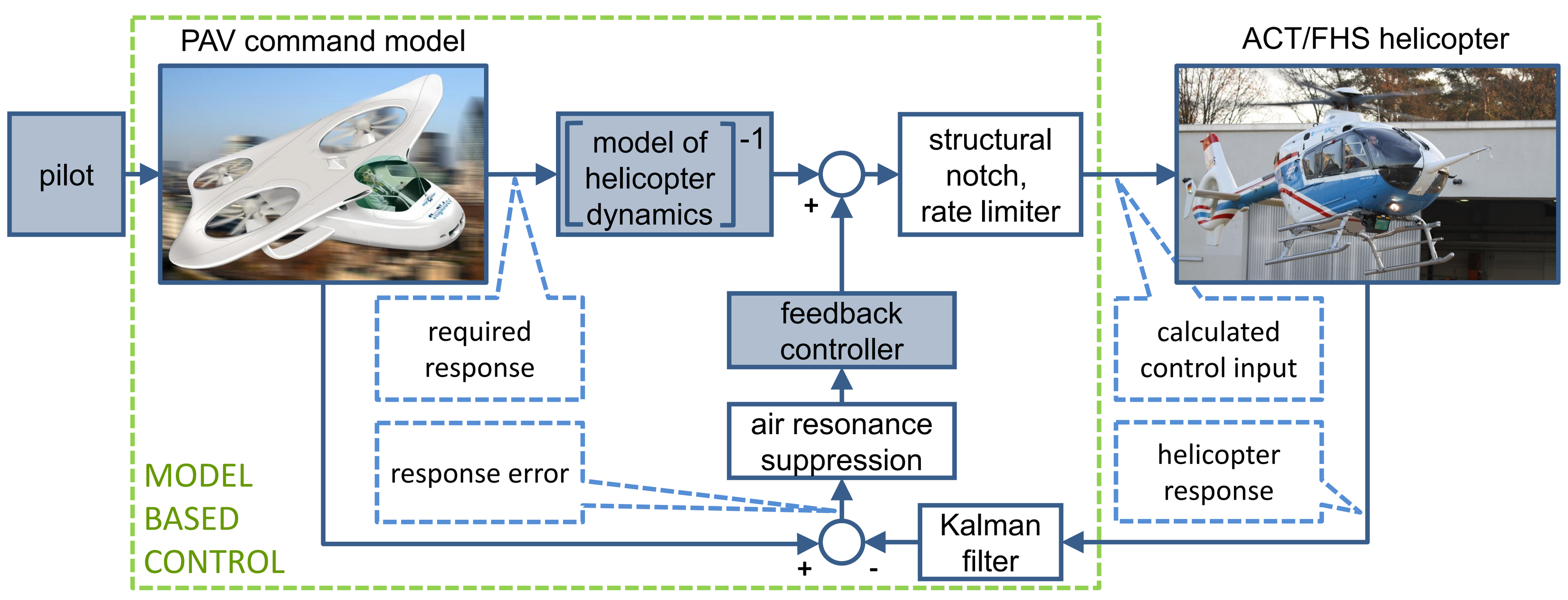
DLR
Deutsches Zentrum
für Luft- und Raumfahrt

In-Flight Simulation of PAV Flight Characteristics

DLR's research helicopter ACT/FHS (Active Control Technology / Flying Helicopter Simulator) is a testbed for a multitude of in-flight experiments, e.g. the development of novel control laws, human-machine interfaces or in-flight simulation of other aircraft. It is equipped with a highly configurable experimental system. The Model Based Control system (MBC) actively suppresses the helicopter's dynamics and imposes the dynamics and control laws defined in the command model. This enables the in-flight simulation of other, potentially not yet existing, aircraft.

The heart of the MBC is a command model that can represent the flight dynamics of a Personal Aerial Vehicle (PAV). The inputs for this model are the pilot's control inputs, the trim values for the initial flight condition and parameter signals for controlling the model during flight tests. The outputs of the model are the desired flight states, their derivatives and the position. These values drive the MBC controllers that let the helicopter behave like a PAV.

Thus, the Flying Helicopter Simulator allows to evaluate PAV flight dynamics in piloted flight test before an actual vehicle is ever built.

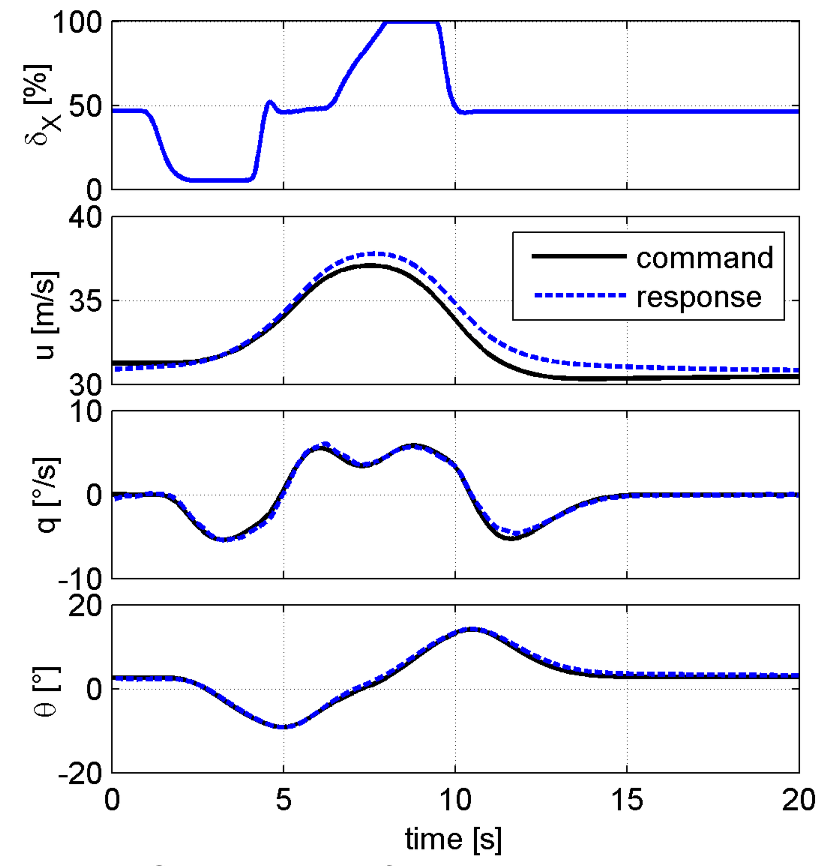


Model Based Control environment for in-flight simulation of a PAV.

Evaluation of Model-Following Capabilities

The model following capabilities are assessed in time-domain as proposed by Ref. 1 and 2. Doublet inputs are used in order to produce approximately 10° attitude on-axis responses. Data channels included for the assessment are the body-fixed velocities, turn rates and the Euler angles.

The diagram below shows the comparison of commanded signals (required response) and resulting helicopter response recorded in ground-based simulation. The root mean square (RMS) error gives an overview of the overall model time-domain accuracy. It is the weighted error of the deviation between commanded input and helicopter response in each data channel. Flight dynamics modelling of helicopters is generally rated to be acceptably accurate when the RMS error lies below 2.0.



Comparison of required response and simulated helicopter response after longitudinal doublet input.

The table below shows the calculated errors for inputs in each control axis in a simulated flight at 60 kts (30.7 m/s). The shown signals and RMS errors indicate good model following capabilities for the simulated forward flight.

Root mean square errors for inputs in each control axis:

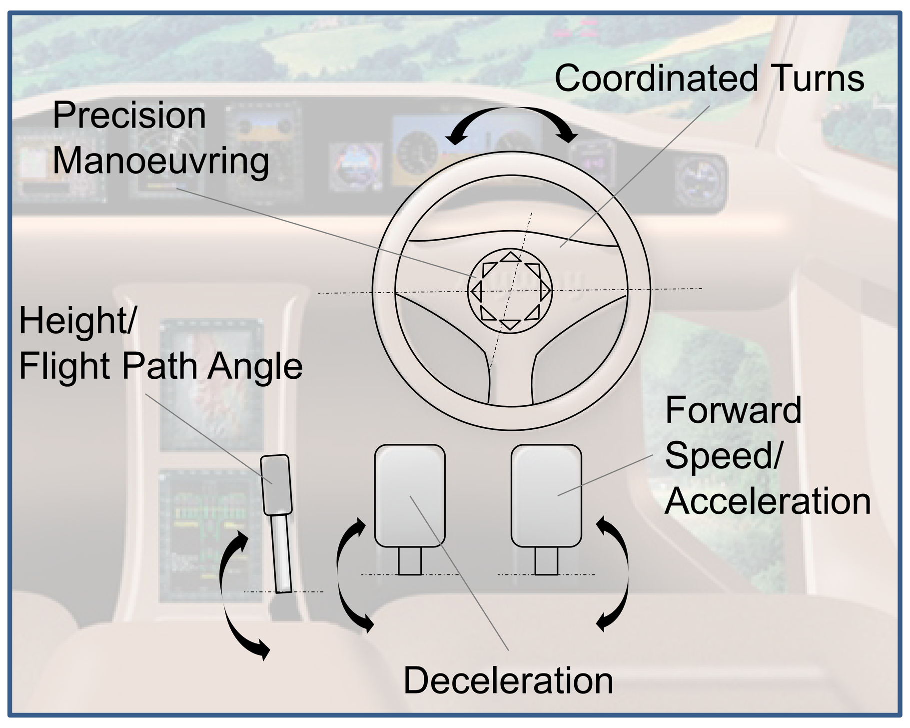
Lon (X)	Lat (Y)	Ped (P)	Col (0)
1.3	0.8	1.3	0.7

[1] Tischler, M.B., Remple, R.K., *Aircraft and Rotorcraft System Identification, Engineering Methods with Flight-Test Examples*, AIAA Education Series, American Institute of Aeronautics and Astronautics, Inc., Reston, Virginia, 2006..

[2] Fujizawa, B.T., *Control Law Design and Validation for a Helicopter In-Flight Simulator*, Thesis, The Faculty of California Polytechnic State University, San Luis Obispo, 2010).

Steering Wheel Control for PAVs

The FHS features conventional controls as well as active sidesticks. For PAV in-flight simulation it has additionally been equipped with a steering wheel. A unique safety concept allows the usage of such prototype hardware in flight. The conventional mechanical control system has been replaced by a full authority digital flight control system using fly-by-wire and fly-by-light technology. The evaluation pilot conducts any experiment from the right seat. His control inputs are fed through the experimental system. This allows the flexible design of new control laws. The safety pilot on the left seat overseas any experiment and takes over control whenever needed. His control inputs are directly fed through the core system and override any inputs coming from the evaluation pilot or the experimental system.

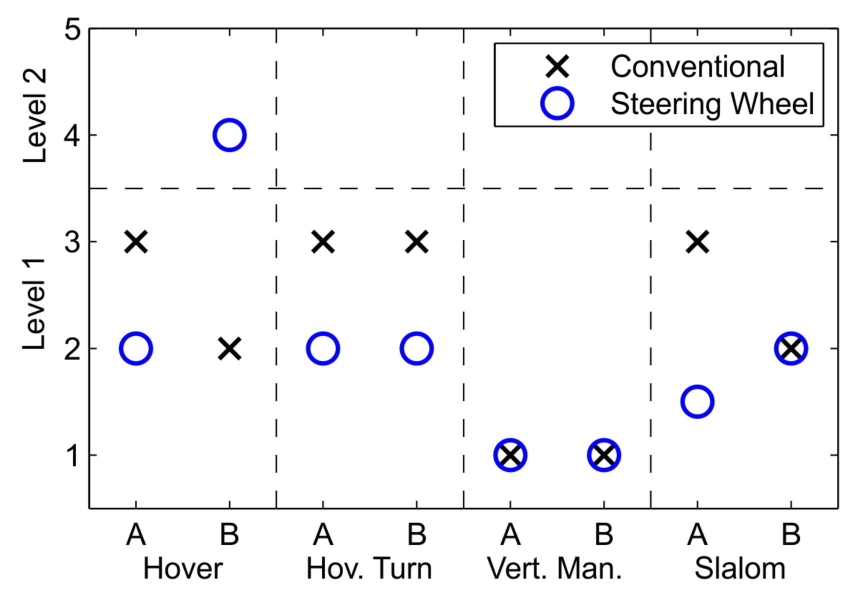


Steering wheel control concept.

The steering wheel is installed on the right cockpit side and used only by the evaluation pilot. By turning the wheel the pilot commands coordinated turns. Like in ground-based vehicles the pedals are now used to control the acceleration and deceleration of the helicopter. A vertical control lever is used for controlling the height. Finally, an 8-way switch in the centre of the wheel can be used for precision manoeuvring.

Handling Qualities Evaluation

Before going into flight test, the new steering wheel control concept was evaluated in ground-based simulation and compared to conventional controls. In order to evaluate the control concepts without the influence of possible MBC deficiencies, the command model was used without the control loop in direct simulation. Two pilots (200 and 600 flight hours) participated in the handling qualities study. The mission task elements (MTE) Hover, Hovering Turn, Vertical Manoeuvre and Slalom were selected for evaluation. After performing each manoeuvre several times each pilot gave a handling qualities rating (HQR) according to Cooper-Harper. The Cooper-Harper scale defines a HQR value of 1 to 3 as Level 1 or desired performance whereas higher values indicate Level 2 or adequate performance. As the diagram below shows the simulated PAV characteristics generally received very good ratings. Despite initial scepticism by the pilots, the steering wheel received the same or even better ratings than the conventional controls. Except for the Hover MTE where the more experienced pilot B did not like the 8-way switch for precision manoeuvring Some of the comments pilots made when flying a helicopter with steering wheel for the first time were "Surprisingly easy, quite comfortable" or "Very easy to learn".



Handling qualities ratings of pilot A and B for conventional and steering wheel control. Lower values indicate better handling qualities.

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