Aerodynamic study of helicopter with different configuration, different profile of rotor blade and modified fuselage

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ABSTRACT

We designed a complete coaxial rotor configuration helicopter with coaxial pusher type rotor. We made an aerodynamic analysis over complete model as well as rotor analysis. Based on the result of the old model, we modify the design of fuselage and rotor. Normally in helicopter, maneuvering is done by rotor motion and its effects. Some helicopter such as S-97 raider uses tail wing control surface. To study the combination of rotor effect and control surface deflection, we designed pusher coaxial rotor along with tail wing which has elevator and rudder surfaces. We found the $C_p$ distribution along fuselage reference line due to deflection of rudder. Moreover, we compare performance modified model and the actual model.

INTRODUCTION

Actual fuselage is designed by considering measurements of S-97 raider. And with the help of reference 5 the actual rotor is designed. By considering the tip vortices and increased performance of other profile airfoil, we designed a rotor with “S-Series Modified with Transonic and Biconvex Airfoil” profiles and with tip sweep back.

If RPM of upper rotor and lower rotor are different, there will be side forces exist in fuselage. And $C_p$ distribution of Fuselage reference line taken for difference rotor RPM and deflection of rudder control surface. Variation of Center of pressure for different RPM is also recorded.

DESIGN

ROTOR BLADE DESIGN (S-series)

Rotor blade is generally including set of airfoil at different location with different twist. The complete detail of main rotor blade as follow,

<table>
<thead>
<tr>
<th>Station No.</th>
<th>Radial Station(r/R)</th>
<th>Chord(mm)</th>
<th>Twist(degree)</th>
<th>Airfoil</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.05</td>
<td>300</td>
<td>10</td>
<td>S818</td>
</tr>
<tr>
<td>2</td>
<td>0.15</td>
<td>300</td>
<td>9</td>
<td>S818</td>
</tr>
<tr>
<td>3</td>
<td>0.25</td>
<td>300</td>
<td>8</td>
<td>S818</td>
</tr>
<tr>
<td>4</td>
<td>0.35</td>
<td>300</td>
<td>7</td>
<td>S818</td>
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<tr>
<td>5</td>
<td>0.45</td>
<td>300</td>
<td>6</td>
<td>S825</td>
</tr>
<tr>
<td>6</td>
<td>0.55</td>
<td>300</td>
<td>5</td>
<td>S825</td>
</tr>
<tr>
<td>7</td>
<td>0.65</td>
<td>300</td>
<td>4</td>
<td>S825</td>
</tr>
<tr>
<td>8</td>
<td>0.75</td>
<td>300</td>
<td>3</td>
<td>S825</td>
</tr>
<tr>
<td>9</td>
<td>0.85</td>
<td>300</td>
<td>2</td>
<td>S826</td>
</tr>
<tr>
<td>10</td>
<td>0.95</td>
<td>300</td>
<td>1</td>
<td>S826</td>
</tr>
</tbody>
</table>

Main rotor blade radius: 4750mm

<table>
<thead>
<tr>
<th>r/R</th>
<th>Radius r (m)</th>
<th>Twist angle (deg)</th>
<th>Chord C (m)</th>
<th>Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.016</td>
<td>83.33</td>
<td>5</td>
<td>300</td>
<td>S817</td>
</tr>
<tr>
<td>0.0333</td>
<td>166.66</td>
<td>5</td>
<td>300</td>
<td>S820</td>
</tr>
<tr>
<td>0.05</td>
<td>250</td>
<td>5</td>
<td>300</td>
<td>S826</td>
</tr>
</tbody>
</table>

Pusher type propeller blade radius: 1300mm

ROTOR BLADE DESIGN (S-Series Modified with Transonic and Biconvex Airfoil)

Main Rotor Blade Specification
<table>
<thead>
<tr>
<th>Whitcomb</th>
<th>40 Degree Sweep from Leading Edge</th>
<th>NLF(1)-0115</th>
<th>Biconvex</th>
<th>Biconvex</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.17</td>
<td>850</td>
<td>6</td>
<td>300</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Upper Main Rotor Diameter –D

Lower Main Rotor Diameter- D1= 0.72D

(Lower blade)

(Upper Blade)
### Propeller Specification

<table>
<thead>
<tr>
<th>r/R</th>
<th>Radius r (m)</th>
<th>Twist angle (deg)</th>
<th>Chord C (m)</th>
<th>Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.033</td>
<td>33.33</td>
<td>5</td>
<td>300</td>
<td>S817</td>
</tr>
<tr>
<td>0.066</td>
<td>66.66</td>
<td>5</td>
<td>300</td>
<td>S820</td>
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<tr>
<td>0.100</td>
<td>100</td>
<td>5</td>
<td>300</td>
<td>S826</td>
</tr>
<tr>
<td>0.425</td>
<td>425</td>
<td>3</td>
<td>300</td>
<td>NLF(1)-0115</td>
</tr>
<tr>
<td>0.75</td>
<td>750</td>
<td>1.5</td>
<td>300</td>
<td>Biconvex</td>
</tr>
<tr>
<td>0.85</td>
<td>850</td>
<td>0.5</td>
<td>300</td>
<td>Biconvex</td>
</tr>
<tr>
<td>0.1</td>
<td>1000</td>
<td>0</td>
<td>300</td>
<td>Biconvex</td>
</tr>
</tbody>
</table>

**30 Degree Sweep Back from Leading Edge**

**Leading Propeller-D**

**Rear Propeller-D1=0.86D**

(Leading Propeller)
HELICOPTER FUSELAGE DESIGN

A helicopter with a body like that of a fighter aircraft have been designed to make the body streamlined. Here the draft of complete body with stub wing and tail wing with different control surface deflection. Fuselage
with deflection capability of -30degree to +30 degree for both elevator and rudder is shown below.

Fuselage with 30, -30degree rudder as follow
WING DESIGN

COMPLETE DESIGN

LOVELY PROFESSIONAL UNIVERSITY

COMPLETE COMBAT HELICOPTER

Model 1
Introduction to CFD

Type: Flow Analysis  
Mesh: ICEM - CFD  
Pre Processing: CFX - Pre  
Solver: CFX – Solver  
Post Processing: CFD - Post

**DOMAIN CREATION AND MESHING PROCEDURE: ICEM-CFD**

- First of all, import the geometry using the option `FILE-IMPORT GEOMETRY-STEP/IGES FILE` to browse the file.
- Specify the part name separately to each part which require specific mesh elements such as
  - Blade surface
  - Hub
  - Helicopter body
  - Wing
  - Elevator
  - Rudder
- Then have to create a body to specify different material.
  - Blade body
  - Helicopter body
  - Hub body
- Wing body
- Elevator body
- Rudder body

- Have to make 5 domains to analyze this model completely
  - **Fluid1** - cylindrical domain for upper main rotor, to give rotation for fluid near the upper main rotor.
  - **Fluid2** - cylindrical domain for lower main rotor, to give rotation for fluid near the lower main rotor.
  - **Fluid3** - cylindrical domain for first tail rotor, to give rotation for fluid near the first tail rotor.
  - **Fluid4** - cylindrical domain for second tail rotor, to give rotation for fluid near the second tail rotor.
  - **Flow** - rectangular domain for a complete model to give velocity of flow or opening condition.

MESH

[Diagram of helicopter mesh]

**COMPLETE DOMAIN**

**HELI.CO.PTER**

**BLADE MESH**
ANSYS CFX-PRE

Have to specify boundary condition for 2 major cases, such as

- **Hovering** and
- **Forward flight**

### HOVERING OF HELICOPTER

This state of helicopter achieves when weight of the helicopter equals to the lift.

Area of the blade is calculated by the formula,

\[
S = \frac{NCR}{A}
\]

Coefficient of thrust is calculated by the formula,

\[
C_T = \int_0^1 C_L x^2 \, dx
\]

The tip speed ratio is given by,

\[
\lambda_i = \frac{V_i}{V_T}
\]

### BOUNDARY CONDITIONS

All fluid I have considered inside the whole domain has a temperature of 25 degree Celsius and inner domain surrounding main rotors and propellers contains fluid1 (upper main rotor), fluid2, fluid3 (propeller closer to the rear side helicopter body) and fluid4 are in a rotating condition. The detail of each domain is as given below.
Fluid2 having a Negative value of Fluid1 in case of angular velocity.

Fluid4 having a negative value of Fluid3 in the case of angular velocity.

Outer domain of flow having a fluid at stationery and interface with fluid1, fluid2, fluid3 and fluid4 with the flow domain having a frame change as Frozen rotor.
For hovering, open boundaries of the flow domain are set at the pressure of 101325Pa and the temperature of 298K.

For forward flight, in the control volume inlet velocity is specified, and a total pressure of 101325Pa and a total temperature as 298K for outer domain.

**SOLVER**

A maximum of 1000 iterations for a simulation with double precision parallel environment and auto time scale.

**CALCULATING THE DRAG OF A COMPLETE MODEL 1 IN FORWARD FLIGHT**

**MODEL PROPERTY**

Complete model consists of aluminum material of same density throughout the volume

**DOMAIN PROPERTY**

Dimensions: 34000mm x 16000mm x 16000mm

Material property: Air at 25 degree Celsius and continuous fluid

Domain model:

- Reference pressure : 1 atm
- Domain motion : stationary

Fluid model:

- Heat transfer : total energy
- Turbulence model : K-epsilon

**MESH**

![Mesh Diagram](image-url)
DOMAINE

Inlet condition (left most surface in above figure):

- Normal velocity: 50 – 200 m/s
- Temperature: 298 K

Outlet condition (right most surface in above figure):

- Relative pressure: 0 pa

Velocity vs Drag of complete model 1 graph as follow

CALCULATING THE DRAG OF A COMPLETE MODEL 1 IN VERTICAL FLIGHT

MODEL PROPERTY

Complete model consists of aluminum material of same density throughout the volume
DOMAIN PROPERTY

Dimensions: 34000mm x 16000mm x 16000mm

Material property: Air at 25 degree Celsius and continuous fluid

Domain model:

- Reference pressure: 1 atm
- Domain motion: stationary

Fluid model:

- Heat transfer: total energy
- Turbulence model: K-epsilon

MESH

DOMIAN:
Inlet condition (left most surface in above figure):

- Normal velocity: 50 – 200 m/s
- Temperature: 298 K

Outlet condition (right most surface in above figure):

- Relative pressure: 0 pa

Velocity vs Drag of complete model graph as follow
ROTOR ANALYSIS (S-Series Profile)

Determining the appropriate inter-rotor spacing of pusher type rotor for better performance: model 1

![Inter-rotor spacing vs thrust (rotor1)](image1)

Determining the appropriate inter-rotor spacing of Main rotor for better performance: model 1

![Inter-rotor spacing vs thrust (rotor2)](image2)
ROTOR ANALYSIS (S-Series Profile with Transonic and Biconvex)

Determining the appropriate inter-rotor spacing of pusher type rotor for better performance: model 2

![Propeller Performance Graph](image1)

Determining the appropriate inter-rotor spacing of Main rotor for better performance: model 2

![Inter-rotor Spacing vs Thrust Graph](image2)

HELICOPTER WITH 15 DEGREE RUDDER DEFLECTION

STREAMLINE PATTERN

(RPS: MAIN ROTOR-1=-0.2rev/s, MAIN ROTOR-2=0.2rev/s,
TAIL ROTOR-1=1rev/s, TAIL ROTOR-2=-1REV/S)

INLET condition=208m/s
**Cₚ DISTRIBUTION ON LEFT AND RIGHT SIDE OF HELICOPTER (WHILE VIEW FROM FRONT)**

*Cₚ* variation on left and right surface of helicopter due to rudder moment

**HELICOPTER WITH DIFFERENTIAL MAIN ROTORS RPM**

**STREAMLINE PATTERN**

(RPS: MAIN ROTOR-1=2rev/s, MAIN ROTOR-2=1rev/s, TAIL ROTOR-1=1rev/s, TAIL ROTOR-2=-1REV/S)

INLET condition=208m/s
DISTRIBUTION ON LEFT AND RIGHT SIDE OF HELICOPTER (WHILE VIEW FROM FRONT)

CENTER OF PRESSURE CALCULATION OF COMPLETE MODEL 1:

<table>
<thead>
<tr>
<th>REVOLUTION PER SECOND</th>
<th>CENTER OF PRESSURE (mm)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>1</td>
<td>2996.3918</td>
<td>125.698</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>4.39E+03</td>
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<tr>
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<td>4674.9032</td>
<td>146.885</td>
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<tr>
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<td>4745.5655</td>
<td>148.202</td>
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</tr>
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<td>4778.7043</td>
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</table>
CENTER OF PRESSURE CALCULATION OF COMPLETE MODEL 2:

<table>
<thead>
<tr>
<th>REVOLUTION PER SECOND</th>
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<td>5</td>
<td>2896.32</td>
<td>144.45</td>
</tr>
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</table>
Co-efficient of Thrust Comparison For S-series, Onera and S-series with transonic and biconvex airfoil

CT COMPARISON

- ONERA PROFILE BLADE
- S-SERIES WITH SUPER CRITICAL PROFILE BLADE
- S-series profile Blade
Co-efficient of Torque Comparison For S-series, Onera and S-series with transonic and biconvex airfoil

![Cq Comparison Diagram]

**HELCOPTER IN FORWARD FLIGHT: MODEL 2**

![Helicopter Forward Flight Diagram]
RESULTS AND CONCLUSION:

- The value $C_D$ of modified fuselage is less than the 0.13 and lower than the fuselage used in Model 1.
- The value $C_Q$ of modified rotor is higher than actual S profile blade, but the value of $C_T$ is less compared to actual S profile blade.
- Appropriate Inter-rotor distance of
  - S-Series Profile pusher coaxial propeller is 360mm
  - S-Series Profile Main coaxial rotor is 490mm
  - S-Series Profile with Transonic and Biconvex pusher coaxial propeller is 0mm (i.e) Hub thickness 200mm
  - S-Series Profile with Transonic and Biconvex main coaxial rotor is 490mm
- $C_p$ Distribution over fuselage reference line due to differential main rotor RPM and rudder deflection is studied.
- Center of pressure for different RPM is plotted.
- Comparison of $C_T$ and $C_Q$ for different rotor design is plotted.
- Aerodynamics Analysis of Modified fuselage with graph $C_L$ vs Alpha, $C_D$ vs Alpha and $CL/CD$ Vs Alpha.
Reference:

2. An experimental investigation on aerodynamic performance of a coaxial rotor system with different rotor spacing and wind speed- Yao Lei, Yue Bai, Zhijun Xu, Qingjia Gao and Changjun Zhao
4. The methods of drag force measurement in wind tunnels- Mats Sandberg and Hans Wigö
5. NREL Advanced Research Turbine (ART) Aerodynamic Design of ART-2B Rotor Blades Dayton A. Griffin