Technische Universität Berlin
Institut für Luft- und Raumfahrt
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2. Homework - Flight Control
Analysis of Dynamic Aircraft Behaviour and Design of Control Systems for Manual and Automatic Flight

In this homework you will control the NANO TALON UAV. Therefore you will design two control laws and test them in the *Virtual Flight Test Environment*.[1] The reference state by which the non-linear equations of motion have been linearised is the stationary horizontal flight at an altitude just above ground at a velocity of 17 m/s IAS. The equations of longitudinal and lateral motion are given in the coupled state space (see Matlab file at ISIS).

Talon UAV (c), AlphaLink Engineering GmbH

The first part of the homework includes the design of a bank angle controller, a yaw damper and a turn coordination. Additionally to the bank angle, a roll rate controller is to be designed. The overall controller is then called a rate command/attitude hold controller.
In the second part focusses on the longitudinal motion and the design an airspeed controller with the use of the Linear Quadratic Output Feedback method.
The following tasks are designed to correspond to the procedure used in the design of flight controllers. First analyse the eigenbehaviour, then derive requirements, design the controller and show that the requirements are met. The last step evaluates the corresponding controllers in a nonlinear simulation in the *Virtual Flight Test Environment*.

1 Task: Analysis of the Eigenbehaviour

Analyse the eigenbehaviour of the aircraft for by performing the following tasks:

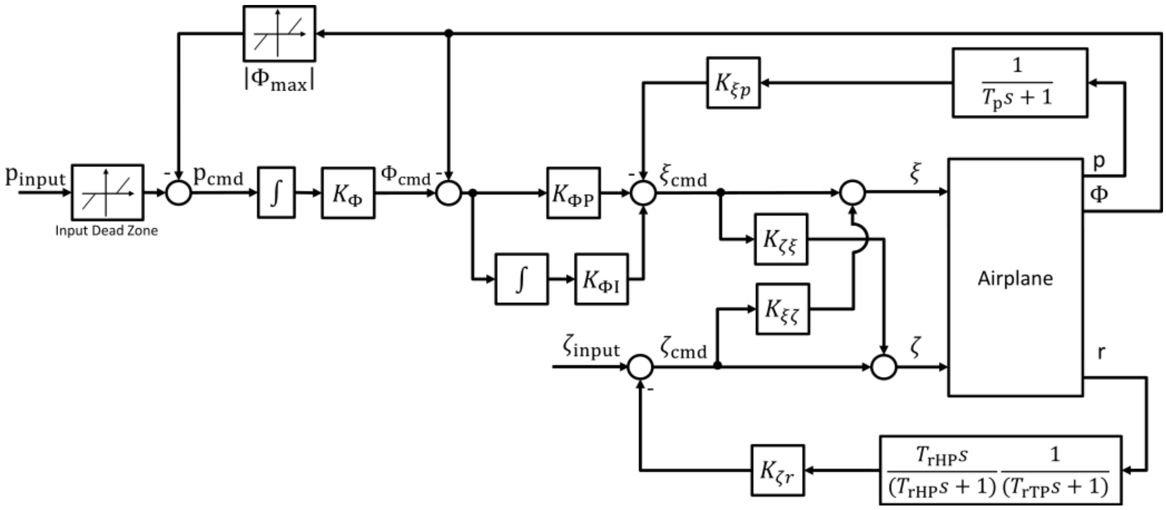
1. Download the full state space at the ISIS-page and examine it. Which entries in the state space matrices could lead to coupling of the lateral and longitudinal motion? Build up the corresponding state spaces in *Matlab*. Show if the lateral and longitudinal motion can be treated as decoupled motions.

2. Examine and evaluate the flight qualities using the MIL-F-8785C specification.

[1] Virtual Flight Test Environment: https://alphalink-vfte.com

2 Task: Design of a Rate Command/Attitude Hold Controller

The aircraft is designed to be flown manually, with the pilot commanding the roll rate and rudder deflections. The block diagram is shown in Fig. 2. To improve the flight characteristics of the lateral motion, roll and yaw dampers are integrated (SAS). Feed forward controller is implemented to improve turn coordination. Further, low-pass filters are added to reduce the noise of the roll and yaw rate sensors. For the design procedure the nonlinear blocks in the controller diagram can be omitted, as time constants for the filters use $T_p = T_{rTP} = 0.1$ s and $T_{rHP} = 2$ s.



Structure of the RC/AH Controller used in the *Virtual Flight Test Environemnt*

Complete and document the following tasks:

1. Explain the operating principle of a Rate Command/Attitude Hold controller.
2. For a coordinated turn, the sideslip angle has to be compensated by a feed forward controller. Calculate the gains $k_{\zeta\xi}$ and $k_{\xi\zeta}$ to achieve a steady sideslip angle of $\beta = 0$ (better decoupling beta and p). (Hint: Make use of the fact that the dynamics are linear). Show the improvement.
3. To improve the flying qualities, feed back the filtered yaw rate r to the rudder. Choose a gain $k_{\zeta r}$, such that the requirements of MIL-F 8785 C are met. Show the improvement.
4. Choose a gain $k_{\xi p}$ to dampen the roll mode and close the loop. Again, the requirements of the MIL-F 8785 C are the reference (see also Figure 2 of the 1st homework). Show the improvement.
5. The outer loop of the control structure aims to command a bank angle. What problems arise by using an integrator in your controller when actuators are saturated? Is the integrator necessary in this case? Give reasons for your answer. Omit the integrator $K_{\Phi I}$ and design a proportional controller $K_{\Phi P}$ by calculating the gain margin first and then choose a gain, such that requirements of MIL-F-9490D are fulfilled. Now, add the integrator $K_{\Phi I}$ to improve your results. Show the improvement.
6. For the last step, design the feed forward gain K_Φ such that the commanded roll rate can be achieved. Check the MIL - F- 9490D for requirements and show the behaviour of your controller.
7. After you have designed your controllers, they are now to be tested in the nonlinear simulation environment VFTE lesson 4. To do so, conduct the following flight test in open and closed loop:
   - Climb to a height of 20m and stabilize the aircraft. Make a 360° turn with a bank angle of $\Phi = 15°$.
   - The maximum allowed deviations are $\Delta H = 2$ m (note: MiL specifies other limits) and $\Delta\Phi = 5°$ as well as $\Delta V = 2.5$ m/s

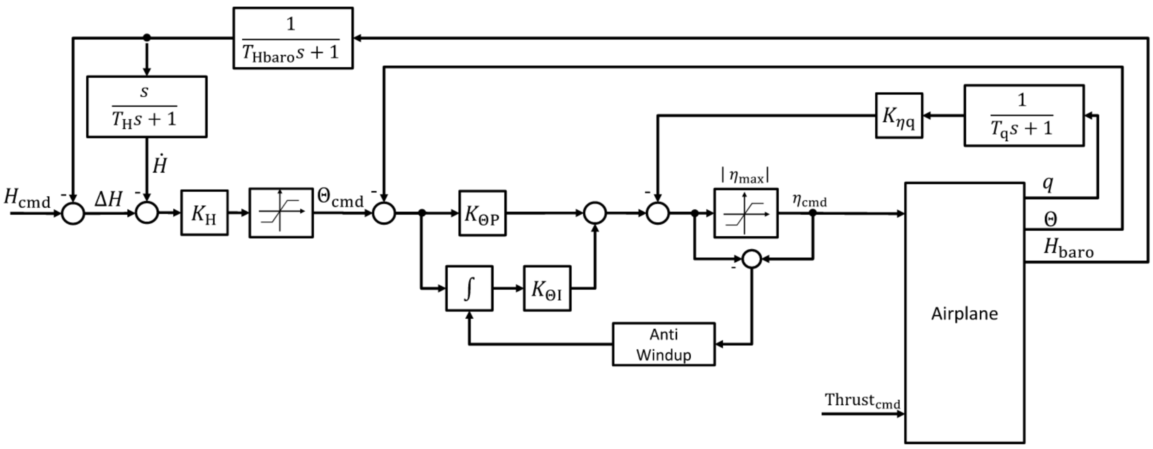
Complete the following tasks:

(a) Perform the simulator tests with the open-loop aircraft! Evaluate the results with respect to specified tolerances (plot the tolerances also). Use the data recordings for this purpose and plot the used data. Use the impressions you gained during the tests to assess the flight characteristics. Please also describe your test equipment (Joystick, etc.).

(b) Perform the simulator tests with the closed-loop aircraft (your controllers)! Evaluate the results with respect to the specified tolerances (plot the tolerances also). Use the data recordings for this purpose and plot the used data. Use the impressions you gained during the experiments to assess the flight characteristics and compare the dynamics of the open-loop aircraft with the closed-loop aircraft! Note: For the evaluation only the results of one pilot have to be used. Please note, however, that it makes sense to compare the open- and closed-loop flight of the same pilot!

3 Task: Design of an Altitude Controller with the LQR Output Feedback Method

In this task the elevator will be used to maintain and change the altitude. Altitude control will be derived, together with a pitch controller. Therefore all gains are optimised in one step by applying the LQR Output-Feedback for the tracker problem. The controller structure is shown in Fig. 3. It consists of a pitch damper, a PI-pitch attitude controller, filter for altitude, a limiter for the elevator deflection and an anti-windup solution to prevent problems with the integrator. The anti-windup can be ignored in the design. The thrust is commanded directly by the pilot who must observe the velocity.



Structure of the Altitude Controller used in the *Virtual Flight Test Environment*

Complete and document the following tasks:

1. Name the requirements for an altitude controller as well as for attitude control, both with respect to MIL-F-9490D.

2. Explain the purpose and function of the high-pass and low-pass filter for H_{baro}.

3. With the help of Figure 3 and a *Matlab* script, convert the controller structure into the tracker problem. Filter constants are $T_q = 0.05s$, $T_H = 0.5s$ s and $T_{Hbaro} = 1s$. Proceed as follows:

   (a) Prepare the open loop plant by deriving the filters into state space models manually. State the extended state space.

(b) Since the different controllers are interconnected, the outputs of the open loop aircraft must be extended to apply the LQR output method. Find a way to do so and set up the plant. (Hint: Start by looking at the control law, the gains might also be converted.)

(c) Write a function which calculates the performance index.

(d) Find initial gains for a starting point of the minimisation problem by closing the loops one by one.

(e) Define the weighting matrices and find a controller by minimising the performance index.

(f) Repeat the last step until you find a suitable solution which meets the requirements. Explain the final selection of weights in the optimisation and demonstrate as well as list the fulfillment of requirements.

4. After you have designed your controllers, they are now to be tested in the nonlinear simulation environment VFTE lesson 7.

   (a) In the VFTE activate the controller and increase the airspeed to $V_A = 19\ m/s$. Is the controller able to maintain the altitude?

   (b) Now command an altitude of $H = 200$ m.

   (c) Evaluate the results with respect to the requirements in MIL-F-9490D. Use the data recordings for this purpose and plot the used data.

Submission Date and Hints

- Submissions of the homework is on **21.02.2024 at 23:59** o'clock at ISIS.
- Later submissions will not be considered!
- The homework must be done by at least three students.
- Only one solution is valid per group.
- The paper must contain a cover page, a table of contents and a declaration of originality (Eigenständigkeitserklärung) to be signed by all students!
- Matlab/Simulink or SciLab/Xcos is recommended as an aid. A comprehensible and sufficient approach should be presented for tasks that are carried out with these tools. The corresponding source code has to be attached to the appendix and the text has to refer to the place in the source code! The result is to be mentioned in the text. The codes must be provided as well (all functions used), and they should be operative.
- If you use Matlab/SciLab for calculations, always show the basic approaches.
- For simulations with Simulink/XCos, it is necessary to specify the simulation step size, simulation time and integration method used in addition to the model.
- Tasks that have to be performed analytically or require a detailed calculation are to be derived comprehensibly in the text. Numerical values should only be used at the end of the calculation! In case of doubt, the state space representation is always the starting point of every derivation!
- **SI units should always be used.** For plots and figures, angles must be displayed in 1°.
- Graphics must be legible. If necessary, the font size of the graphic must be adapted to the font size of the text! Each axis of a diagram must be completely labelled (formula symbol and unit)!
- Foreign intellectual property must be labelled! This is especially the case for derivations or images taken from a book or script. Wikipedia is not an accepted source for derivations!