# Rotor 51A

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## About

Rotor 51A is part of a research program designed to obtain experimental reference information for the selection of fans for propulsion systems for short-haul aircraft using the externally blown flap as the powered lift system. The rotor 51A is made of 12 blades and was designed for a tip-sgeed of 243.8 meters per second, a design efficiency of 0.863 and a pressure ratio of 1.15. However, experimental values are lower than expected design values (design efficiency: 0.836, pressure ratio: 1.111). The lower than design total pressure ratio was attributed to the failure to obtain the design energy input into the rotor.

- Original NASA technical report [(cite:osborn1974performance> Osborn W. M., Steinke R. «Performance of a 1.15-pressure-ratio Axial-flow Fan Stage with a Blade Tip Solidity of 0.5» 1974. pdf)]:

```
@TechReport{osborn1974performance,
  author           = {Osborn, Walter Martin and Steinke, Ronald J},
  date             = {1974},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
States},
  title            = {Performance of a 1.15-pressure-ratio Axial-flow Fan
Stage with a Blade Tip Solidity of 0.5},
  number           = {NASA-TM X-3052},
  url              = {https://ntrs.nasa.gov/citations/19740021256},
}
```

- Pictures :

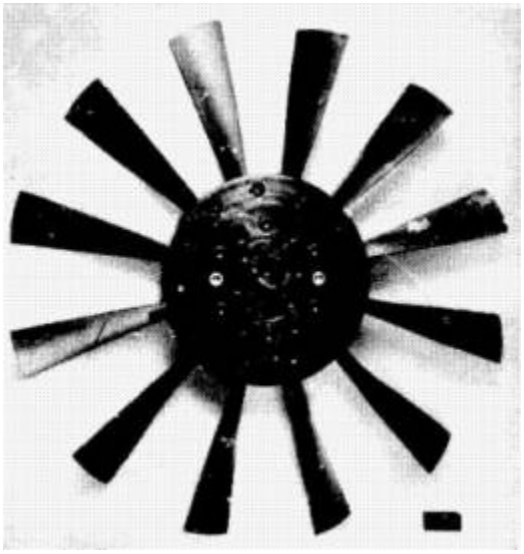


Fig. 1 https://ntrs.nasa.gov/citations/19740021256 p.67

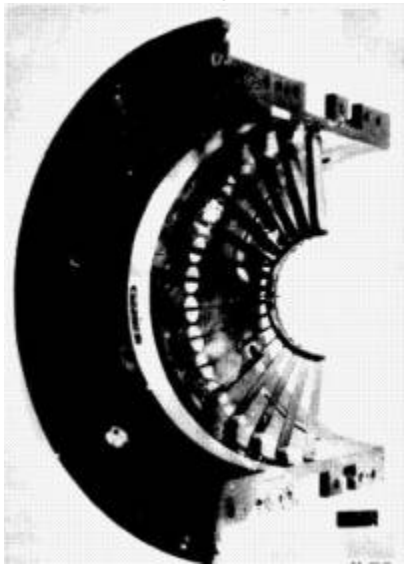


Fig. 2 https://ntrs.nasa.gov/citations/19740021256 p.67

### Useful documents

- downloadable models (Git project)
  - NASA technical report (.pdf)
  - rotor51a_original.csv (.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:osborn1974performance)]. Corresponding models are computed with the open-source code OpenMCAD[(cite:Kojtych_2022_gene_aubes)].

## Geometry

The geometry of rotor 51A is described in the original NASA report by the following table. The lenghts are in inches and the angles in degrees.

TABLE IV. - BLADE GEOMETRY FOR ROTOR 51A

| RP | PERCENT SPAN | RADII R1 | RADII R2 | BLADE ANGLES K1C | BLADE ANGLES K1T | BLADE ANGLES K2C | DELTA INC | CONE ANGLE |
|---|---|---|---|---|---|---|---|---|
| TIP | 1. | 25.411 | 25.411 | 52.15 | 47.86 | 43.[illegible] | 4.59 | 0.057 |
| | 5. | 24.648 | 24.638 | 51.23 | 46.66 | 42.09 | 4.69 | -0.130 |
| 2 | 11. | 23.872 | 23.876 | 50.26 | 45.38 | 41.52 | 4.96 | 0.057 |
| 3 | 15. | 23.193 | 23.114 | 49.26 | 44.18 | 38.86 | 5.43 | 0.258 |
| 4 | 31. | 21.744 | 21.828 | 46.16 | 39.[illegible] | 35.43 | [illegible].72 | 0.997 |
| 5 | 51. | 17.623 | 17.781 | 41.54 | 33 | 24.87 | 11.89 | 1.835 |
| 6 | 71. | 14.545 | 14.732 | 35.92 | 25 | 14.83 | 15.84 | 2.091 |
| 7 | 85. | 12.513 | 12.446 | 31.20 | 19. | [illegible].05 | [illegible].75 | 1.619 |
| 8 | 91. | 11.569 | 11.684 | 29.46 | 17.[illegible] | 4.83 | 18.09 | 1.274 |
| 9 | 95. | 10.847 | 10.922 | 27.65 | 14.98 | 2.31 | 18.29 | 0.834 |
| HUB | 100. | 10.162 | 10.162 | 25.91 | 13.02 | 0.31 | 18.46 | 0.057 |

| RP | BLADE THICKNESSES T1 | BLADE THICKNESSES TM | BLADE THICKNESSES T2 | AXIAL DIMENSIONS Z1 | AXIAL DIMENSIONS ZM | AXIAL DIMENSIONS Z2 | AXIAL DIMENSIONS Z3 |
|---|---|---|---|---|---|---|---|
| TIP | 0.366 | 0.332 | 0.366 | 0.353 | 2.496 | 2.496 | 4.823 |
| | 0.364 | 0.332 | 0.364 | 0.332 | 2.496 | 2.496 | 4.851 |
| 2 | 0.368 | 0.348 | 0.368 | 0.324 | 2.495 | 2.495 | 4.882 |
| 3 | 0.[illegible] | 0.361 | 0.[illegible] | 0.[illegible] | 2.494 | [illegible].494 | 4.911 |
| 4 | 0.399 | 0.521 | 0.399 | 0.197 | 2.488 | 2.488 | 4.994 |
| 5 | 0.151 | 0.765 | 0.149 | 0.102 | 2.485 | 2.485 | 5.096 |
| 6 | 0.196 | 0.978 | 0.196 | 0.052 | 2.488 | 2.488 | 5.163 |
| 7 | 0.[illegible] | 1.057 | 0.211 | 0.032 | 2.495 | 2.495 | 5.[illegible]72 |
| 8 | 0.213 | 1.064 | 0.213 | -0.001 | 2.498 | 2.498 | 5.[illegible]65 |
| 9 | 0.[illegible] | 1.062 | 0.213 | -0.021 | 2.501 | 2.501 | 5.152 |
| HUB | 0.212 | 1.062 | 0.212 | 0.000 | 2.504 | 2.504 | 5.138 |

## Aerodynamic design

| | units | values |
|---|---|---|
| **pressure ratio** | [-] | 1.111 |
| **mass flow** | [kg/s] | 30.27 |
| **tip speed** | [m/s] | 213,3 |
| **tip solidity** | [-] | 0.5 |
| **aspect ratio** | [-] | 3.08 |
| **rotative speed** | [%] | 90 to 120 % of design speed |

## Material properties

The material of rotor 51A is not defined in the original NASA report. A generic titanium Ti-6Al-4V is considered:

| | units | values |
|---|---|---|
| **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 | 2578.59 | 410.40 |
| 2 | 2B | 8044.80 | 1280.37 |
| 3 | 1T | 10763.98 | 1713.14 |

# 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 | 2560.66 | 407.541 |
| 2 | 2B | 8009.99 | 1 274.83 |
| 3 | 1T | 10726.52 | 1 707.18 |

- from the reduced order model:

| Mode | Type | Natural angular frequency (rad/sec) | Natural frequency (Hz) |
|---|---|---|---|
| 1 | 1B | 2560.75 | 407.556 |
| 2 | 2B | 8013.95 | 1275.46 |
| 3 | 1T | 10729.8 | 1707.7 |

Modèles téléchargeables

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**Libre accès**

**lien vers le projet Git**

# À propos

Le rotor 51A fait partie d'un programme de recherche visant à obtenir des résultats expérimentaux de référence pour la sélection de soufflantes pour les avions court-courrier utilisant des volets à soufflage externe. Le rotor 51A possède 12 pales et a été conçu pour une vitesse de pointe de 243,8 mètres par seconde, un rendement de 0,863 et un taux de compression de 1,151 à vitesse nominale. Toutefois, les caractéristiques expérimentales effectivement mesurées sont inférieures (rendement de 0,836 et taux de compression de 1,111), en raison de l'impossibilité d'obtenir un apport d'énergie suffisant en entrée du rotor.

- Rapport technique original [(cite:osborn1974performance)]:

```
@TechReport{osborn1974performance,
  author           = {Osborn, Walter Martin and Steinke, Ronald J},
  date             = {1974},
  institution      = {NASA Lewis Research Center Cleveland, OH, United
States},
  title            = {Performance of a 1.15-pressure-ratio Axial-flow Fan
Stage with a Blade Tip Solidity of 0.5},
  number           = {NASA-TM X-3052},
  url              = {https://ntrs.nasa.gov/citations/19740021256},
}
```

- Photographies :

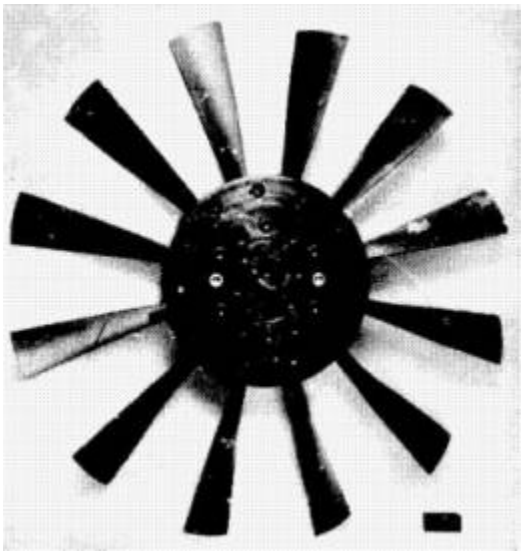


Fig. 1 https://ntrs.nasa.gov/citations/19740021256 p.67

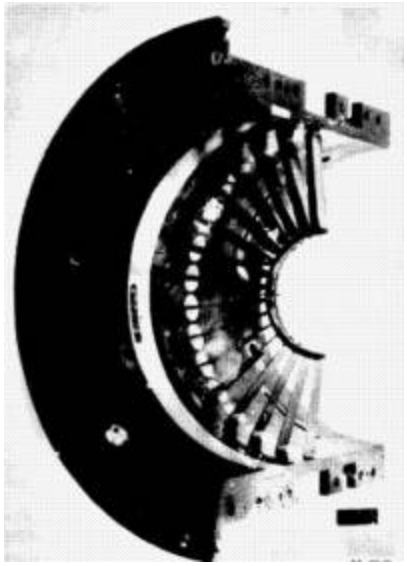


Fig. 2 https://ntrs.nasa.gov/citations/19740021256 p.67

**Documents utiles**

- modèles téléchargeables (lien vers projet Git)
  - rapport technique original de la NASA (.pdf)
  - rotor51a_original.csv (.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:osborn1974performance)]. Les modèles associés sont obtenus avec le code en libre accès OpenMCAD[(cite:Kojtych_2022_gene_aubes)].

## Géométrie

La géométrie du rotor 51A est décrite dans le rapport d'origine de la NASA par les tableaux suivants. Les grandeurs sont en pouces et en degrés.

TABLE IV. - BLADE GEOMETRY FOR ROTOR 51A

| RP | PERCENT SPAN | RADII R1 | R2 | BLADE ANGLES K1C | K1 | K2C | DELTA INC | CONE ANGLE |
|---|---|---|---|---|---|---|---|---|
| TIP | 0. | 25.411 | 25.411 | 52.15 | 47.86 | 43.[illegible] | 4.59 | 0.057 |
| | 5. | 24.648 | 24.638 | 51.23 | 46.66 | 42.09 | 4.69 | -0.130 |
| 2 | 10. | 23.872 | 23.876 | 50.26 | 45.38 | 41.[illegible] | 4.98 | 0.057 |
| 3 | 15. | 23.095 | 23.114 | 49.26 | 44.16 | 38.86 | 5.45 | 0.258 |
| 4 | 30. | 20.744 | 20.828 | 46.16 | 39.[illegible] | 35.45 | [illegible].72 | 0.997 |
| 5 | 50. | 17.623 | 17.781 | 41.54 | 33 | 24.87 | 11.89 | 1.835 |
| 6 | 70. | 14.545 | 14.732 | 35.92 | 25 | 4.85 | 15.84 | 2.093 |
| 7 | 85. | 12.500 | 12.446 | 31.21 | 19. | [illegible].25 | 17.75 | 1.619 |
| 8 | 90. | 11.569 | 11.684 | 29.46 | 17.[illegible] | 4.65 | 18.09 | 1.274 |
| 9 | 95. | 10.647 | 10.922 | 27.65 | 14.98 | 2.31 | 18.29 | 0.634 |
| TIP | 100. | 10.162 | 10.162 | 25.91 | 13.32 | 0.01 | 18.46 | 0.057 |

| RP | BLADE THICKNESSES T1 | TM | T2 | AXIAL DIMENSIONS Z1 | ZMC | ZMT | Z2 |
|---|---|---|---|---|---|---|---|
| TIP | 1.166 | 1.352 | 1.166 | 1.353 | 2.496 | 2.496 | 4.820 |
| | 1.164 | 1.352 | 1.164 | 1.351 | 2.496 | 2.496 | 4.851 |
| 2 | 1.168 | 1.348 | 1.168 | 1.334 | 2.495 | 2.495 | 4.882 |
| 3 | 1.[illegible] | 1.351 | 1.[illegible] | 1.[illegible] | 2.494 | [illegible].494 | 4.911 |
| 4 | 1.199 | 1.321 | 1.199 | 1.197 | 2.488 | 2.488 | 4.994 |
| 5 | 1.151 | 1.765 | 1.149 | 1.112 | 2.485 | 2.485 | 5.096 |
| 6 | 1.196 | 1.978 | 1.196 | 1.151 | 2.488 | 2.488 | 5.163 |
| 7 | 1.[illegible] | 1.[illegible] | 1.211 | 1.112 | 2.495 | 2.495 | 5.[illegible] |
| 8 | 1.[illegible] | 1.[illegible] | 1.[illegible] | -0.[illegible] | 2.498 | 2.498 | 5.[illegible] |
| 9 | 1.[illegible] | 1.[illegible] | 1.[illegible] | -0.[illegible] | 2.501 | 2.501 | 5.152 |
| TIP | 1.[illegible] | 1.[illegible] | 1.212 | 0.000 | 2.504 | 2.504 | 5.138 |

## Caractéristiques aérodynamiques

| | unités | valeurs |
|---|---|---|
| **taux de compression** | [-] | 1.111 |

| | unités | valeurs |
|---|---|---|
| **débit massique** | [kg/s] | 30.27 |
| **vitesse en tête** | [m/s] | 213,3 |
| **solidité en tête** | [-] | 0.5 |
| **allongement** | [-] | 3.08 |
| **vitesse de rotation** | [%] | 90 à 120 % de la vitesse de conception |

## Propriétés matériau

Le matériau original du rotor 51A n'est pas défini dans le rapport de la NASA. Un alliage de titane Ti-6Al-4v est considéré :

| | unités | 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 | 2578,59 | 410,40 |
| 2 | 2F | 8044,80 | 1280,37 |
| 3 | 1T | 10763,98 | 1713,14 |

## 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 | 2560,66 | 407,54 |
| 2 | 2F | 8009,99 | 1 274,83 |
| 3 | 1T | 10726,52 | 1 707,18 |

- pour le modèle réduit :

| Mode | Type | Pulsation propre (rad/sec) | Fréquence propre (Hz) |
|---|---|---|---|
| 1 | 1F | 2560,75 | 407,56 |
| 2 | 2F | 8013,95 | 1275,46 |
| 3 | 1T | 10729,80 | 1707,70 |

Document issu de la page wiki:
**https://wiki.lava.polymtl.ca/public/modeles/rotor_51a/accueil?rev=1723064460**

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