MATLAB AND SIMULINK IN AEROSPACE PROJECTS AT THE DEPARTMENT OF CONTROL ENGINEERING FEE CTU

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Abstract

Matlab and Simulink are extensively used in national- and European-level aerospace research projects at our Department. These software tools, along with dedicated commercial and free toolboxes, are used to share data with partners, like large linearized structural models of flexible aircraft, to propose optimal placement of actuators and sensors, for rapid prototyping of signal processing algorithms like sensors fusion of GPS/INS/magnetometer data, and for design of advanced controllers, like H-infinity optimal and robust dampers of wing or fuselage damping modes for a next-generation passenger aircraft, or model-predictive-control laws for automatic recovery of a fighter aircraft upon loss of pilot's orientation.

The presentation is based on selected results achieved within the EC project (FP7) ACFA, Active control for flexible aircraft, coordinated by EADS Innovation Works Munich, www.acfa2020.eu, and the Czech government supported MPO project Fly-by-wire system for subsonic aircraft, with Aero Vodochody.

1 Flight Recovery System

Primary task of an automatic recovery system is to solve a situation when pilot loses orientation. This space disorientation happens when there is a variance of angle position between what pilot thinks and real physical angle position of the airplane. This situation occurs firstly in case when the pilot cannot see the horizon (by low or zero visibility, during a night flight over monotonous terrain without distinct segmentation, when wrongly reading/failure of position indicators, with disturbance of the pilot and losing concentration under high pressure e.g.). Main reason of disorientation is the fact that human sensors of angular velocity (inner ear – semicircular channels) are insensitive to angular speeds under 2°/s. If the pilot does not have visual information this insensitiveness is integrating and becoming a drift. This drift leads to lose bearings. Automatic recovery system can stabilize the plane without involving the pilot and bring it to slightly climbing flight. Then the system hands over the control back to the pilot.

This whole procedure has a few limit factors. Above all it is a marginal angle of attack and sideslip angle (separation of the streamline from the profile – aerodynamic limitation), maximum pitch and roll rate (mechanical limitations of the plane), maximum folds in particular directions (physiological pilot protection) and a control limit (maximum helm deviation and maximum velocity of position change). On this account was a model predictive control (MPC) method chosen. Discrete model is described as follows:

$$\begin{aligned} x(k+1) &= M \cdot x(k) + N \cdot u(k) \\ y(k) &= C \cdot x(k) + D \cdot u(k) \end{aligned}$$

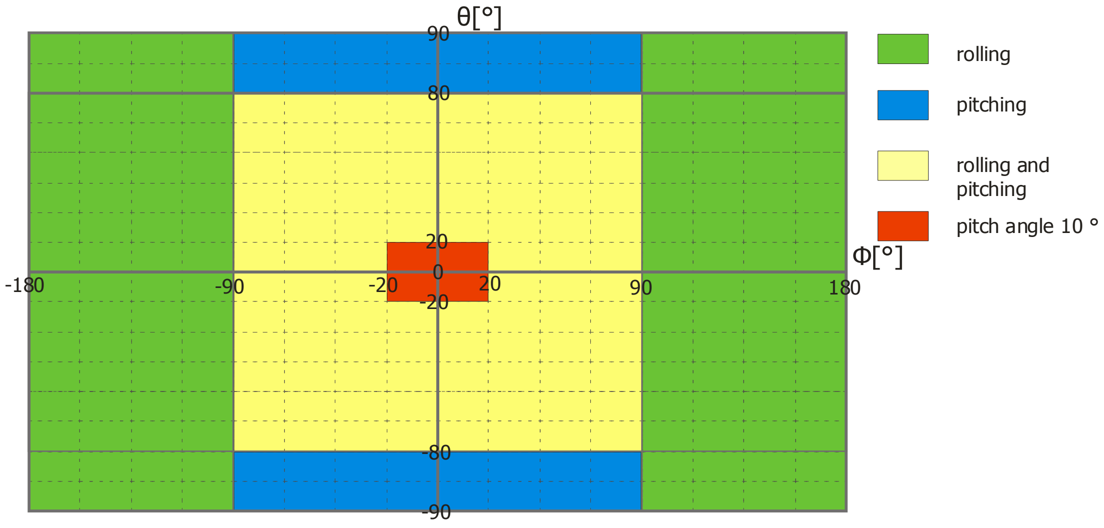
We search for control sequence *u(k)* on the prediction horizon with length T_p which minimizes following criterion:

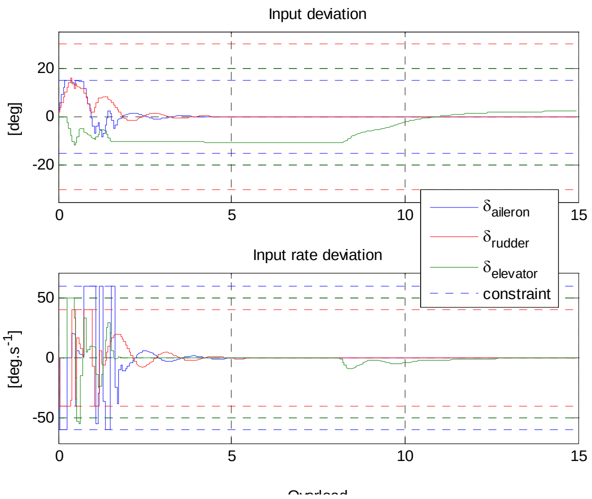
$$J=\sum_{t=0}^{T-1}\left\{q(t)[y(t)-w(t)]^2+r(t)u(t)^2\right\}$$

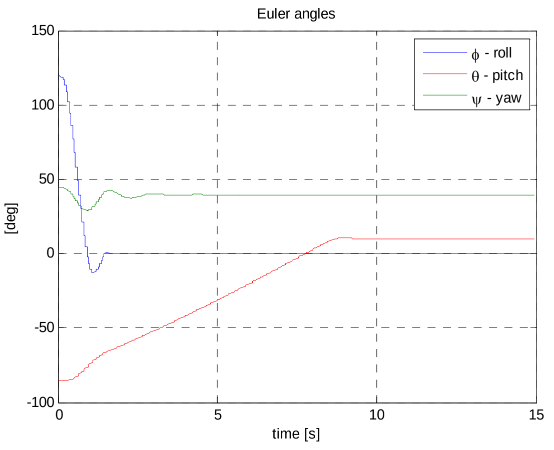
Where *q(t)* and *r(t)* are weights of regulation deviation and control action, *w(t)* is referential signal. In dependence on its position angles it determines next control/motion of the plane. It is used quadratic programming for criterion solving and minimization function has following form:

$$\min J(x)=\min_{x}\frac{1}{2}x^T Hx+f^T x$$

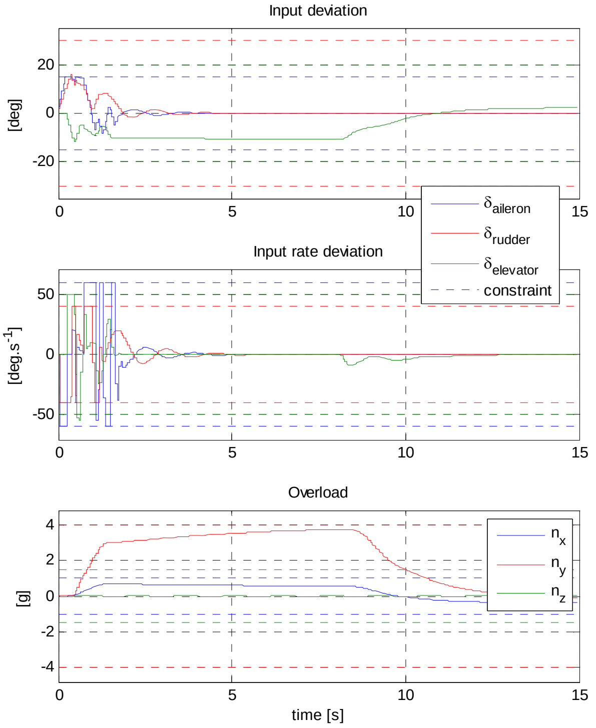
Superior decision level for MPC is a θ- Φ diagram. Diagram defines the procedure of controlling the plane in various plane positions. In the concrete by which way/logic is recovery control leaded to stabilize the airplane. Such system logic can be preferably described by Φ-θ diagram. Location of the airplane is in every moment given by two values Φ (roll) and θ (pitch).

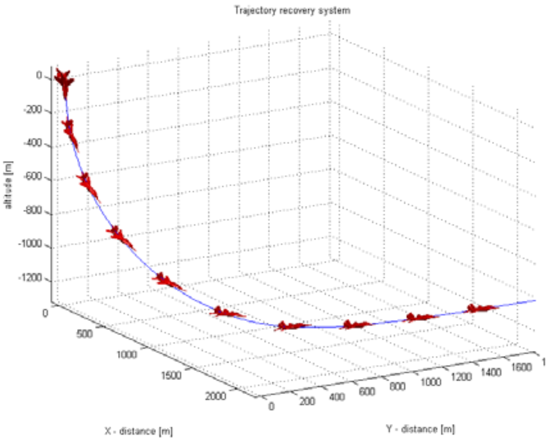






flight angles during recovery





path of flight

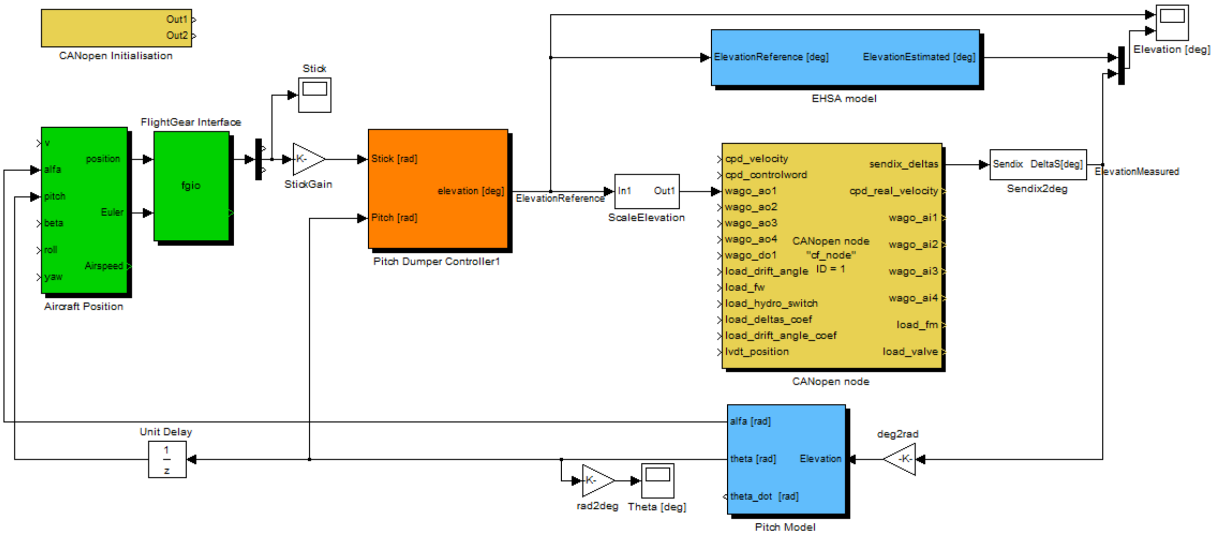
2 Hardware in the Loop Simulation of FBW components

We have used Matlab based simulator for proof of concept validation of components of the Flight-by-Wire (FBW) control system via hardware in the loop (HIL) simulation. The validated components are control laws of the flight control computer (FCC), dynamics of the new electro-hydraulic servo actuator (EHSA) with mechanical redundancy and control logic of dual channel, fail-save electronic control unit (ECU).

The basic principle of the hardware in the loop (HIL) simulation is based on connection of real hardware devices (EHSA with ECU, hydraulic and mechanical subsystems and control surface in our case) with a computer based simulator providing a real-time numerical simulation of the rest of the system (control law of FCC and plane in our case) in the closed loop.

A modular HIL platform is used to evaluate possible contribution of the FBW to the plane controllability. Control law designed in Simulink is executed by embedded computer representing FCC. The real EHSA with the most important mechanical parts and hydraulic subsystem is mounted on hydraulic stand and controlled by dual channel ECU. The angle of the control surface is measured via sensor and the aerodynamic force loading the rudder is imposed via a hydraulic cylinder. The system contains an embedded computer executing the numerical model of the plane in real time. Peripherals are interconnected via CANopen field bus, which makes this architecture very flexible and extensible. Simulink provides user interface, which allows flexible test design and evaluation in the same environment where the model and control law was developed. The flight simulator FlightGear (FG) is used to evaluate the FBW system from ergonomic point of view by pilots.

The Hydraulic stand is the central part of the HIL simulator. It consists of the real hydraulic actuator and related hydraulic equipment, mechanical transmission and the hydraulic actuator, which is controlled to simulate the aerodynamic load of the control surface. The hydraulic stand therefore contains all real components providing any undesirable features as a friction, backlash and other nonlinearities or unknown dynamics. It is therefore the crucial part of the HIL simulator need for the system validation.



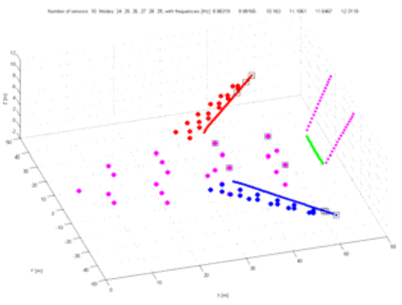
Model for the HIL simulation.

3 Active vibrations reduction for a BWB aircraft

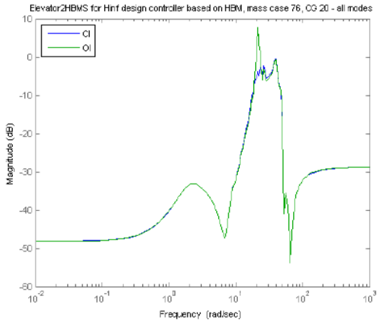
New concepts of high-capacity passenger aircraft are in development for a decade in the USA and Europe. Among the proposed concepts, the blended-wing-body type appears most appealing due to high efficency, low noise, high capacity, low noise.

On the other hand, being in principle a relatively lightweight mechanical structure, is prone to strong vibrations that can be induced both by exogenous forces (turbulences, gusts) and pilot’s (or autopilot’s) aggressive commands.

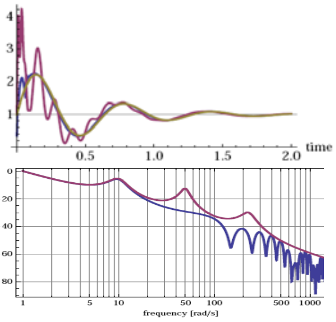
The following figures demonstrate some results achieved so far. Optimal configuration of selected sensors is depicted on the leftmost figure, calculated by minimization of the Fisher information matrix criterion. Middle figure demonstrates performance of a feedback controller for damping selected modes. The rightmost figure then shows response of the pitch-rate signal to step in elevator compared to a PosiCast filtered reference signal response.



Optimal sensor placement. EFI method, modes 24 to 29 considered, 10 sensors placed.



Hinf feedback controller. Attenuation of wing-bending mode by 5-7dB (for various configurations).



PosiCast prefilter. Elimination of pilot-induced--vibrations at the hull-bending-mode frequency.

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4 Acknowledgement

This work was supported by Ministry of Industry and Trade of the Czech Republic under Project FT—TA3/044, by the Ministry of Education of the Czech Republic under contract No. 1M0567, and by the European Commission under project ACFA 2020, contract No. 213321.