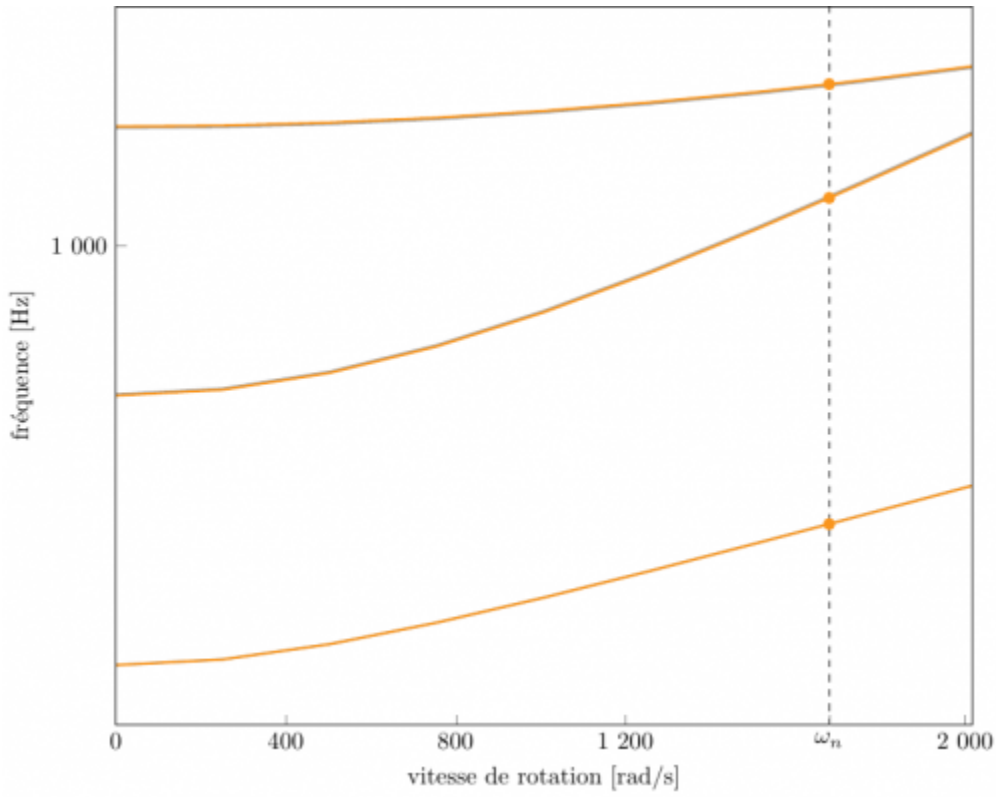


diagramme de Campbell calculé avec une précharge centrifuge linéaire, noeuds du pied d'aube encastrés (vitesse nominale ω_n = 1 679,94 rad/s),

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_66/accueil?rev=1722630713

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