An Initial Investigation on RPM-Controlled Rotor Performance Characteristics for a UAM Multirotor Concept Vehicle by Varying Blade Pitch Angle Distribution

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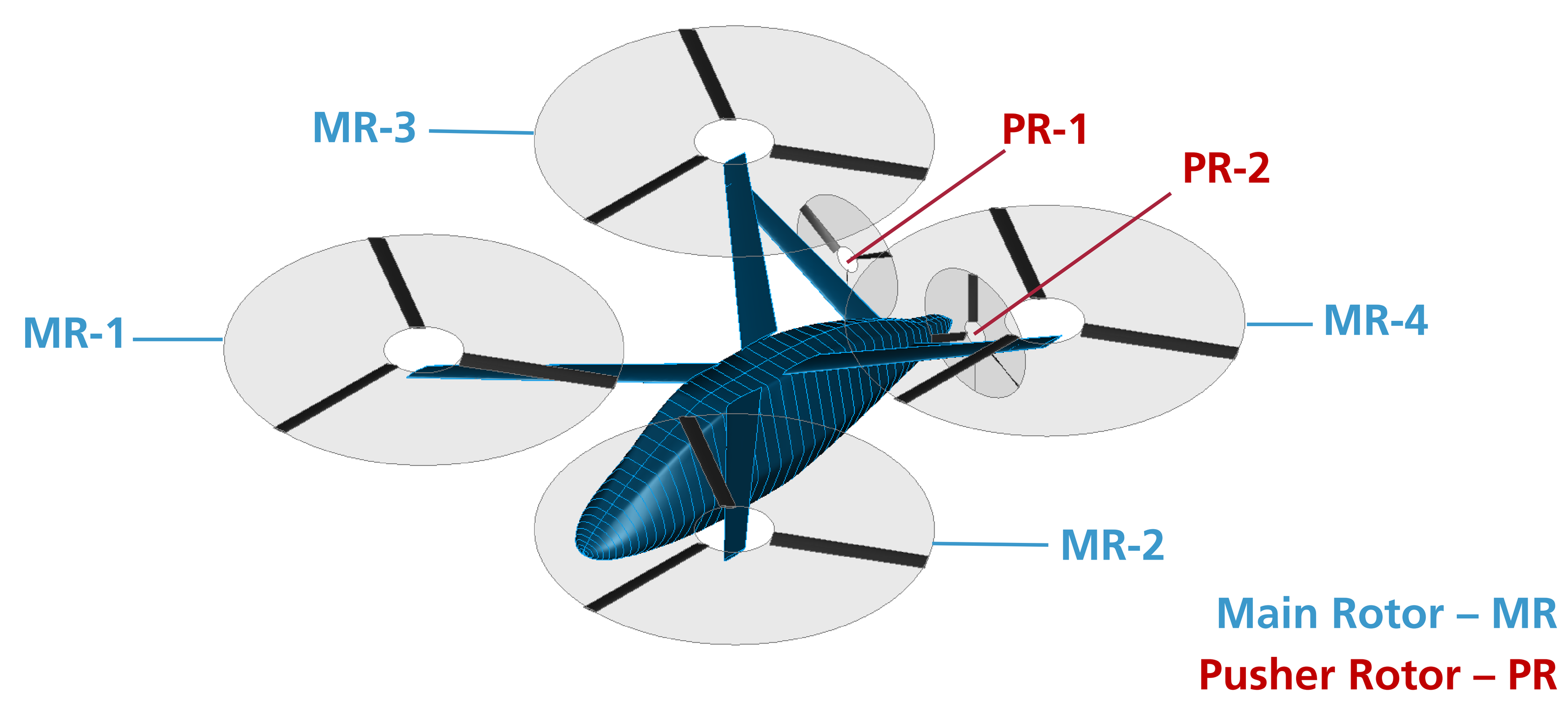
1. Introduction

The Medical Personnel Deployment Vehicle (MPDV) is a multirotor UAM concept, initially developed within the scope of the DLR project *URBAN-Rescue* for fast air transport of an Emergency Physician (EP) to the dispatched area in the course of first line emergency services. The determined design mission imposes two challenges on the rpm-controlled main rotors: first, to deliver an efficient hover performance; second, to prevent the blade stall at the advancing rotor side in cruise. An optimal blade pitch angle distribution plays a key role in achieving these challenges. This study investigates the impact of the blade pitch angle distribution on the MPDV main rotor performance. Five blade variants are selected upon varying the local blade pitch angles for hover and high-speed cruise, taken as design points. The selected blade variants are then compared in a wider flight speed range.

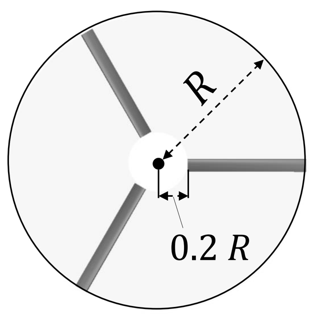
2. The Medical Personnel Deployment Vehicle



3. Isolated Main Rotor Analysis

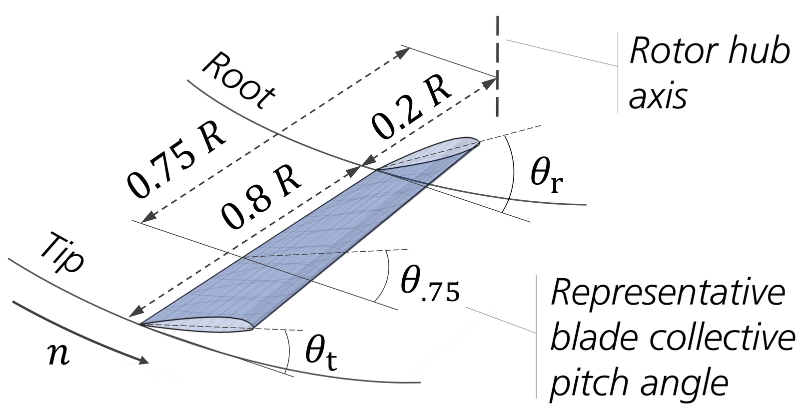
Reference Rotor

- Radius $R = 1.97$ m
- Solidity $\sigma = 0.08$
- Rectangular blade
- Airfoil: NACA 23012



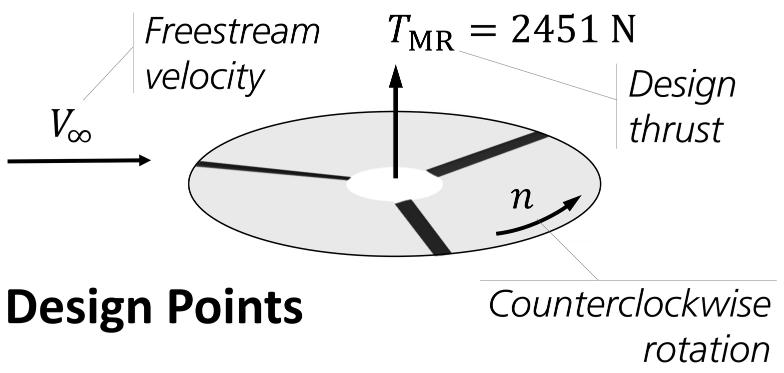
Blade Pitch Angle Distribution

- Linear distribution between pitch angles at the root θ_r and the tip θ_t
- Blade twist $\theta_{tw} = (\theta_t - \theta_r)/(0.8\,R)$
- Blade collective represented at 75 % R



Numerical Analysis Setup

- Blade element momentum theory
- Pitt-Peters inflow model
- Induced power loss factor $\kappa = 1.1$
- Rigid rotor (no blade elasticity)



Design Points

- **DP 1:** HOGE @ VFM
  - $V_\infty = 0$ km/h
  - $\rho = \rho_0 = 1.225$ kg/m^3 (MSL)
- **DP 2:** Cruise @ HFM
  - $V_\infty = 150$ km/h (41.6 m/s)
  - $\rho/\rho_0 = 0.953$ ($H = 500$ m)

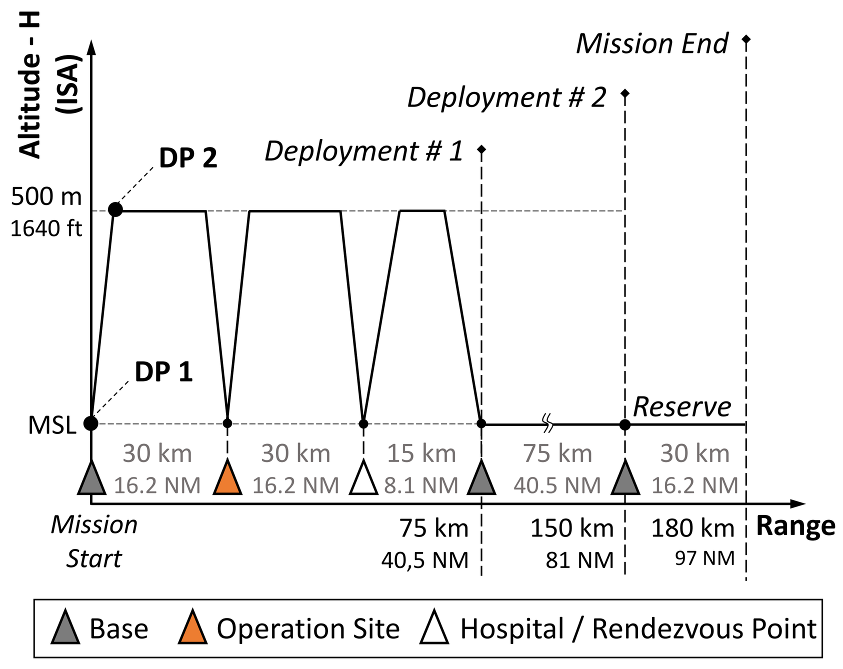
Vehicle Configuration

- Electrically driven rpm-controlled thrust
  - 4 main rotors - MR
  - 2 pusher rotors - PR
- Hybrid-electrical power train
- Tandem seating: 1 Pilot + 1 EP
- Initial design mass: 1 t

Control Modes

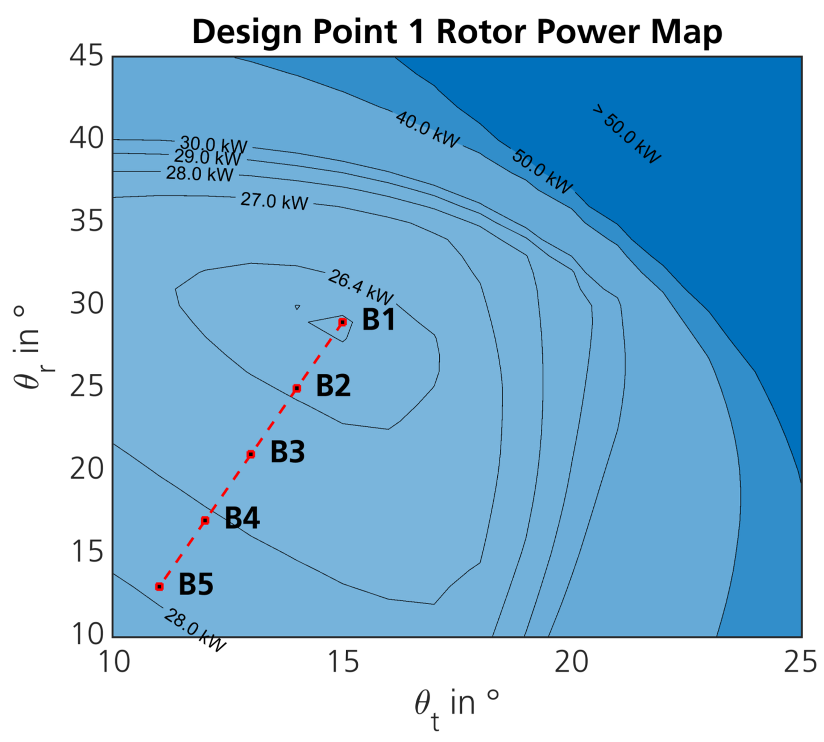
- **VFM -** Vertical Flight Mode
  - Hover to slow forward flight regime
  - Vehicle control only by MR
  - PR inactive
- **HFM -** Horizontal Flight Mode
  - Intermediate to high-speed cruise regime
  - MR for vertical thrust, roll and pitch control
  - PR for forward thrust and yaw compensation

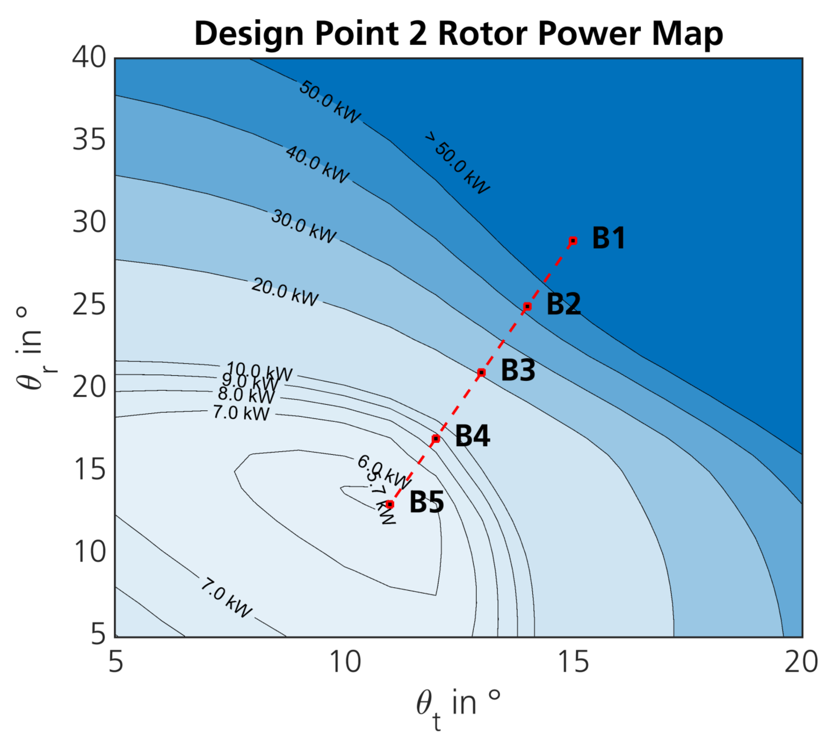
Design Mission

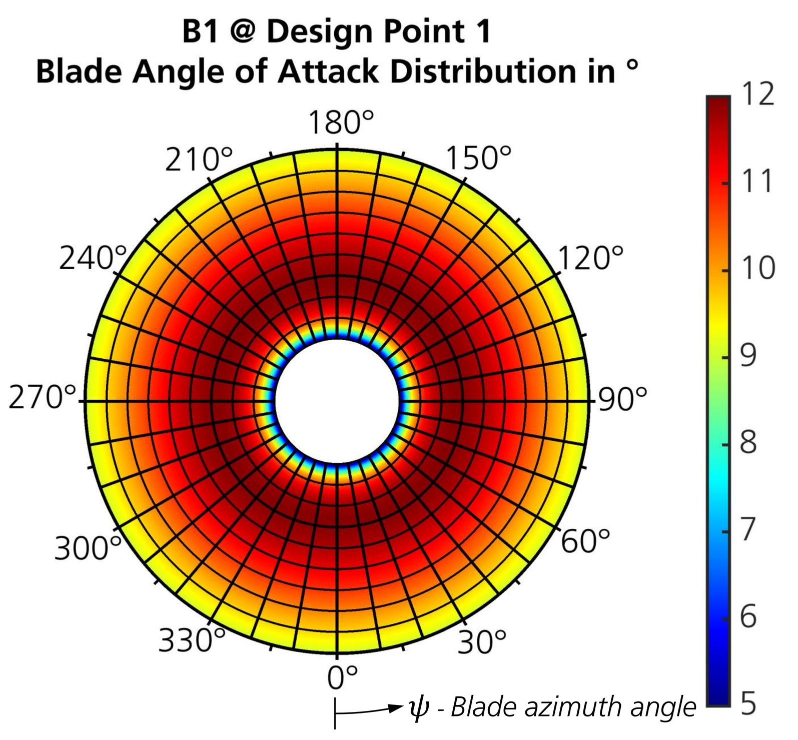


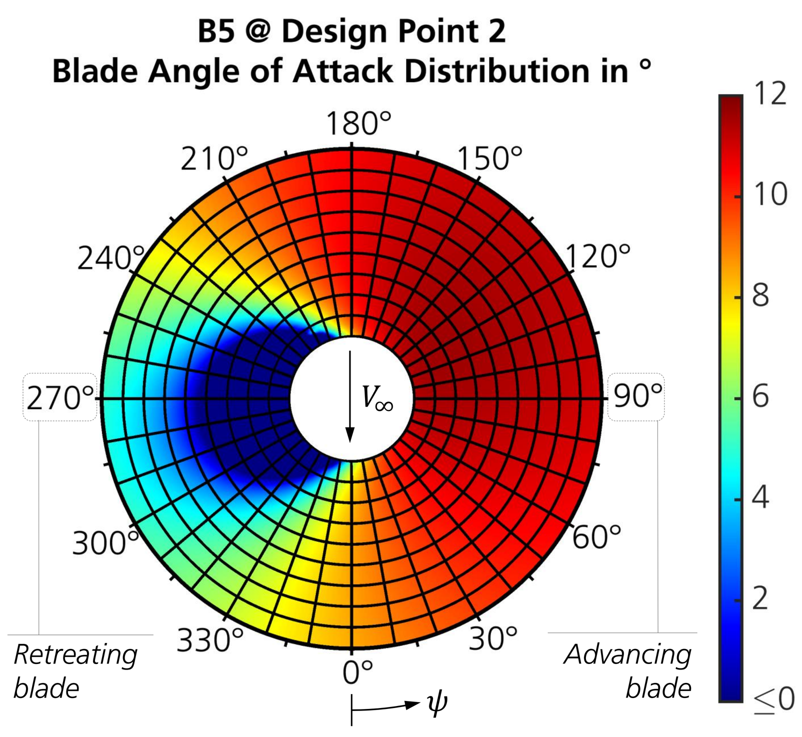
- 150 km mission range + 30 km reserve
- 2 mission deployments with 3 segments
- 60 s hover out of ground effect (HOGE)
- VFM at hover, HFM at cruise
- Cruising altitude: 500 m (1640 ft)
- Cruising speed: 150 km/h (~81 kts)

4. Design Point Performance







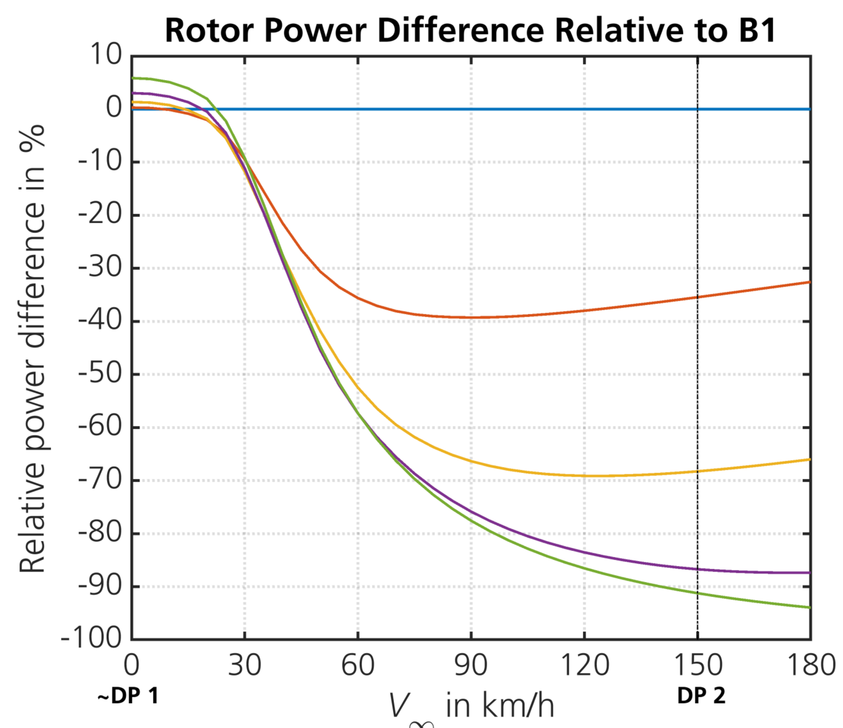


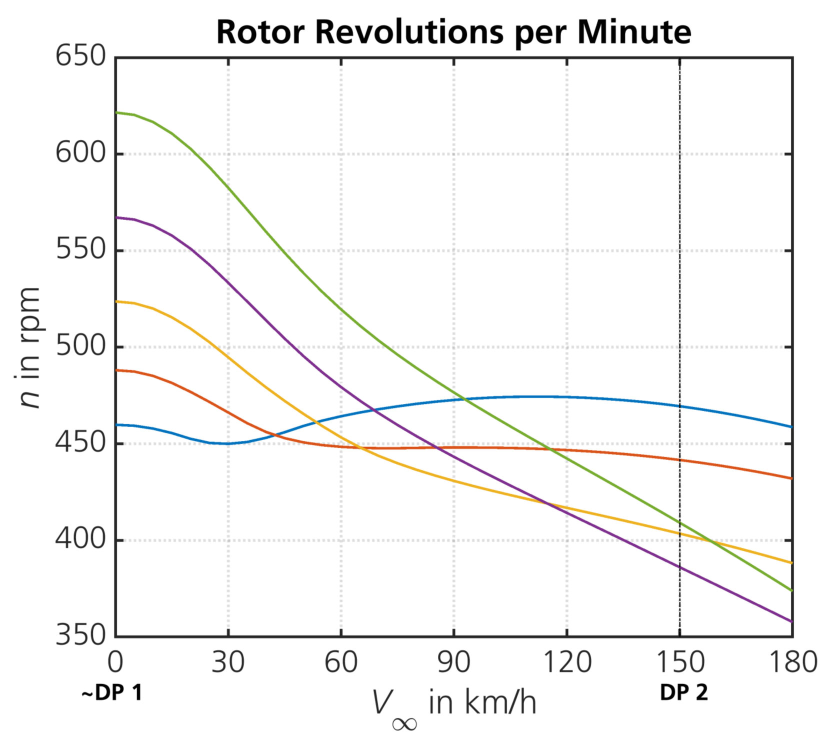
5. Off-Design Performance

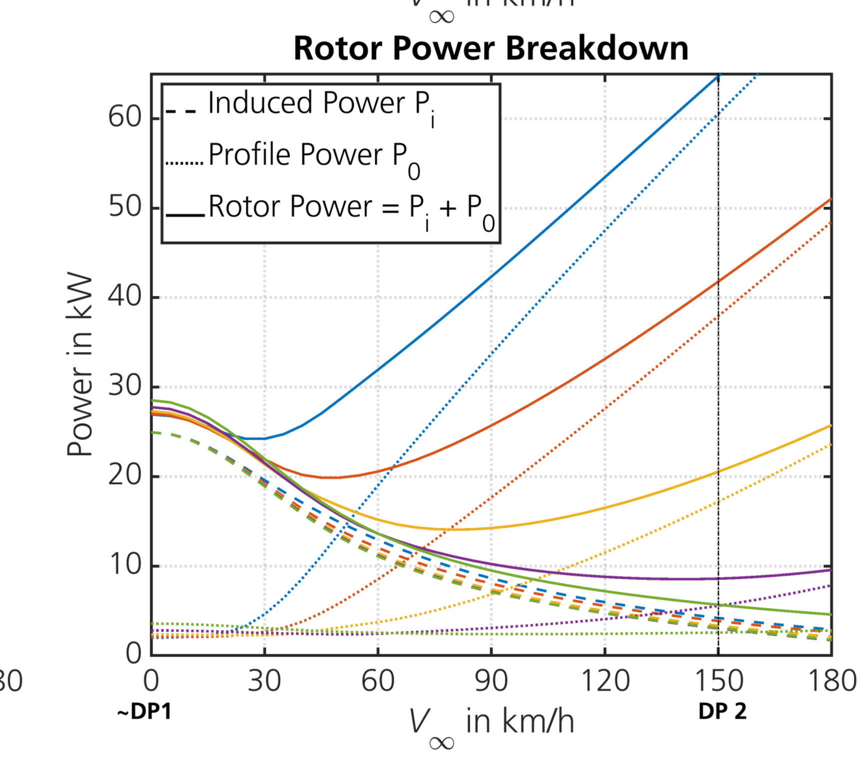
Conditions

- Cruise @ HFM, $H = 500$ m
- V_∞-sweep from 0 to 180 km/h

Blade	θ_r in °	θ_t in °	θ_{tw} in °/m	$\theta_{.75}$ in °
B1	29	15	−8.88	24.11
B2	25	14	−6.98	21.17
B3	21	13	−5.08	18.21
B4	17	12	−3.17	15.26
B5	13	11	−1.27	12.30







6. Conclusions

In hover case (**DP 1**), a broad range of root-tip pitch angle combinations can be chosen with minimal increase on the rotor power with respect to the optimum (i.e. **B1**, high blade twist and collective). For the high-speed cruise flight case (**DP 2**), this range presents a relatively smaller area concentrated about the optimum point (i.e. **B5**, low blade twist and collective). Moreover, **B5** shows that blades optimized for high-speed cruise also exhibit acceptable performance characteristics in hover with a reasonable compromise on the rotational frequency and therefore on the rotor power, hence representing the most beneficial option.

7. Outlook

- Further investigation on the blade geometry to improve the rotor performance characteristics and to reduce the rotor static and dynamic hub loads:
  - Variable chord distribution,
  - Non-linear pitch angle distribution,
  - Use of sophisticated airfoils more suitable for rpm-controlled rotors
- Study of the rotor transient response to evaluate power requirements for rotor control
- Sizing of the concept MPDV with the optimized rotors

3rd Urban Air Mobility Symposium
July 5, 2023, Cochstedt / Germany

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