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Geometry of dragonfly wing sections - Influence on lift and drag

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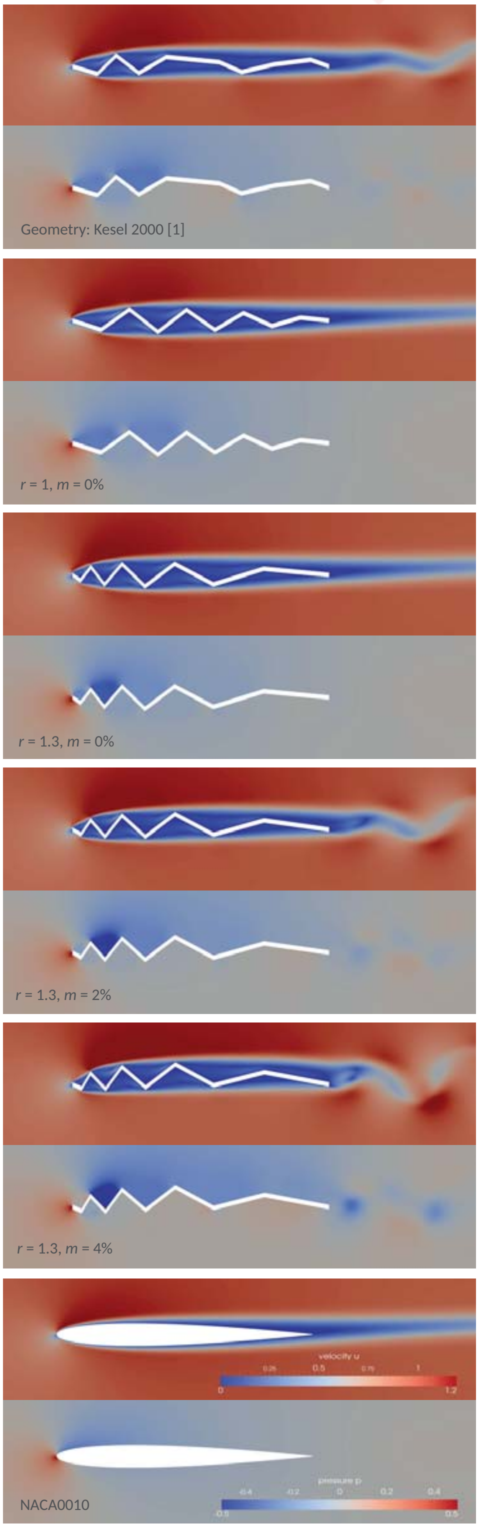

Fig. 1: Dimensionless velocity and pressure fields of flows around dragonfly wing section from [1], corrugated wing sections (different expansion factors *r*, cambers *m)* and NACA0010, all at angle of attack of 3° and Reynolds number of 4000.

Introduction

Wing sections of dragonflies exhibit corrugated profiles. Previous investigations reveal for Reynolds numbers up to Re = 16000 and an incidence of 3° that the lift to drag ratios of a dragonfly wing section are superior to those of an ordinary symmetric NACA0010 profile. This work intends to contribute to the question: Which influence does the geometry of dragonfly wing sections exert on lift and drag. Therefore, the wing section is abstracted by a sequence of 9 line elements. Length and arrangement of elements are calculated by mathematical functions. Parameters are length distribution of line elements (expansion factor $1.0 \leq r \leq 1.4$) and camber $0\% \leq m \leq 4\%$. Results are obtained by computational fluid dynamics. At Re = 4000 and angles of attack $-3° \leq \alpha \leq 3°$ lift and drag coefficients are compared to those of wing sections of an original dragonfly [1] and a NACA0010 profile.

Results and Discussion

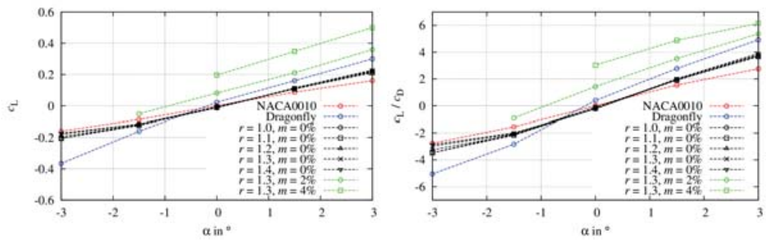

Fig. 2: Lift coefficient c_L and ratio of lift to drag coefficient c_L/c_D versus angle of attack α for different wing section profiles: NACA0010, dragonfly (Kesel 2000), constructed profiles with various expansion factors *r* and cambers *m*.

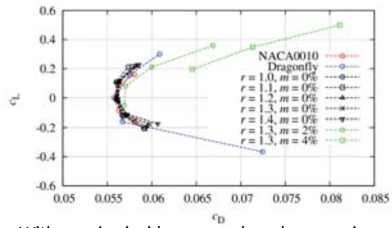

Fig. 3: Lift coefficient c_L versus drag coefficient c_D for different wing section profiles.

> **Aerodynamics of dragonfly wing sections seems to be strongly influenced by camber but less by distribution of the lengths of line elements**

- With growing incidence α and camber *m* an increase in lift and drag coefficient (c_L, c_D) arises, which is in accordance with [2]. This results from rising velocity and diminishing pressure at the upper side of the wing sections (Fig. 1 - Fig. 3).
- In the investigated ranges, incidence α and camber *m* exert a much higher influence on c_L and c_D than expansion factor *r.* The distribution of lengths of line elements seems to be of minor relevance for aerodynamics in comparison to camber (Fig. 2, Fig. 3).
- At constant incidence α and growing camber *m* the flow can descend to a transient state. In the wake of the corresponding profiles, a Kármán vortex street appears (Fig. 1).
- Results indicate: With adequate choice of expansion factor *r* and camber *m*, the aerodynamic properties of the dragonfly wing section may be emulated – to be proven in future.

Material and Methods

The coordinates of the endings of each line element in direction of chord line are calculated by a geometric series and perpendicular to chord line by a NACAxx10 profile. Maximum camber occurs at 40% of chord length. For $r = 1$ the projection lengths to chord line of all line elements are equal, for $r > 1$ the projection length of elements increases from leading to trailing edge.

All quantities are normalized. Characteristic quantities are cord length *l*, depth *b* of the profiles, inflow velocity u_{inf} and density ρ of the fluid. Flow velocity is normalized by u_{inf} and pressure by ρu^2_{inf}. Reynolds number, drag and lift coefficient are defined as follows

$$Re=\frac{\rho u_{inf} l}{\mu}, \quad c_D=\frac{F_D}{1/2 \rho u_{inf}^2 l b}, \quad c_L=\frac{F_L}{1/2 \rho u_{inf}^2 l b}.$$

Continuity and momentum equation for constant fluid properties and two-dimensional flow

$$\frac{\partial u_i}{\partial x_i}=0, \quad \frac{\partial u_i}{\partial t}+\frac{\partial u_i u_j}{\partial x_j}=-\frac{\partial p}{\partial x_i}+\frac{1}{Re}\frac{\partial^2 u_i}{\partial x_j^2}$$

are solved by the open-source code OpenFOAM. The discretisation is of second order in time and space (transient term: three-time-level scheme, convective term: LUST). A structured grid is used for NACA0010 (270 864 cells) and a hybrid grid for the dragonfly profiles (around 390 000 cells). In both cases, the edge length of the smallest cell at the surfaces of the profiles amounts to 10^{-3}. The maximum Courant number is 0.8 and the blocking of the profiles less than 0.5%.

Literature

[1] Kesel AB (2000) Aerodynamic characteristics of dragonfly wing sections compared with technical airfoils. Journal of Experimental Biology 203, 3125-35
[2] Okamoto M, Yusada K, Azuma A (1996) Aerodynamic characteristics of the wings and the body of a dragonfly. Journal of Experimental Biology 199, 281-94