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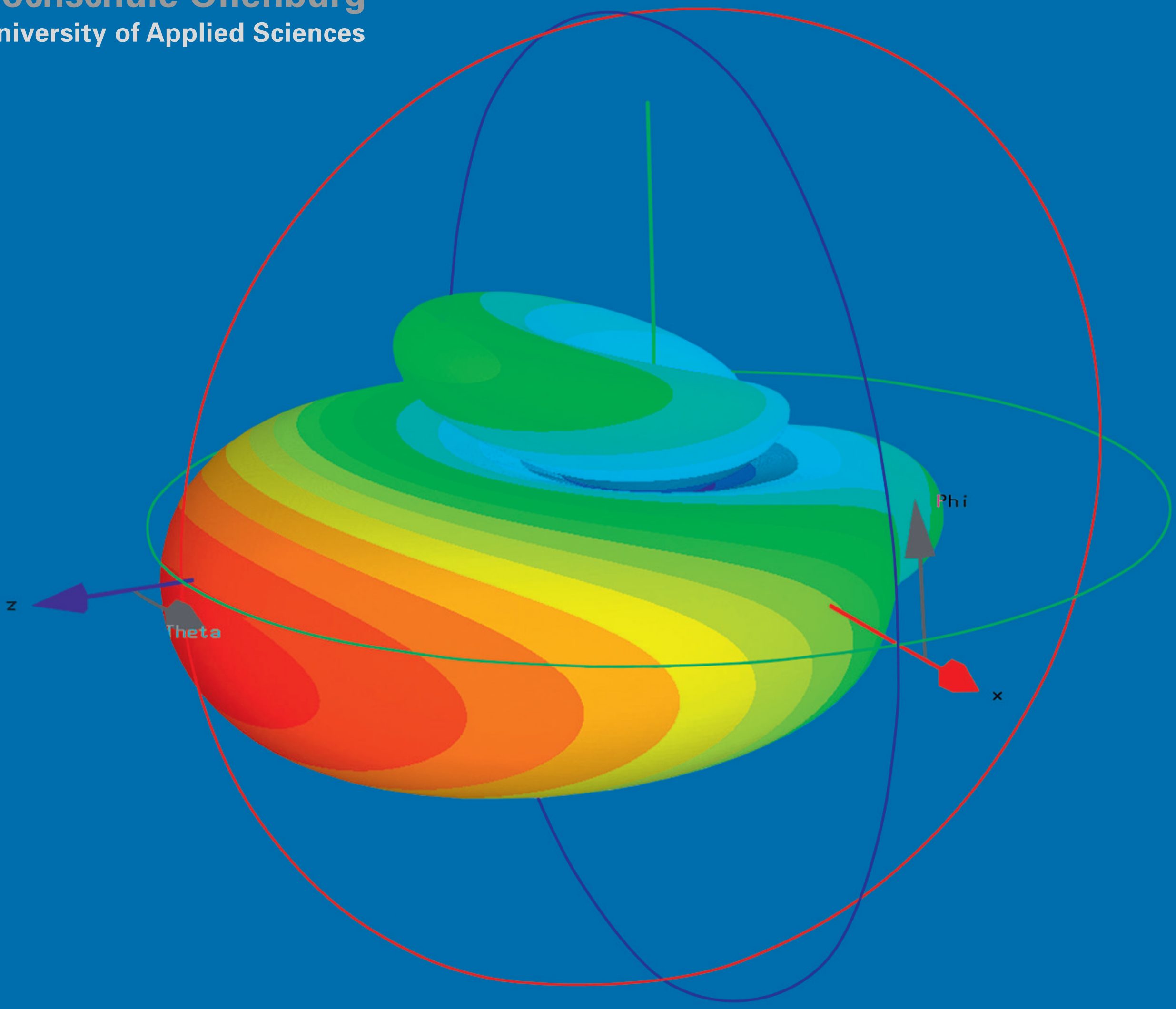
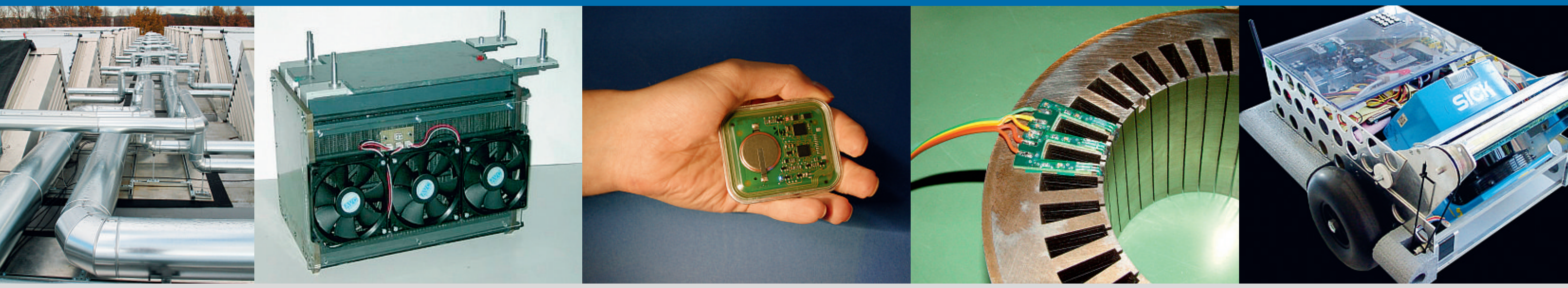


Beiträge aus Forschung und Technik 2008



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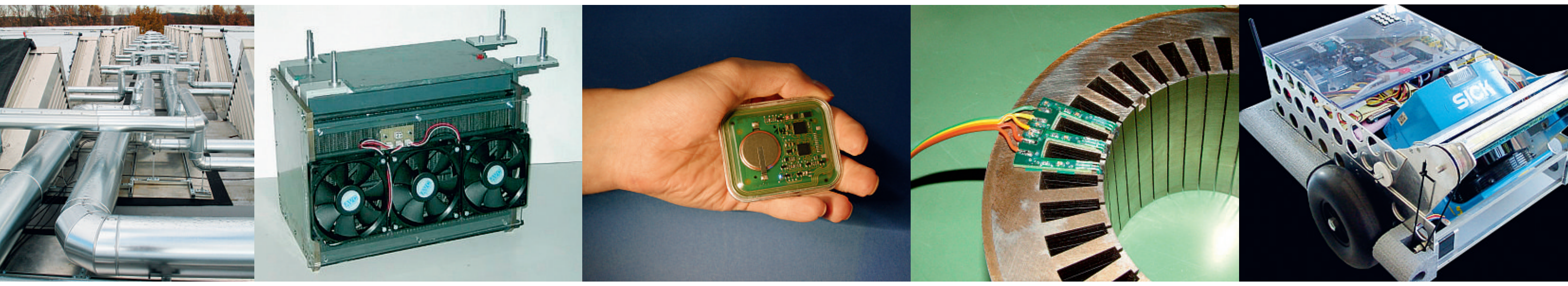

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2.3 Ab Initio Calculation of the Behaviour of a Model Helicopter

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Abb. 2.3-1 *Model-Helicopter T-REX 600 frame without motor and accumulator*

Introduction

At the University of Applied Science Offenburg, the development of a flight control system for a model helicopter of type Align T-REX 600 is under way. The helicopter has a flight mass of about 3 kg, a rotor diameter of about 1.35 m, a brushless torquer motor and is electrically powered using lithium-polymer-cells. For the flight control development, a simulation of the model aircraft is required. Mathematical models for model aircrafts are generally not available. These models for helicopters are quite involved and are not very accurate, because it is hard to model the airflow, especially during hover, near ground and at fast descend rates. Despite these expected inaccuracies, a mathematical model would give much insight into the helicopters behaviour – especially in order to decouple the steering axis in a feed forward controller part – and can serve as a test-bed for testing the flight control software.

In order to avoid wind tunnel testing, an ab-initio-model is tried, using all available data of the helicopter like masses and dimensions. It turns out, that the main rotor thrust is well modelled, giving some trust into the model. However, it is very tedious to calculate the time constant of the Bell-Hiller-bar, therefore this value is left to be measured in the true model. All other values required can be estimated from the airframe itself.

Helicopter model

The T-REX 600 frame without motor and accumulator is shown in Fig. 2.3-1. As it is the case with most classic type two-bladed helicopters, the blades are linked to the rotor head with a teeter hinge, a Bell-Hiller stabilizer bar is involved to stabilize roll and pitch movements somewhat.

In full-size helicopters, the blades are hinged in two axis near the rotor head and can be rotated along their length in order to change the attack angle of the blades during rotation. For these large blades, free movement of the blades is mandatory in order to avoid excessive torques at the rotor head.

The blades are allowed to flap up and down during rotation while seeing strong centrifugal forces. The resonance frequency of this flapping motion is almost equal to the rotation speed of the rotor, the exact value is depending on the position of the flapping hinge. The flapping of the blades introduce Coriolis-forces, which move the blades for and back in the rotor plane. That's why the blades are also allowed to move freely in the rotor plane. Centrifugal forces actually strengthen the blades into a conically shaped rotor "plane". A tilted swash-plate changes the air inflow angle to the blades via appropriate mechanical links cyclically during rotation. The flapping motion lags the feathering motion by about 90 degrees, thereby tilting the rotor tip-plane. The flapping motion is heavily damped; the damping coefficient being governed by Lock's number. The outcome of a quite involved theory about these movements is, that the rotor plane is tilted fast in respect to the rotor shaft axis according to the position of the swash-plate. Normally, the links from the swash-plate to the blades are offset in such way that the phase lag is accounted for. In this case, swash-plate and rotor tip plane become parallel.

In this model helicopter, the teeter hinge of the two blades is made of a pair of offsetted O-rings in the rotor head. These O-rings yield torques to be transferred from the rotor to the frame allowing effective 3D-stunt flieght. The O-rings also serve for the purpose of additionally damping the flapping and the lagging motion and provide a teeter hinge stop. The tail rotor is linked to the main gear with a tooth belt, autorotation is possible.

The operational blade tip velocity of the main rotor is about 130 m/s allowing safe forward velocities of several 10 m/s. Blades and the main parts of the frame are made of carbon reinforced composite and aluminium, ball bearings and well-fitting ball links are used throughout.

Forces and moments in the body frame

In this model all forces and moments due to the rotor, tail rotor, mars, inertia and air drag are included. The inflow velocities of the rotors are implemented as well. The helicopter model is calculated in the body frame and is transferred using the cosinus-matrix via roll, pitch and yaw angles into the navigation frame.

Refinements

The transfer functions of the servos used in the helicopter have to be modelled. The servos typically make a 45 degree turn within 0.15 s and could be modelled as output rate limited, first order low pass filters.

The motor needs some time to speed up and slow down due to the large moment of inertia of the rotor. The torque of the motor can be modelled depending on the rotation speed and mean voltage behind the PWM-controller. Knowing the angular momentum of the rotor, the rotational acceleration can be modelled.

Rotors in US-helicopters are rotating counter clockwise, the T-Rex rotor is rotating clockwise. This has to be accounted for in using available mathematical models. Several signs have to be reversed.

Simulations and test

The first approximation to the flight control system has been successfully designed using a model, linearized around hover-mode.

This more elaborate model presented has been implemented in MathCAD for the refined layout of the flight control scheme of the helicopter and will be implemented in C in order to test the flight control software. The issues of this model are:

- defining the feed forward part of the flight controller,
- checking the control stability for excessive flight states,
- defining safe operating regimes for the helicopter.

At large forward speed a sudden collective pitch change will lead to a strong sudden roll moment change, for which the roll controller has to account for. A low-g manoeuvre – sudden reduction of pitch – will also require a sudden roll input change. These flight regimes stress the hardware hardly and are furthermore hard to control; they should be therefore avoided.

This model will be tested during flight tests with the model-helicopter.

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