Mitteilung

Fachgruppe: Drehflügler

Maximum Thrust of Helicopter Rotors in Hover:
Impact of Comprehensive Code Aerodynamic Modeling

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Introduction:
Computation of maximum thrust of a helicopter rotor is a challenging task even in hover, because it occurs with a significant amount of stalled region over the rotor blade, which makes a stationary solution using computational fluid dynamics codes impossible. Therefore, a comprehensive rotor code is employed and the impact of aerodynamic modeling on the results is investigated. To isolate the aerodynamic modeling effects from blade design and its elastic response, the blade is assumed rigid, rectangular and linear twisted (Bo105 model rotor geometry and airfoil NACA 23012, 4 blades, radius $R = 2$ m, solidity $\sigma = 0.077$, blade twist -8 deg, tip Mach number $M = 0.641$).

Models affecting maximum airfoil lift:
The airfoil's aerodynamic coefficients are modelled analytially in terms of section normal force, chord force and pitching moments, based on the dynamic pressure of the speed of sound: $C_{n,c,m}M^2$. They include stall angle (α_{SS}) and Mach number (M) effects, yawed flow (yaw angle β) conditions and centrifugal force (CF) effects on the boundary layer, the latter two resulting in a steady stall delay $\Delta\alpha_{SS}$ to larger angles of attack (α). Due to analytic modeling, unsteady aerodynamics result in dynamic lift overshoot and a post-stall vortex shedding model can also be enabled, resulting in unsteady aerodynamic response. Examples are given in **Fig. 1**.

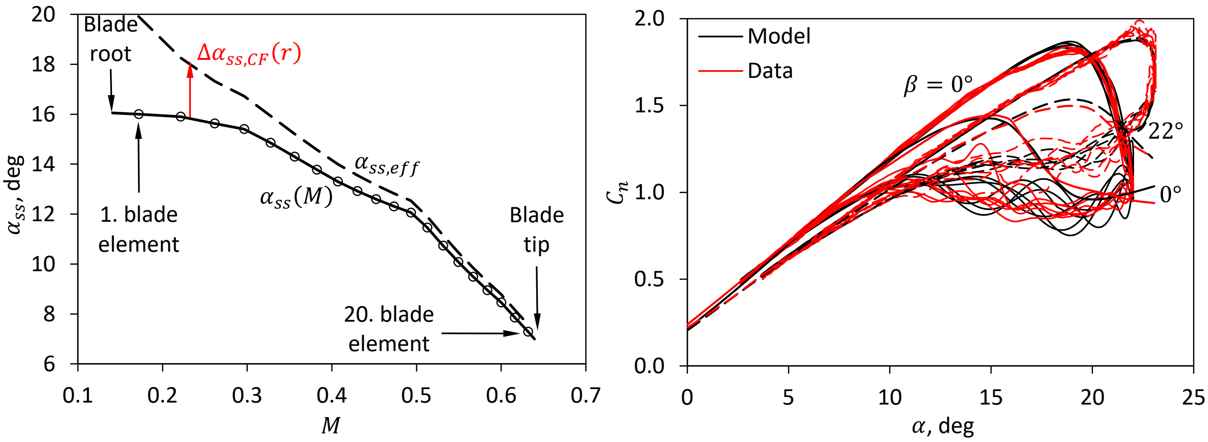

Fig. 1: Impact of modeling features on airfoil aerodynamics. Left: stall delay due to CF model; right: post-stall vortex shedding with and without yaw angle and comparison with data.

The inflow ratio (λ_i) models employed here are no inflow (none), Glauert's constant inflow, Mangler's inflow with non-linear radial distribution, and a prescribed vortex wake (PW) geometry model including blade-vortex interaction. All of them can be combined with a tip loss model, enforcing zero lift at the blade tip and root via additional indcued inflow from a radial position r_{tl} to the tip. Example inflow distributions for the same thrust are given in **Fig. 2** (left) and the impact of the tip loss model on a standard spanwise loading is shown right for a variation of r_{tl}.

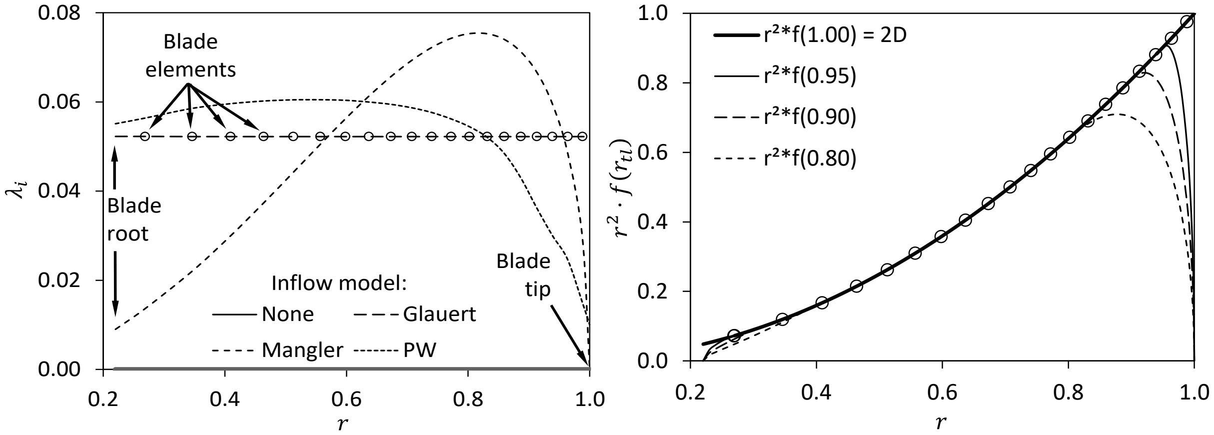

Fig. 2: Inflow distributions (left) and effect of tip loss model (right).

Results:

The rotor blade collective control angle Θ_{75} is increased from moderate lift up to the point of maximum thrust C_T (or, specific blade loading C_T/σ) and beyond, where the thrust due to increasing amount of stall and associated loss of lift is reducing. **Fig. 3** shows results and includes data from wind tunnel test. No inflow is non-physical and achieves the highest thrust, becaue the blade twist resembles the distribution of stall angles and avoids local stall to a large extent. The inflow distributions of Glauert and PW are similar and results as well, stall first occurs at the blade tip. The Mangler model with more inflow in the tip region results in higher lift capability than the PW model. For all inflow models, 2D aerodynamics up to the tip ($r_{tl} = 1$) allow for higher thrust than a large area of tip loss ($r_{tl} = 0.8$). Employing the CF model increases the thrust once the stall angle without it is reached.

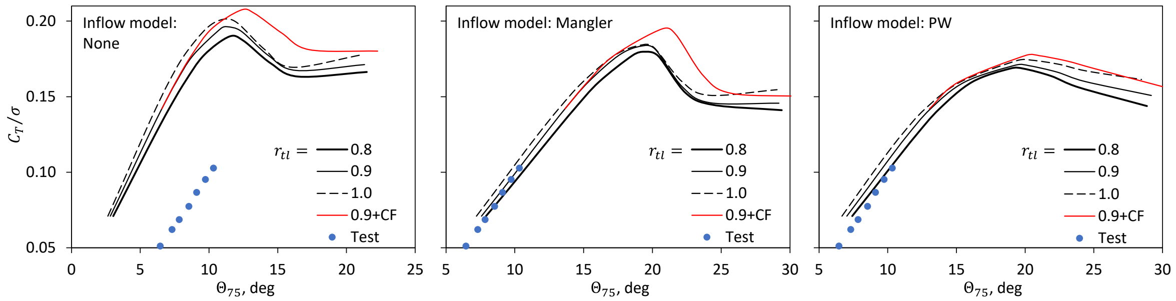

Fig. 3: Impact of inflow model, tip loss and CF on thrust curce and comparison with data

Conclusions:

1. Constant inflow or prescribed wake model have larger inflow ratio in the inner parts of the rotor and less in the outer region than the Mangler model. This leads to smaller angles of attack in the inner regions and larger ones at the blade tip, compared to the Mangler model.

2. The highest possible thrust is obtained by the Mangler model, because of its high inflow in the outer region of the blade, where the stall angle of attack is the lowest due to the high Mach number.

3. Increasing the tip loss region reduces the maximum possible thrust. Realistic values for high thrust range from $r_{tl} = 0.8 - 0.9$.

4. The CF model delays steady stall to higher angles of attack more in the root than in the tip region and has a significant impact on increasing the maximum thrust prediction.

5. All models have a physical background, but data are needed to tune the model parameters, e.g. r_{tl} or $\alpha_{SS,CF}$ to the most realistic values.