# Rotor 21

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## Original model

Rotor 21 is part of a research program to study the experimental performances of a stage when the design blade loading in the rotor tip region has been substantially reduced. In order to produce the same overall pressure ratio as a reference stage (rotor 11), the blade loading levels in the midspan portion of the present rotor blade had to be relatively high.

- Original technical report [(cite:schmidt1978design>Schmidt. «Performance With and Without Inlet Radial Distortion of a Transonic Fan Stage Designed for Reduced Loading in the Tip Region » 1978. pdf)]:

```
@TechReport{schmidt1978design,
  author           = {Schmidt, James F. and Ruggeri, Robert S.},
  date             = {1978},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
States},
  title            = {Performance With and Without Inlet Radial Distortion
of a Transonic Fan Stage Designed for Reduced Loading in the Tip Region},
  number           = {NASA-TP-1294},
  url              = {https://ntrs.nasa.gov/citations/19780022114}}
```

- Picture :

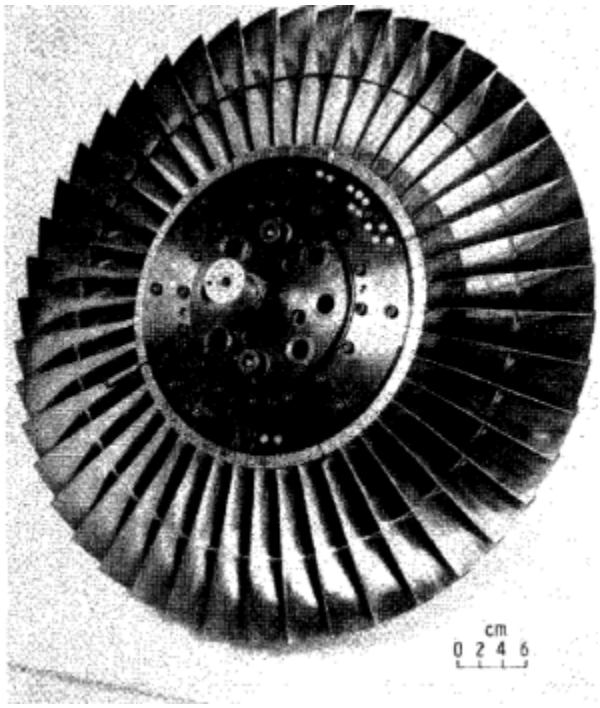



Fig1. https://ntrs.nasa.gov/citations/19780022114 p.68

**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. 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:schmidt1978design)]. Corresponding models are computed with the open-source code OpenMCAD[(cite:Kojtych_2022_gene_aubes)].

# Geometry

The geometry of rotor 21 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 21

| RP | PERCENT SPAN | RADII RI | RADII RO | BLADE ANGLES KIC | BLADE ANGLES KTC | BLADE ANGLES KOC | DELTA INC | CONE ANGLE |
|---|---|---|---|---|---|---|---|---|
| TIP | 0. | 25.184 | 24.859 | 67.16 | 68.45 | 66.50 | 2.49 | -10.943 |
| 1 | 5. | 24.720 | 24.321 | 65.46 | 66.09 | 63.55 | 2.68 | -12.184 |
| 2 | 10. | 24.209 | 23.783 | 63.63 | 63.54 | 60.68 | 2.91 | -11.940 |
| 3 | 30. | 21.977 | 21.630 | 57.00 | 53.33 | 50.06 | 3.95 | -7.386 |
| 4 | 50. | 19.509 | 19.478 | 51.69 | 43.35 | 37.36 | 5.12 | -0.536 |
| 5 | 53. | 19.186 | 19.209 | 51.09 | 42.21 | 35.65 | 5.27 | 0.386 |
| 6 | 55. | 18.861 | 18.940 | 50.51 | 41.10 | 33.91 | 5.41 | 1.320 |
| 7 | 58. | 18.534 | 18.671 | 49.93 | 40.04 | 32.15 | 5.56 | 2.257 |
| 8 | 60. | 18.204 | 18.402 | 49.36 | 39.03 | 30.56 | 5.70 | 3.194 |
| 9 | 70. | 16.863 | 17.326 | 47.12 | 35.49 | 23.43 | 6.26 | 6.996 |
| 10 | 90. | 14.112 | 15.173 | 42.06 | 31.67 | 15.87 | 7.39 | 14.856 |
| 11 | 95. | 13.420 | 14.635 | 40.49 | 31.40 | 16.47 | 7.70 | 16.870 |
| HUB | 100. | 12.700 | 14.097 | 38.77 | 31.28 | 17.72 | 8.03 | 19.264 |

| 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 | 0.149 | 0.051 | 1.100 | 1.947 | 2.326 | 2.782 |
| 1 | 0.051 | 0.157 | 0.051 | 1.033 | 1.949 | 2.314 | 2.880 |
| 2 | 0.051 | 0.166 | 0.051 | 0.960 | 1.951 | 2.296 | 2.976 |
| 3 | 0.051 | 0.208 | 0.051 | 0.661 | 1.943 | 2.109 | 3.334 |
| 4 | 0.051 | 0.255 | 0.051 | 0.379 | 1.925 | 1.766 | 3.663 |
| 5 | 0.051 | 0.261 | 0.051 | 0.347 | 1.923 | 1.716 | 3.699 |
| 6 | 0.051 | 0.268 | 0.051 | 0.315 | 1.921 | 1.664 | 3.735 |
| 7 | 0.051 | 0.274 | 0.051 | 0.285 | 1.919 | 1.612 | 3.769 |
| 8 | 0.051 | 0.280 | 0.051 | 0.255 | 1.917 | 1.560 | 3.801 |
| 9 | 0.051 | 0.306 | 0.051 | 0.148 | 1.910 | 1.350 | 3.915 |
| 10 | 0.051 | 0.361 | 0.051 | 0.018 | 1.911 | 0.989 | 4.020 |
| 11 | 0.051 | 0.375 | 0.051 | 0.007 | 1.912 | 0.918 | 4.013 |
| HUB | 0.051 | 0.391 | 0.051 | 0.000 | 1.914 | 0.850 | 3.997 |

# Aerodynamic design

| | unit | values |
|---|---|---|
| **pressure ratio** | [-] | 1.57 |
| **mass flow** | [kg/s] | 29.5 |
| **tip speed** | [m/s] | 425 |
| **tip solidity** | [-] | 1.28 |
| **aspect ratio** | [-] | 2.5 |
| **number of blades** | [-] | 44 |
| **rotative speed** | [rad/s] | 1686 |

# Material properties

The original material of the rotor 21 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 |
| **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 | 1512.88 | 240.783 |
| 2 | 2B | 5410.9 | 861.171 |
| 3 | 1T | 8729.48 | 1389.34 |

## 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 | 1507.80 | 239.974 |
| 2 | 2B | 5410.47 | 861.103 |
| 3 | 1T | 8689.96 | 1383.05 |

- from the reduced order model:

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|---|---|---|---|
| 1 | 1B | 1507.89 | 239,988 |
| 2 | 2B | 5411.17 | 861.216 |
| 3 | 1T | 8691.72 | 1383.33 |

Fichiers téléchargeables
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**Libre accès**

**lien vers le projet Git**

# À propos

Le rotor 21 fait partie d'un programme de recherche visant à étudier les performances expérimentales d'un étage de soufflante lorsque la charge des aubes dans la région de l'extrémité du rotor a été considérablement réduite. Afin de produire le même taux de compression global que l'étage de référence (rotor 11), les niveaux de charge des aubes dans la partie médiane de l'aube du rotor actuel ont été relativement augmentés.

- Rapport technique original [(cite:schmidt1978design>Schmidt. «Performance With and Without Inlet Radial Distortion of a Transonic Fan Stage Designed for Reduced Loading in the Tip Region » 1978. pdf)]:

```
@TechReport{schmidt1978design,
  author           = {Schmidt, James F. and Ruggeri, Robert S.},
  date             = {1978},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
States},
  title            = {Performance With and Without Inlet Radial Distortion
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  number           = {NASA-TP-1294},
```

```
  url                = {https://ntrs.nasa.gov/citations/19780022114}}
```

- Photographie :

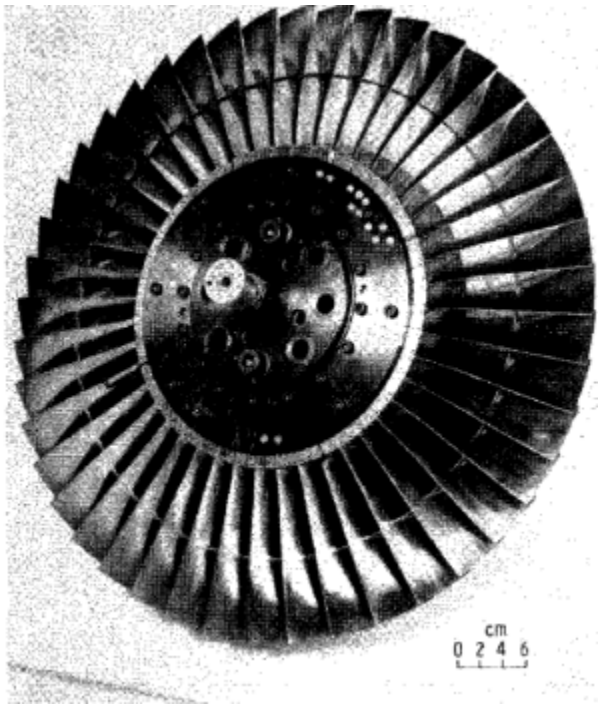



Fig1. https://ntrs.nasa.gov/citations/19780022114 p.68

**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>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:schmidt1978design)]. Les modèles associés sont obtenus avec le code en libre accès OpenMCAD[(cite:Kojtych_2022_gene_aubes)].

# Géométrie

La géométrie du rotor 21 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 21

| RP | PERCENT SPAN | RADII RI | RADII RO | BLADE ANGLES KIC | BLADE ANGLES KTC | BLADE ANGLES KOC | DELTA INC | CONE ANGLE |
|---|---|---|---|---|---|---|---|---|
| TIP | 0. | 25.184 | 24.859 | 67.16 | 68.45 | 66.50 | 2.49 | -10.943 |
| 1 | 5. | 24.720 | 24.321 | 65.46 | 66.09 | 63.55 | 2.68 | -12.184 |
| 2 | 10. | 24.209 | 23.783 | 63.63 | 63.54 | 60.68 | 2.91 | -11.940 |
| 3 | 30. | 21.977 | 21.630 | 57.00 | 53.33 | 50.06 | 3.95 | -7.386 |
| 4 | 50. | 19.509 | 19.478 | 51.69 | 43.35 | 37.36 | 5.12 | -0.536 |
| 5 | 53. | 19.186 | 19.209 | 51.09 | 42.21 | 35.65 | 5.27 | 0.386 |
| 6 | 55. | 18.861 | 18.940 | 50.51 | 41.10 | 33.91 | 5.41 | 1.320 |
| 7 | 58. | 18.534 | 18.671 | 49.93 | 40.04 | 32.15 | 5.56 | 2.257 |
| 8 | 60. | 18.204 | 18.402 | 49.36 | 39.03 | 30.36 | 5.70 | 3.194 |
| 9 | 70. | 16.863 | 17.326 | 47.12 | 35.49 | 23.43 | 6.26 | 6.996 |
| 10 | 90. | 14.112 | 15.173 | 42.06 | 31.67 | 15.87 | 7.39 | 14.856 |
| 11 | 95. | 13.420 | 14.635 | 40.49 | 31.40 | 16.47 | 7.70 | 16.870 |
| HUB | 100. | 12.700 | 14.097 | 38.77 | 31.28 | 17.72 | 8.03 | 19.264 |

| 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 | 0.149 | 0.051 | 1.100 | 1.947 | 2.326 | 2.782 |
| 1 | 0.051 | 0.157 | 0.051 | 1.033 | 1.949 | 2.314 | 2.880 |
| 2 | 0.051 | 0.166 | 0.051 | 0.960 | 1.951 | 2.296 | 2.976 |
| 3 | 0.051 | 0.208 | 0.051 | 0.661 | 1.943 | 2.109 | 3.334 |
| 4 | 0.051 | 0.255 | 0.051 | 0.379 | 1.925 | 1.766 | 3.663 |
| 5 | 0.051 | 0.261 | 0.051 | 0.347 | 1.923 | 1.716 | 3.699 |
| 6 | 0.051 | 0.268 | 0.051 | 0.315 | 1.921 | 1.664 | 3.735 |
| 7 | 0.051 | 0.274 | 0.051 | 0.285 | 1.919 | 1.612 | 3.769 |
| 8 | 0.051 | 0.280 | 0.051 | 0.255 | 1.917 | 1.560 | 3.801 |
| 9 | 0.051 | 0.306 | 0.051 | 0.148 | 1.910 | 1.350 | 3.915 |
| 10 | 0.051 | 0.361 | 0.051 | 0.018 | 1.911 | 0.989 | 4.020 |
| 11 | 0.051 | 0.375 | 0.051 | 0.007 | 1.912 | 0.918 | 4.013 |
| HUB | 0.051 | 0.391 | 0.051 | 0.000 | 1.914 | 0.850 | 3.997 |

# Caractéristiques aérodynamiques

| | unités | valeurs |
|---|---|---|
| **taux de compression** | [-] | 1,57 |
| **débit massique** | [kg/s] | 29,5 |
| **vitesse en tête** | [m/s] | 425 |
| **solidité en tête** | [-] | 1,28 |
| **allongement** | [-] | 2,5 |
| **nombre d'aubes** | [-] | 44 |
| **vitesse de rotation** | [rad/s] | 1686 |

# Propriétés matériau

Le matériau original du rotor 21 n'est pas défini dans le rapport de la NASA.

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

| | unité | valeurs |
|---|---|---|

| | 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 | 1B | 1512,88 | 240,783 |
| 2 | 2B | 5410,9 | 861,171 |
| 3 | 1T | 8729,48 | 1389,34 |

# 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 | 1B | 1507,80 | 239,974 |
| 2 | 2B | 5410,47 | 861,103 |
| 3 | 1T | 8689,96 | 1383,05 |

- pour le modèle réduit :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|---|---|---|---|
| 1 | 1B | 1507,89 | 239,988 |
| 2 | 2B | 5411,17 | 861,216 |
| 3 | 1T | 8691,72 | 1383,33 |

</tabs>

Document issu de la page wiki:
**https://wiki.lava.polymtl.ca/public/modeles/rotor_21/accueil?rev=1679267561**

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