# Rotor 6

- Français
- English

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**Git project**

## Original model

Rotor 6 is part of a research program to study the effects of blade shape on efficiency and stall margin. A series of transonic rotors, including rotor 6 and 7, were design with the same exit total pressure distribution to investigate the effects of blade shape.

- Original technical report [1]:

```
@TechReport{reid1973design,
  author           = {Reid, Lonnie and Kovich, George},
  date             = {1973},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
States},
  title            = {Overall and blade-element performance of a transonic
compressor stage with multiple-circular-arc blades at tip speed of 419
meters per second},
  number           = {NASA-TM X-2731},
  url              = {https://ntrs.nasa.gov/citations/19730011268},
}
```

- Picture :

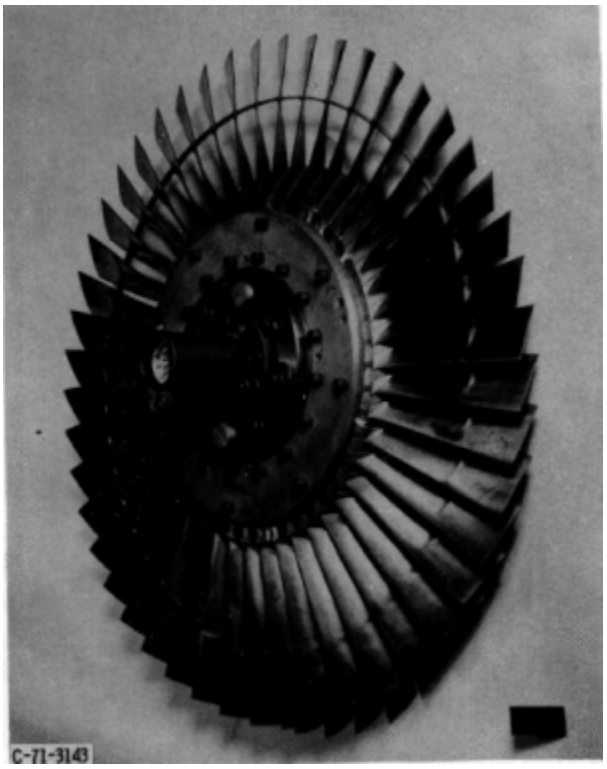



Fig1. https://ntrs.nasa.gov/citations/19730011268 p.63

**Useful documents**

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

  rotor6.pdf
- CSV file of the blade geometry :

  rotor6_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 6 is described in the original NASA report by the following tables. The lengths are in centimeters and the angles in degrees.

TABLE IV. - BLADE GEOMETRY FOR ROTOR 6

| RP | PERCENT SPAN | RADII RI | RO | BLADE ANGLES KIC | KTC | KOC | DELTA INC | CONE ANGLE |
|---|---|---|---|---|---|---|---|---|
| TIP | 0. | 25.024 | 24.938 | 61.27 | 59.53 | 48.55 | 2.57 | -2.167 |
| 1 | 5. | 24.681 | 24.443 | 60.39 | 58.83 | 48.51 | 2.75 | -5.794 |
| 2 | 10. | 24.151 | 23.949 | 59.08 | 57.74 | 48.33 | 3.03 | -4.776 |
| 3 | 30. | 21.932 | 21.972 | 54.43 | 53.07 | 45.16 | 4.18 | 0.842 |
| 4 | 40. | 20.778 | 20.983 | 52.27 | 50.40 | 42.35 | 4.77 | 4.083 |
| 5 | 43. | 20.485 | 20.736 | 51.75 | 49.69 | 41.52 | 4.91 | 4.922 |
| 6 | 45. | 20.190 | 20.489 | 51.22 | 48.96 | 40.63 | 5.06 | 5.771 |
| 7 | 48. | 19.893 | 20.242 | 50.70 | 48.23 | 39.71 | 5.21 | 6.638 |
| 8 | 50. | 19.593 | 19.995 | 50.19 | 47.49 | 38.76 | 5.35 | 7.520 |
| 9 | 70. | 17.083 | 18.018 | 46.38 | 41.40 | 29.63 | 6.46 | 15.492 |
| 10 | 90. | 14.203 | 16.041 | 44.06 | 36.61 | 17.09 | 7.30 | 26.699 |
| 11 | 95. | 13.376 | 15.546 | 43.89 | 36.11 | 13.27 | 7.42 | 30.360 |
| HUB | 100. | 12.736 | 15.052 | 43.87 | 35.93 | 9.32 | 7.48 | 31.741 |

| RP | BLADE THICKNESSES TI | TM | TO | AXIAL DIMENSIONS ZIC | ZMC | ZTC | ZOC |
|---|---|---|---|---|---|---|---|
| TIP | 0.051 | 0.149 | 0.051 | 0.773 | 1.843 | 2.194 | 3.055 |
| 1 | 0.051 | 0.156 | 0.051 | 0.745 | 1.843 | 2.171 | 3.087 |
| 2 | 0.051 | 0.167 | 0.051 | 0.704 | 1.844 | 2.134 | 3.119 |
| 3 | 0.051 | 0.211 | 0.051 | 0.541 | 1.834 | 1.941 | 3.257 |
| 4 | 0.051 | 0.233 | 0.051 | 0.460 | 1.826 | 1.818 | 3.335 |
| 5 | 0.051 | 0.239 | 0.051 | 0.440 | 1.825 | 1.785 | 3.356 |
| 6 | 0.051 | 0.245 | 0.051 | 0.420 | 1.823 | 1.752 | 3.378 |
| 7 | 0.051 | 0.251 | 0.051 | 0.399 | 1.821 | 1.716 | 3.399 |
| 8 | 0.051 | 0.257 | 0.051 | 0.377 | 1.817 | 1.677 | 3.418 |
| 9 | 0.051 | 0.305 | 0.051 | 0.206 | 1.791 | 1.336 | 3.578 |
| 10 | 0.051 | 0.360 | 0.051 | 0.055 | 1.755 | 0.947 | 3.709 |
| 11 | 0.051 | 0.376 | 0.051 | 0.023 | 1.741 | 0.845 | 3.728 |
| HUB | 0.051 | 0.389 | 0.051 | 0.000 | 1.728 | 0.768 | 3.745 |

# Aerodynamic design

| | unit | value |
|---|---|---|
| **pressure ratio** | [-] | 1.63 |
| **mass flow** | [kg/s] | 29.6 |
| **tip speed** | [m/s] | 419 |
| **tip solidity** | [-] | 1.3 |
| **aspect ratio** | [-] | 2.5 |
| **number of blades** | [-] | 47 |
| **rotative speed** | [rad/s] | 1675.51 |

# Material properties

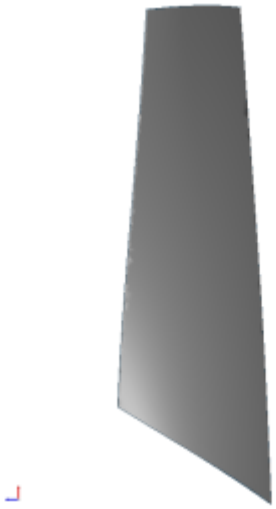
The material of rotor 6 is not defined in the original NASA report. A 200-grade maraging steel is considered:

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

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 | 1640.38 | 261.075 |
| 2 | 2B | 6276.11 | 998.874 |
| 3 | 1T | 8059.88 | 1282.77 |

## Initial blade

The **initial blade** is defined with in-house LAVA parameters[4] 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 | 1645.39 | 261.872 |
| 2 | 2B | 6297.39 | 1002.26 |
| 3 | 1T | 8100.85 | 1289.29 |

- from the reduced order model:

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|---|---|---|---|
| 1 | 1B | 1644.74 | 261.77 |
| 2 | 2B | 6299.96 | 1002.67 |
| 3 | 1T | 8102.8 | 1289.6 |

Fichiers téléchargeables
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**Libre accès**

**lien vers le projet Git**

# À propos

Le rotor 6 fait partie d'un programme de recherche visant à étudier les effets de la forme des pales sur l'efficacité et la marge de décrochage. Une série de rotors transsoniques ont été conçus avec la même distribution de pression totale de sortie pour étudier les effets de la forme des pales. On retrouve par exemple le rotor 6 et 7.

- Rapport technique original [1]:

```
@TechReport{reid1973design,
  author           = {Reid, Lonnie and Kovich, George},
  date             = {1973},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
States},
  title            = {Overall and blade-element performance of a transonic
compressor stage with multiple-circular-arc blades at tip speed of 419
meters per second},
  number           = {NASA-TM X-2731},
  url              = {https://ntrs.nasa.gov/citations/19730011268},
}
```

- Photographie :

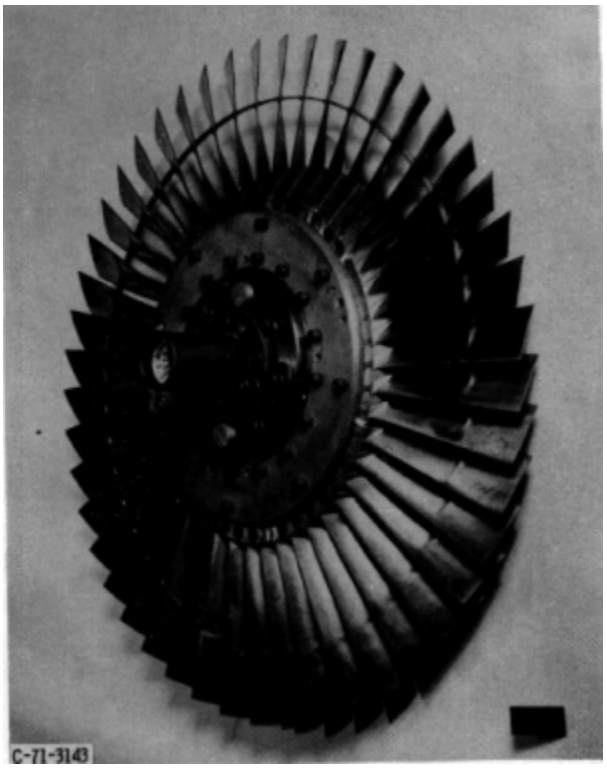


Fig1. https://ntrs.nasa.gov/citations/19730011268 p.63

**Documents utiles**

- modèles téléchargeables (lien vers projet Git)
- PDF du rapport de la NASA :
  rotor6.pdf
- Fichier CSV de la géométrie :
  rotor6_original.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[1]. Les modèles associés sont obtenus avec le code en libre accès OpenMCAD[2].

# Géométrie

La géométrie du rotor 6 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 6

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|---|---|---|---|---|---|---|---|---|
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| 1 | 5. | 24.681 | 24.443 | 60.39 | 58.83 | 48.51 | 2.75 | -5.794 |
| 2 | 10. | 24.151 | 23.949 | 59.08 | 57.74 | 48.33 | 3.03 | -4.776 |
| 3 | 30. | 21.932 | 21.972 | 54.43 | 53.07 | 45.16 | 4.18 | 0.842 |
| 4 | 40. | 20.778 | 20.983 | 52.27 | 50.40 | 42.35 | 4.77 | 4.083 |
| 5 | 43. | 20.485 | 20.736 | 51.75 | 49.69 | 41.52 | 4.91 | 4.922 |
| 6 | 45. | 20.190 | 20.489 | 51.22 | 48.96 | 40.63 | 5.06 | 5.771 |
| 7 | 48. | 19.893 | 20.242 | 50.70 | 48.23 | 39.71 | 5.21 | 6.638 |
| 8 | 50. | 19.593 | 19.995 | 50.19 | 47.49 | 38.76 | 5.35 | 7.520 |
| 9 | 70. | 17.083 | 18.018 | 46.38 | 41.40 | 29.63 | 6.46 | 15.492 |
| 10 | 90. | 14.203 | 16.041 | 44.06 | 36.61 | 17.09 | 7.30 | 26.699 |
| 11 | 95. | 13.376 | 15.546 | 43.89 | 36.11 | 13.27 | 7.42 | 30.360 |
| HUB | 100. | 12.736 | 15.052 | 43.87 | 35.93 | 9.32 | 7.48 | 31.741 |

| RP | BLADE THICKNESSES TI | TM | TO | AXIAL DIMENSIONS ZIC | ZMC | ZTC | ZOC |
|---|---|---|---|---|---|---|---|
| TIP | 0.051 | 0.149 | 0.051 | 0.773 | 1.843 | 2.194 | 3.055 |
| 1 | 0.051 | 0.156 | 0.051 | 0.745 | 1.843 | 2.171 | 3.087 |
| 2 | 0.051 | 0.167 | 0.051 | 0.704 | 1.844 | 2.134 | 3.119 |
| 3 | 0.051 | 0.211 | 0.051 | 0.541 | 1.834 | 1.941 | 3.257 |
| 4 | 0.051 | 0.233 | 0.051 | 0.460 | 1.826 | 1.818 | 3.335 |
| 5 | 0.051 | 0.239 | 0.051 | 0.440 | 1.825 | 1.785 | 3.356 |
| 6 | 0.051 | 0.245 | 0.051 | 0.420 | 1.823 | 1.752 | 3.378 |
| 7 | 0.051 | 0.251 | 0.051 | 0.399 | 1.821 | 1.716 | 3.399 |
| 8 | 0.051 | 0.257 | 0.051 | 0.377 | 1.817 | 1.677 | 3.418 |
| 9 | 0.051 | 0.305 | 0.051 | 0.206 | 1.791 | 1.336 | 3.578 |
| 10 | 0.051 | 0.360 | 0.051 | 0.055 | 1.755 | 0.947 | 3.709 |
| 11 | 0.051 | 0.376 | 0.051 | 0.023 | 1.741 | 0.845 | 3.728 |
| HUB | 0.051 | 0.389 | 0.051 | 0.000 | 1.728 | 0.768 | 3.745 |

# Caractéristiques aérodynamiques

| | unités | valeurs |
|---|---|---|
| **taux de compression** | [-] | 1,63 |
| **débit massique** | [kg/s] | 29,6 |
| **vitesse en tête** | [m/s] | 419 |
| **solidité en tête** | [-] | 1,3 |
| **allongement** | [-] | 2,5 |
| **nombre d'aubes** | [-] | 47 |
| **vitesse de rotation** | [rad/s] | 1675,51 |

# Propriétés matériau

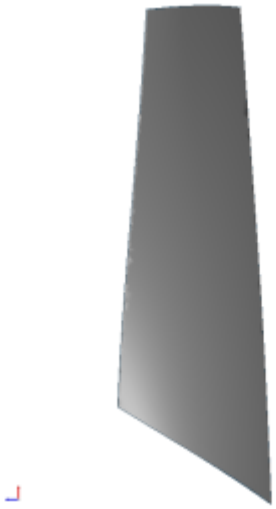
Le matériau original du rotor 6 n'est pas défini dans le rapport de la NASA. Un acier maraging de grade 200 est considéré:

| | unité | valeurs |
|---|---|---|
| **alliage** | [-] | 18-Ni-200-maraging |
| **module d'Young** | [GPa] | 180 |
| **masse volumique** | [kg/m3] | 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 | 1B | 1640,38 | 261,075 |
| 2 | 2B | 6276,11 | 998,874 |
| 3 | 1T | 8059,88 | 1282,77 |

# Aube initiale

L' **aube initiale** est définie par des paramètres spécifiques au LAVA[4] 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 | 1645,39 | 261,872 |
| 2 | 2B | 6297,39 | 1002,26 |
| 3 | 1T | 8100,85 | 1289,29 |

- pour le modèle réduit :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|---|---|---|---|
| 1 | 1B | 1644,74 | 261,77 |
| 2 | 2B | 6299,96 | 1002,67 |
| 3 | 1T | 8102,8 | 1289,6 |

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1. [a, b, c, d] Reid. «Overall and blade-element performance of a transonic compressor stage with multiple-circular-arc blades at tip speed of 419 meters per second » 1973. pdf
2. [a, b, c, d, e, f, g, h] 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
4. [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