An Open-Rotor Distributed Propulsion Aircraft Study

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Agenda

- FanWing Early Development
- SOAR Background
- 3 Research Questions & Results
  - Scalability
  - Power Required
  - Economic Competitiveness
- Conclusions and Questions
FanWing Early Development

[Images of early development stages of FanWing aircraft]
FanWing Early Development

10kg model

1kg model

Flies more efficiently, Faster
SOAR Background

- EU sponsored project, 4 partners
- 3 key research questions: scalability, power requirements, and economic competitiveness
- 1 wind-tunnel test, 1 bench test, unsteady cfd, market & econ analysis
- 4 publications, youtube documentary: soar-project.eu
3 Research Questions

• Scalability
  • Does the vortex scale up to higher fan radii?

• Power Required
  • What is the required power to takeoff mass ratio?

• Economic Competitiveness
  • Is the FanWing Competitive in its selected target markets?
Scalability: Unsteady CFD

- CFD Shows that vortex is present at various operating conditions, even with variations of turbulence model
- Vortex creates a *very* low pressure zone above the curved section generating higher lift coefficients
Scalability: VKI Test
Scalability: VKI Test

Lift coefficient vs tip speed ratio for different AoA in cruise conditions, blade angle=5°, Camber + TER 2.5cm

1. CL for AoA=10°
2. CL for AoA=12°
3. CL for AoA=10°
4. CL for AoA=8°
5. CL for AoA=6°
6. CL for AoA=4°
7. CL for AoA=3°
8. CL for AoA=2°
9. CL for AoA=1°
10. CL for AoA=0°
Scalability: Bench Test

Comparison of Model Data

Effect of Tip Speed on Power Per Static Thrust

- Best Data
  \[ \frac{W}{g} = 0.008 \times \text{Tip Speed (m/s)} \]

Data Points:
- PRESTON 2012, 15 cm
- VKI 2014, 50 cm
- TREV 2013, 60 cm
- TREV 2015, 60 cm

Graph: Rotor Tip Speed (m/s) vs. Watts Mech. (or Grams Total Weight)
Power Required: Torque Comparison

- 16-bl. orig. model
- 16-bl. rev. model
- 8-bl. orig. model
- 8-bl. rev. Model
- 16-blade CFD, AoA = 0°, 5.1 m/s

Rotor speed / rpm

Torque / Nm
Power Required: Aircraft Design Changes
Power Required: Aircraft Design Changes

- Engine (red)
- Cockpit (grey)
- Payload (green)
- Ohs/Wing (light blue)
Power Required: Changes to Empty Mass

Mass Comparison (2000 kg payload class)

- AT502 Baseline Competitor (Markish)
- SOAR FanWing

<table>
<thead>
<tr>
<th>Component</th>
<th>AT502 Baseline Competitor</th>
<th>SOAR FanWing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systems</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Wing</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Engines</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Landing Gear</td>
<td>100</td>
<td>100</td>
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<tr>
<td>Fuselage</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Horizontal Tail</td>
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</table>
Economic Competitiveness
## Power Required: Results

### Power Required Comparison

<table>
<thead>
<tr>
<th>Design</th>
<th>Power to Maximum take-off Mass Ratio (kw/kg)</th>
<th>Take-off Rotation $C_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-22 Tiltrotor</td>
<td>0.384</td>
<td>4.3-5.7</td>
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<tr>
<td>VH-71 Kestral</td>
<td>0.361</td>
<td></td>
</tr>
<tr>
<td>Sikorsky S-92</td>
<td>0.313</td>
<td>4.3-5.7</td>
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<tr>
<td>AW109 Utility Helicopter</td>
<td>0.293</td>
<td></td>
</tr>
<tr>
<td>FW. firefighting</td>
<td>0.231</td>
<td>4.3-5.7</td>
</tr>
<tr>
<td>FW. agricultural</td>
<td>0.223</td>
<td>4.3-5.7</td>
</tr>
<tr>
<td>Bombardier CL-415 STOL firefighter</td>
<td>0.178</td>
<td>1.45</td>
</tr>
<tr>
<td>AT 502 agricultural aircraft</td>
<td>0.172</td>
<td>1.55</td>
</tr>
<tr>
<td>Cessna Caravan Utility Aircraft</td>
<td>0.162</td>
<td>1.91</td>
</tr>
</tbody>
</table>

### FanWing Design Changes

<table>
<thead>
<tr>
<th>Design Category</th>
<th>Change Factor</th>
</tr>
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<tbody>
<tr>
<td>Payload Volume</td>
<td>2x</td>
</tr>
<tr>
<td>Empty Mass</td>
<td>1.17x</td>
</tr>
<tr>
<td>Required Operational Power</td>
<td>1.3x</td>
</tr>
</tbody>
</table>
Economic Competitiveness

- Crop dusting 4000k built, 800-1000 per program
- ~5,000 kg MTOW
- Stall speed ~55 kts
- Takeoff Distance: 351m

- Firefighting (~400 built, 100 per new program)
- 217% acquisition premium over similar sized/powered passenger aircraft
- ~20,000 kg MTOW
- Stall speed: 68 kts
- Takeoff Distance: 815 meters
Economic Competitiveness: 1000kg-2500kg class

Performance Characteristics
- Chemical drop occurs at cruise speed for baseline
- Mission time increases from 3 to 5 hours @ 40m/s for 200km
- 1.2% increase in acquisition cost for FanWing
- Ownership costs / asset utilization dominate operating economics
- 80 m takeoff distance

Existing Markets
- Agriculture
- Firefighting
- 7000 Units, 4000 Units / year

New Markets
- Short haul freight, tourism

Cost per flight:
Economic Competitiveness: 1000kg-2500kg class

- **SOAR (Owner Pilot, 20 flights per month)**
- **SOAR (Owner Pilot, 5 flights per month)**
- **SOAR Business Operator**
- **Baseline (20 flights per month)**

![Bar Chart](chart19.png)
Economic Competitiveness: 10000 kg class

Operating Costs
- 178 km mission with 3 lowspeed fuel drops
- Mission increases from 47 to 99 minutes at 40 m/s
- Ample room to take premium from competitor aircraft

Existing Markets
- Firefighting
- 100 Units, 30 Units / year
- 125% above market for new aircraft

New Markets
- Short haul freight

Cost per flight:
Economic Competitiveness: 10000 kg class

- Government Owner
- Government Charter:
- Baseline (20 flights per month)
Conclusions

- **Scalability:** Does the vortex scale up to higher fan radii?
  - Inconclusive but some potential
  - 60cm test showed presence of vortex

- **Power Required:** What is the required power to takeoff mass ratio?
  - ~30% more than a fixed wing equivalent but less than an equivalent helicopter

- **Economic Competitiveness:** Is the FanWing competitive in its selected target markets?
  - Agri: yes when based at the field with high utilization
  - Firefighting: yes due to premiums commanded by scooping payload multiplier capability
Questions?