Faculty Engineering Technology
Program Mechanical Engineering

UNIVERSITY OF TWENTE.

COLLOQUIUM

Group: **Engineering Fluid Dynamics**

As part of his MSc thesis assignment

J.L. Mulder

will give a presentation, entitled:

Towards the Understanding of Flapping Wing Propulsion

Date: Friday December 20, 2013

Time: 14:30

Room: **Horstgebouw NH 124**

Summary:
Literature shows that flapping wing propulsion is related to the formation of a reverse von Kármán vortex street combined with the formation of Leading Edge Vortices (LEV's) due to dynamic stall. This occurs when the Strouhal (St) number of the motion is large enough. The development and strength of the LEV is strongly influenced by the maximum effective angle of attack during the motion. Strong LEV's contribute to a strong reverse von Kármán street in the wake of the airfoil. In the thrust-producing wake, the air is accelerated in between the vortices, which yields time-averaged a jet-like stream wise velocity profile. The strength of this jet is a measure for the thrust produced.

The goal of the present study is to provide a better understanding of the flapping wing propulsion of a robotic bird and to obtain insight in the effect of varying kinematics. For that purpose the commercial CFD package ANSYS Fluent 14.5 has been used to numerically simulate the flow over a 2D pitching and plunging airfoil. The airfoil motion is implemented using a dynamic mesh controlled by a User Defined Function (UDF), which moves the airfoil within a structured C-grid in a re-meshing unstructured grid. This method has been verified for a pitching and plunging NACA0012 section for laminar as well as turbulent flow using different kinematics parameters. Good agreement is found between the present results and computational data from available literature. Subsequently the computational method has been employed to identify the influence on the flow solution of parameters like dimensionless frequency and pitching amplitude. These results have been compared with experimental results.

The flow over the mid-wing airfoil section of a robotic bird has been numerically simulated more extensively in order to identify the influence of different kinematics. It has been shown that for an increasing Strouhal number (using either a constant velocity and increasing flapping frequency or a constant frequency and decreasing flow velocity), the maximum effective angle of attack increases. This results in a stronger LEV and therewith a stronger reverse von Kármán street in the wake. This produces larger forces and a more pronounced stream wise jet profile behind the airfoil, though with a lower thrust producing efficiency. Furthermore it has been found that higher pitching angles yield lower effective angles of attack. For that case the formed LEV's are milder and higher efficiencies are obtained, however, resulting in a lower cruise velocity. The efficiency for different pitching angles peaks for $0.1<St<0.3$, which is close to the optimum Strouhal regime found in nature. The maximum efficiency points are all found for a similar maximum effective angle of attack of around 11 degrees.

The jet-like velocity profiles obtained for a range of Strouhal numbers are compared with results of experiments performed in the wind tunnel at the University of Twente. The time-averaged stream wise velocity profiles have been measured behind the wing of the robotic bird, flapping at constant frequency for velocities from 4 m/s to 12 m/s. Stream wise jets have been measured with strength of order of magnitude comparable to the ones found in the numerical simulations. The measured variation in jet size with increasing Strouhal number is comparable to the one obtained from the numerical results.

Assessment committee:
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Dr.ir. C.H. Venner
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d.d. ________________