Innovative Propulsors and Engine Integration
Innovativ Framdrivning och Motorinstallation - iFRAM

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Possible technological improvements for more efficient aircraft

Innovative airframes
Novel propulsion systems
New core technologies
Possible technological improvements

Open rotor
The open rotor

- Decreases fuel consumption
- Increases noise
- High bypass ratio
- Impingement of vortices and wakes on rear rotor
How is the noise generated?
How can the noise be decreased?

- Baseline
- Forward sweep
- Increased axial distance
- Clipping

Most suggested solution
The Boxprop

• New, unique, and radically different propeller shape.

• The Boxprop consists of pair-wise tip joined blades.

• The main hypotheses are:
  • Surpressed tip vortex – lower interaction noise
  • Higher structural integrity
  • Forward-swept blades
1. Aerodynamics of the Boxprop

2. Structural dynamics of the Boxprop

3. The counter-rotating Boxprop Open Rotor

4. Ongoing and future work
Aerodynamics of the Boxprop

Cruise performance

- Early Boxprop designs (GPX701) showed little signs of tip vortices in the flow when compared to conventional rotors.
- The thrust levels produced by those Boxprops are comparable to published open rotor front rotors.
- Wake analysis showed that early Boxprops had a tendency to produce excessive amounts of swirl.
- The high amounts of swirl stem from the blade interference in the blade passage.
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Aerodynamics of the Boxprop

Aerodynamic optimization at cruise

- The optimization yielded major improvements in efficiency for the Boxprop.
- The efficiency is 7% higher for the same thrust as the previously shown GPX701 Boxprop (●).
- The designs along the Pareto front share the characteristic "sheared apart" blade shape:
Aerodynamics of the Boxprop

Aerodynamic optimization at cruise
Aerodynamics of the Boxprop

Aerodynamic optimization at cruise

- Swirl has been decreased significantly relative to old Boxprop designs.

- Entropy losses stemming from boundary layers, shocks, wake mixing, etc. have also decreased.

<table>
<thead>
<tr>
<th></th>
<th>Entropy lost work</th>
<th>Radial kinetic</th>
<th>Swirl kinetic</th>
<th>Excess axial kinetic energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legacy Boxprop</td>
<td>7.91%</td>
<td>2.14%</td>
<td>16.31%</td>
<td>1.39%</td>
</tr>
<tr>
<td>Optimized Boxprop</td>
<td>6.09%</td>
<td>2.24%</td>
<td>10.58%</td>
<td>1.74%</td>
</tr>
</tbody>
</table>
Aerodynamics of the Boxprop

Aerodynamic optimization

Mach number at 75% radius

0.70 0.75 0.80 0.85 0.90 0.95 1.00 1.06 1.11 1.16 1.21 1.26 1.31
1. Aerodynamics of the Boxprop

2. **Structural dynamics of the Boxprop**

3. The counter-rotating Boxprop Open Rotor

4. Ongoing and future work
Structural analysis of the Boxprop

FEM simulations on fullscale composite blade

- Static and modal analysis performed
- Effect of material anisotropy and blade thickness investigated
- Loading from inertial (centrifugal) force, fixed support at the hub
- Aerodynamical loading is neglected
- Bending forces dominate, with maximum tensile stresses at tip.
- Stiffening due to centrifugal loads is taken into account in the modal analysis.
Structural analysis of the Boxprop

Modal shapes
1. Aerodynamics of the Boxprop

2. Structural dynamics of the Boxprop

3. The counter-rotating Boxprop Open Rotor

4. Ongoing and future work
Cruise performance targets are set to match the open rotor published by Airbus (2013).

Main design parameters:
- 6 front blades, 11 rear blades
- 4.27 m diameter and hub-to-tip-ratio of 0.4

Boxprop as the front rotor, chosen from existing optimization databases.

Conventional propeller as the rear rotor, designed with an in-house propeller design code (OptoProp).

The counter-rotating Boxprop open rotor
Supersonic regions

\[ T = 19.6 \, kN \]
\[ \eta_{prop} = 84.5\% \]
1. Aerodynamics of the Boxprop

2. Structural dynamics of the Boxprop

3. The counter-rotating Boxprop Open Rotor

4. Ongoing and future work
Ongoing and future work

- Optimization of both front and rear rotors of the counter-rotating Boxprop open rotor.
- Comparison between aerodynamically optimized Boxprop and conventional propellers.
- Develop design for take-off conditions
- Analysis of acoustic signature for the take-off operating point.
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