# Rotor 16

- Français
- English

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## Original model

Rotor 16 is part of a research program to study the effect of weight flow per unit annulus area on the performance of axial-flow fan stages. A series of three stage: rotor 11, 16 and 17 were designed with a weight flow per unit annulus area of 198, 178, and 208 kilograms per second per square meter. All three stages were designed to produce a pressure ratio of 1.57, and all had the same meridional flow path geometry.

- Original technical report [(cite:moore1973design>Moore. «Performance of transonic fan stage with weight flow per unit annulus area of 178 kilograms per sercond per square meter (36.5 (lb/sec)/ft²) » 1973. pdf)]:

```
@TechReport{moore1973design,
  author           = {Moore, R. D. and Urasek, Donald C. and Kovlch,
George},
  date             = {1973},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
States},
  title            = {Performance of transonic fan stage with weight flow
per unit annulus area of 178 kilograms per sercond per square meter (36.5
(lb/sec)/ft²)},
  number           = {NASA-TM X-2904},
  url              = {https://ntrs.nasa.gov/citations/19740001906},
}
```

- Picture :

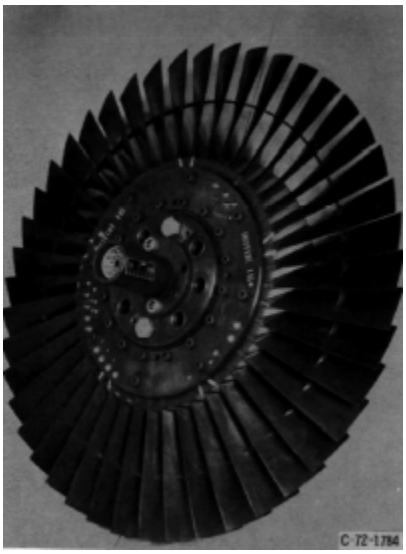


Fig1. https://ntrs.nasa.gov/citations/19740001906 p.64

# Useful documents

- downloadable models (Git project)
- PDF of the NASA report :

  rotor16.pdf
- CSV file of the blade geometry :

  rotor16_original.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. code en libre accès)] 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:moore1973design)]. Corresponding models are computed with the open-source code OpenMCAD[(cite:Kojtych_2022_gene_aubes)].

# Geometry

The geometry of rotor 16 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 16

| RP | PERCENT SPAN | RADII RI | RO | BLADE ANGLES KIC | KTC | KOC | DELTA INC | CONE ANGLE |
|---|---|---|---|---|---|---|---|---|
| TIP | 0. | 25.204 | 24.905 | 67.60 | 66.34 | 61.49 | 2.51 | -9.339 |
| 1 | 5. | 24.683 | 24.364 | 66.48 | 65.43 | 60.78 | 2.75 | -9.519 |
| 2 | 10. | 24.123 | 23.824 | 65.30 | 64.30 | 60.02 | 3.00 | -8.557 |
| 3 | 30. | 21.814 | 21.662 | 60.91 | 58.82 | 56.21 | 4.07 | -3.692 |
| 4 | 45. | 20.034 | 20.041 | 57.80 | 54.80 | 51.78 | 4.90 | 0.161 |
| 5 | 48. | 19.733 | 19.771 | 57.28 | 54.09 | 50.84 | 5.04 | 0.819 |
| 6 | 50. | 19.430 | 19.501 | 56.76 | 53.37 | 49.85 | 5.18 | 1.482 |
| 7 | 53. | 19.126 | 19.231 | 56.24 | 52.64 | 48.79 | 5.32 | 2.149 |
| 8 | 55. | 18.821 | 18.960 | 55.72 | 51.89 | 47.68 | 5.46 | 2.817 |
| 9 | 70. | 16.946 | 17.339 | 52.48 | 47.42 | 39.33 | 6.29 | 7.105 |
| 10 | 90. | 14.280 | 15.178 | 47.87 | 41.70 | 21.76 | 7.35 | 13.772 |
| 11 | 95. | 13.570 | 14.637 | 46.64 | 40.42 | 15.40 | 7.59 | 15.655 |
| HUB | 100. | 12.700 | 14.097 | 45.12 | 39.00 | 8.18 | 7.85 | 19.355 |

| RP | BLADE THICKNESSES TI | TM | TO | AXIAL DIMENSIONS ZIC | ZMC | ZTC | ZOC |
|---|---|---|---|---|---|---|---|
| TIP | 0.051 | 0.151 | 0.051 | 1.016 | 1.891 | 2.284 | 2.839 |
| 1 | 0.051 | 0.161 | 0.051 | 0.978 | 1.892 | 2.263 | 2.879 |
| 2 | 0.051 | 0.171 | 0.051 | 0.935 | 1.894 | 2.239 | 2.923 |
| 3 | 0.051 | 0.213 | 0.051 | 0.756 | 1.895 | 2.101 | 3.111 |
| 4 | 0.051 | 0.247 | 0.051 | 0.629 | 1.895 | 1.950 | 3.258 |
| 5 | 0.051 | 0.252 | 0.051 | 0.608 | 1.894 | 1.921 | 3.284 |
| 6 | 0.051 | 0.258 | 0.051 | 0.585 | 1.893 | 1.889 | 3.311 |
| 7 | 0.051 | 0.263 | 0.051 | 0.562 | 1.892 | 1.857 | 3.339 |
| 8 | 0.051 | 0.269 | 0.051 | 0.538 | 1.890 | 1.822 | 3.367 |
| 9 | 0.051 | 0.304 | 0.051 | 0.394 | 1.878 | 1.591 | 3.551 |
| 10 | 0.051 | 0.355 | 0.051 | 0.168 | 1.843 | 1.190 | 3.832 |
| 11 | 0.051 | 0.369 | 0.051 | 0.096 | 1.827 | 1.065 | 3.904 |
| HUB | 0.051 | 0.386 | 0.051 | 0.000 | 1.804 | 0.902 | 3.977 |

# Aerodynamic design

| | unit | values |
|---|---|---|
| **pressure ratio** | [-] | 1.57 |
| **mass flow** | [kg/s] | 26.5 |
| **tip speed** | [m/s] | 425 |
| **tip solidity** | [-] | 1.3 |
| **aspect ratio** | [-] | 2.6 |
| **number of blades** | [-] | 44 |
| **rotative speed** | [rad/s] | 1686 |

# Material properties

The original material of the rotor 16 is not defined in the NASA report.

Considered properties: Ti-6Al-4V, generic titanium :

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

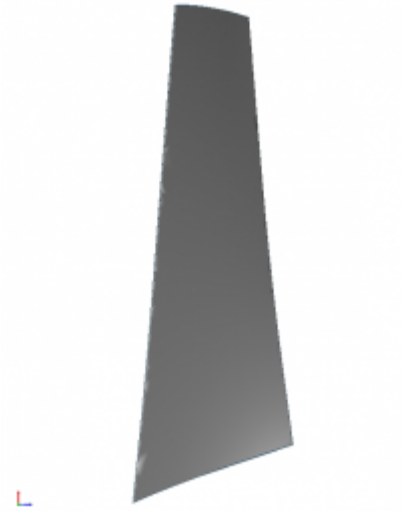
| | unité | valeurs |
|---|---|---|
| **yield stress** | [GPa] | 0.824 |

First three natural frequencies (with clamped root) for the mesh:

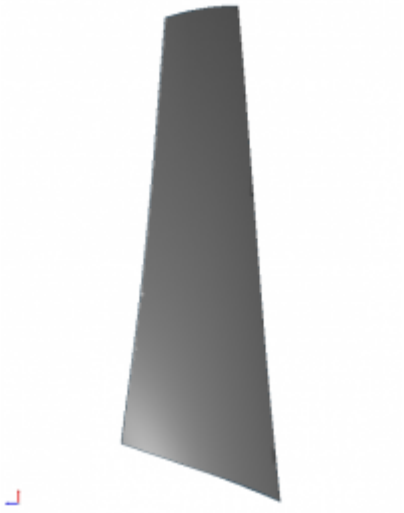
1. (1B): 1440.5 rad/s / 229.3 Hz
2. (2B): 5543.8 rad/s / 882.3 Hz
3. (1T): 7959.1 rad/s / 1266.7 Hz

## 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 | | 1456.25 | 231.77 |
| 2 | | 5431.61 | 864.469 |
| 3 | | 7997.11 | 1272.78 |

# 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 | | 1454.87 | 231.55 |
| 2 | | 5429.48 | 864.129 |
| 3 | | 8000.38 | 1273.3 |

- from the reduced order model:

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|---|---|---|---|
| 1 | | 1454.90 | 231.555 |
| 2 | | 5431.53 | 864.455 |
| 3 | | 8002.64 | 1273.66 |

Fichiers téléchargeables
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**Libre accès**

**lien vers le projet Git**

# Modèle original

Le rotor 16 fait partie d'un programme de recherche visant à étudier l'effet du débit massique par unité de surface annulaire sur les performances des soufflantes à flux axiaux. Une série de trois étages comprenant le rotor 11, 16 et 17 ont été conçus avec un débit massique par unité de surface annulaire de 198, 178 et 208 kilogrammes par seconde par mètre carré. Les trois étages ont été conçus pour produire un rapport de pression de 1.57.

- Rapport technique original [(cite:moore1973design>Moore. «Performance of transonic fan stage with weight flow per unit annulus area of 178 kilograms per sercond per square meter (36.5 (lb/sec)/ft²) » 1973. pdf)]:

```
@TechReport{moore1973design,
```

```
  author           = {Moore, R. D. and Urasek, Donald C. and Kovlch,
George},
  date             = {1973},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
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  title            = {Performance of transonic fan stage with weight flow
per unit annulus area of 178 kilograms per sercond per square meter (36.5
(lb/sec)/ft²)},
  number           = {NASA-TM X-2904},
  url              = {https://ntrs.nasa.gov/citations/19740001906},
}
```

- Photographie :

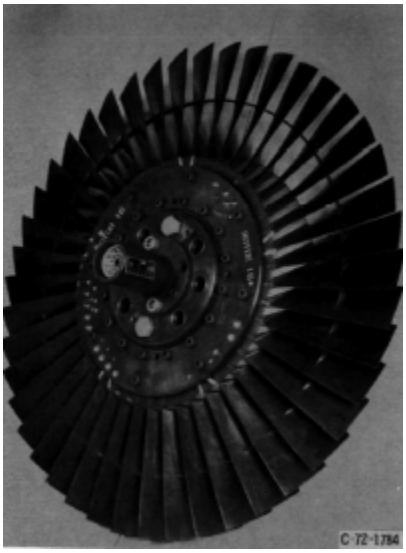


Fig1. https://ntrs.nasa.gov/citations/19740001906 p.64

# Documents utiles

- modèles téléchargeables (lien vers projet Git)
- PDF du rapport de la NASA :

  rotor16.pdf
- Fichier CSV de la géométrie :

  rotor16_original.csv

  , utilisable en entrée de 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. code en libre accès)] 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:moore1973design)]. Les modèles associés sont obtenus avec le code en libre accès OpenMCAD[(cite:Kojtych_2022_gene_aubes)].

# Géométrie

La géométrie du rotor 16 est décrite dans le rapport d'origine de la NASA par les tableaux suivants. Les grandeurs sont en centimètres et en degrés.

TABLE IV. - BLADE GEOMETRY FOR ROTOR 16

| RP | PERCENT SPAN | RADII RI | RADII RO | BLADE ANGLES KIC | BLADE ANGLES KTC | BLADE ANGLES KOC | DELTA INC | CONE ANGLE |
|---|---|---|---|---|---|---|---|---|
| TIP | 0. | 25.204 | 24.905 | 67.60 | 66.34 | 61.49 | 2.51 | -9.339 |
| 1 | 5. | 24.683 | 24.364 | 66.48 | 65.43 | 60.78 | 2.75 | -9.519 |
| 2 | 10. | 24.123 | 23.824 | 65.30 | 64.30 | 60.02 | 3.00 | -8.557 |
| 3 | 30. | 21.814 | 21.662 | 60.91 | 58.82 | 56.21 | 4.07 | -3.692 |
| 4 | 45. | 20.034 | 20.041 | 57.80 | 54.80 | 51.78 | 4.90 | 0.161 |
| 5 | 48. | 19.733 | 19.771 | 57.28 | 54.09 | 50.84 | 5.04 | 0.819 |
| 6 | 50. | 19.430 | 19.501 | 56.76 | 53.37 | 49.85 | 5.18 | 1.482 |
| 7 | 53. | 19.126 | 19.231 | 56.24 | 52.64 | 48.79 | 5.32 | 2.149 |
| 8 | 55. | 18.821 | 18.960 | 55.72 | 51.89 | 47.68 | 5.46 | 2.817 |
| 9 | 70. | 16.946 | 17.339 | 52.48 | 47.42 | 39.33 | 6.29 | 7.105 |
| 10 | 90. | 14.280 | 15.178 | 47.87 | 41.70 | 21.76 | 7.35 | 13.772 |
| 11 | 95. | 13.570 | 14.637 | 46.64 | 40.42 | 15.40 | 7.59 | 15.655 |
| HUB | 100. | 12.700 | 14.097 | 45.12 | 39.00 | 8.18 | 7.85 | 19.355 |

| RP | BLADE THICKNESSES TI | BLADE THICKNESSES TM | BLADE THICKNESSES TO | AXIAL DIMENSIONS ZIC | AXIAL DIMENSIONS ZMC | AXIAL DIMENSIONS ZTC | AXIAL DIMENSIONS ZOC |
|---|---|---|---|---|---|---|---|
| TIP | 0.051 | 0.151 | 0.051 | 1.016 | 1.891 | 2.284 | 2.839 |
| 1 | 0.051 | 0.161 | 0.051 | 0.978 | 1.892 | 2.263 | 2.879 |
| 2 | 0.051 | 0.171 | 0.051 | 0.935 | 1.894 | 2.239 | 2.923 |
| 3 | 0.051 | 0.213 | 0.051 | 0.756 | 1.895 | 2.101 | 3.111 |
| 4 | 0.051 | 0.247 | 0.051 | 0.629 | 1.895 | 1.950 | 3.258 |
| 5 | 0.051 | 0.252 | 0.051 | 0.608 | 1.894 | 1.921 | 3.284 |
| 6 | 0.051 | 0.258 | 0.051 | 0.585 | 1.893 | 1.889 | 3.311 |
| 7 | 0.051 | 0.263 | 0.051 | 0.562 | 1.892 | 1.857 | 3.339 |
| 8 | 0.051 | 0.269 | 0.051 | 0.538 | 1.890 | 1.822 | 3.367 |
| 9 | 0.051 | 0.304 | 0.051 | 0.394 | 1.878 | 1.591 | 3.551 |
| 10 | 0.051 | 0.355 | 0.051 | 0.168 | 1.843 | 1.190 | 3.832 |
| 11 | 0.051 | 0.369 | 0.051 | 0.096 | 1.827 | 1.065 | 3.904 |
| HUB | 0.051 | 0.386 | 0.051 | 0.000 | 1.804 | 0.902 | 3.977 |

# Caractéristiques aérodynamiques

| | unités | valeurs |
|---|---|---|
| **taux de compression** | [-] | 1,57 |
| **débit massique** | [kg/s] | 26,5 |
| **vitesse en tête** | [m/s] | 425 |
| **solidité en tête** | [-] | 1,3 |
| **allongement** | [-] | 2,6 |
| **nombre d'aubes** | [-] | 44 |
| **vitesse de rotation** | [rad/s] | 1686 |

# Propriétés matériau

Le matériau original du rotor 16 n'est pas défini dans le rapport de la NASA.

Propriétés considérées : alliage de titane Ti-6Al-4v :

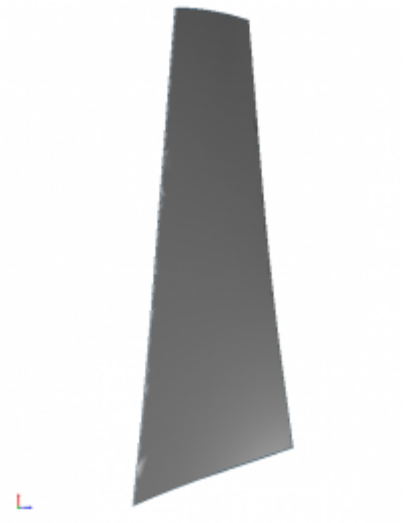
| | unité | valeurs |
|---|---|---|
| **alliage** | [-] | Ti-6Al-4v |
| **module d'Young** | [GPa] | 108 |
| **masse volumique** | [kg/m3] | 4400 |
| **coefficient de Poisson** | [-] | 0,34 |
| **limite élastique** | [GPa] | 0,824 |

Fréquences des trois premiers modes (noeuds de la base encastrés) pour le maillage :

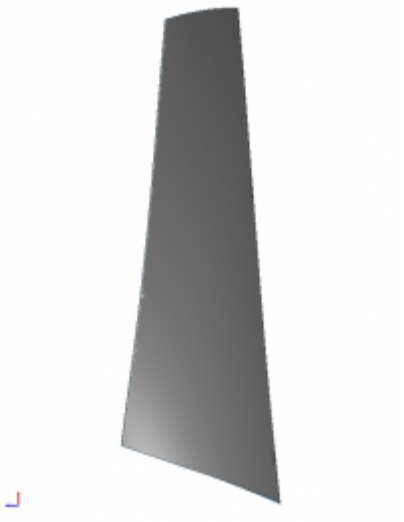
1. (1B): 1440,5 rad/s / 229,3 Hz
2. (2B): 5543,8 rad/s / 882,3 Hz
3. (1T): 7959,1 rad/s / 1266,7 Hz

## 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 | | 1456.25 | 231.77 |
| 2 | | 5431.61 | 864.469 |
| 3 | | 7997.11 | 1272.78 |

## 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 | | 1454.87 | 231.55 |
| 2 | | 5429.48 | 864.129 |
| 3 | | 8000.38 | 1273.3 |

- pour le modèle réduit :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|---|---|---|---|
| 1 | | 1454.90 | 231.555 |
| 2 | | 5431.53 | 864.455 |
| 3 | | 8002.64 | 1273.66 |

</tabs>

Document issu de la page wiki:
**https://lava-wiki.meca.polymtl.ca/public/modeles/rotor_16/accueil?rev=1677119643**

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