Adaptive Fuzzy Control Strategies for a Zeppelin

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Abstract: The German town Friedrichshafen has an old tradition in building airships. In the moment a follower of the legendary Zeppelin will be build using new technologies. For the control concept this is a challenge because difficult flight manoeuvres are to consider like vertical take off and landing as well as comfortable cruise at different speeds and especially the transition phase between these both manoeuvres. Because of the non exactly known complexity and non-linearity of the airship dynamics good preconditions are given for a fuzzy control concept. The dependency of the dynamics on the strongly variable environmental conditions as for example the airships speed relatively to the surrounding air and the use of different steering components like pivot drives for take-off and landing and the elevation for high speeds requires a high adaptivity of the controller. In this paper the results of a study concerning the usage of a fuzzy concept for control of the pitch axis for all these flight manoeuvres are presented and will be verified by means of realistic simulations.

1. Introduction

Building airships has an old tradition in the German town Friedrichshafen, where in these times a follower of the legendary Zeppelin will be constructed: the Zeppelin NT [1]. An artificial picture is depicted in Figure 1 and some technical details of the airship are listed in Table 1. Typical areas for the use of such an airship at present are [2]:

- technical applications like environmental monitoring and inspection,
- tourism,
- scientific areas like atmospheric physics and chemistry,
- and last but not least commercial employment so as advertising or TV platform for sport events.

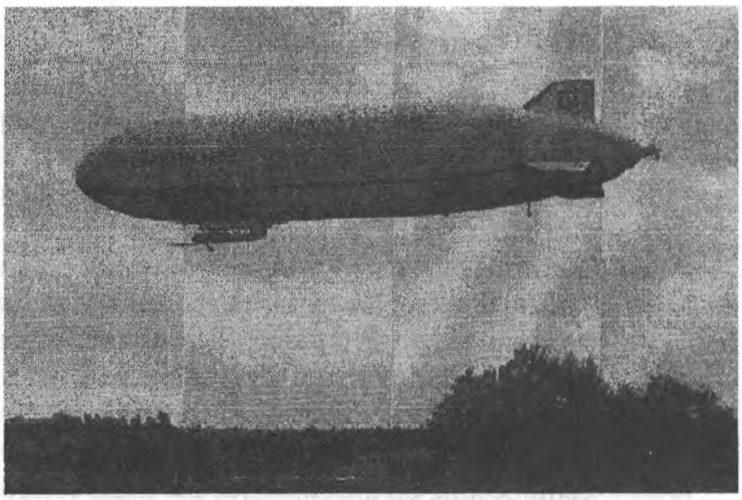

Figure 1: Picture of the Zeppelin NT

The new airship shall not only be an exact copy of the old Zeppelin, but new technologies shall be incorporated where ever it is possible. To assist the development of a control concept for this airship built with current technology a lot of experience from aeroplane control aspects can be considered. In both cases there are some similar tasks for flight control, such as attitude stabilisation of the yaw-, pitch- and roll- axes, underlying speed control for stability augmentation and complete auto-pilot-functions. No doubt, for the airship the speed range is smaller than for aeroplanes but there are other difficult and completely different flight manoeuvres to consider, which complicate a control concept and prevent the simple copying of aeroplane flight control concepts, like:

- vertical take off and landing,
- comfortable cruising at different flight speeds,
- the transition phase between both these flight conditions, and
- finally, the docking manoeuvre at the end of the landing phase with variable strength and wind directions

Table 1: Some preliminary technical dates of the Zeppelin NT

Length	63 m
Diameter	13 m
Weight including maximum payload	5380 kg
Payload	1300 kg
Maximum speed	140 km/h
Maximum flight height	2500 m
Maximum flight time	36 hours

While for cruising at different flight speeds the design of the pitch axis controller with classical methods [3] as well as using a fuzzy concept [4] has been successfully performed, the emphasis of this paper is to extend the design of a fuzzy control concept for the pitch axis to the more complicate manoeuvres "vertical take off and landing" and especially "the transition phase into the horizontal flight".

2. Fuzzy Control Concept

The challenge for a flight control concept of an airship lies in its typical characteristics:

- Related to the size normally it flies with a relatively slow velocity. Therefore the surrounding, partial distributed air conditions have a dominant influence to the flight behaviour which is very badly to model.
- The wings for aerodynamically steering possibilities are relatively small.
- The input variables for influencing the flight behaviour of the airship has continuously to be changed between propeller thrust for vertical take off or landing and the elevator deflection during relatively fast cruise.
- The support structure of the airship is light resulting in high flexibility.
- For balancing the airship the centre of gravity can be well-aimed displaced complicating on the other side the flight control.

But on the other side from these features the following topics result which destine the airship control problem for fuzzy logic:

- the airship is a highly non-linear system,
- a lot of external disturbances which are heavy to model influence the airship,
- even the detailed mathematical / physical model is limited with respect to accuracy
- and finally a control concept has to adapt the variations of different parameters.
- On the other side airship pilots have a detailed flight experience which they can formulate verbally.

While for the control concept during cruising at different speeds due to the aerodynamically dominance the airship is mainly steered by the elevator deflection, the dominant steering devices during vertical take off and landing are three pivot drives oriented perpendicular, one located at each side of the hull and the third is located at the stern. After turning by 90° they can also be used to increase the cruise speed and improve manoeuvrability. The most challenging control actions are necessary for the transition phase when the pivot drives have to be turned.

The control concept for cruising has the following characteristics: It considers the error signal e (desired pitch-angle minus measured pitch-angle) as well as the angle speed Θ and adapts the fuzzy rules to the true air speed v of the surrounding air. It is supported by the signal "integration of the error". Because for the flight manoeuvre "cruise" the aerodynamically influences dominate the flight behaviour, only the elevator deflection η is used as steering input. All these variables excluding the true airspeed v are devided into 7 fuzzy sets. The rule base consists of some 50 rules.

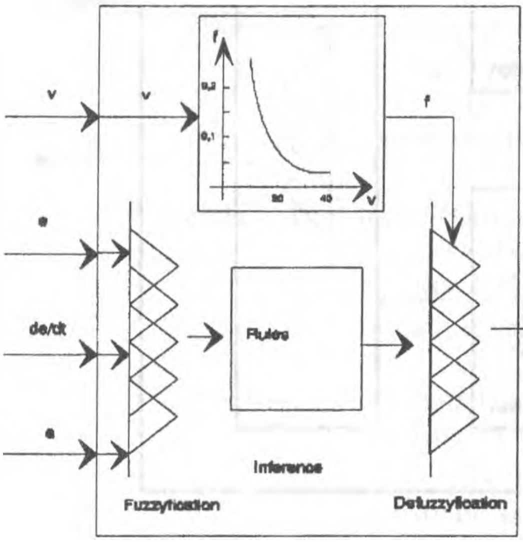

Figure 2: Structure of the Fuzzy-Controller

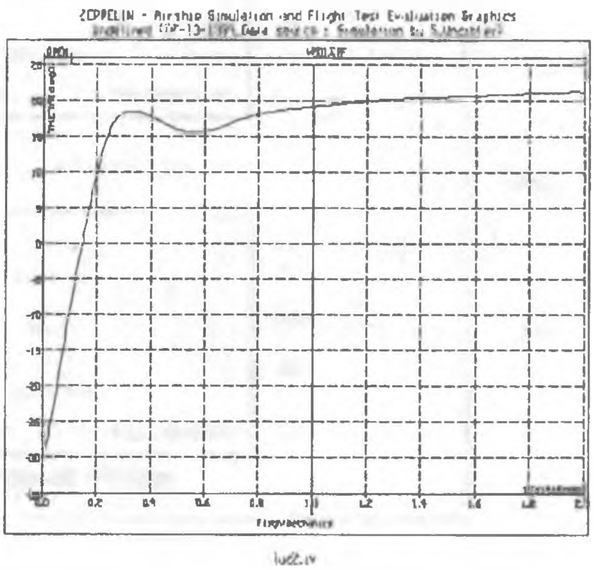

Figure 3: Pitch angle Θ at a climb and reacceleration manoeuvre

The main problem for control is to include the varying speed of the surrounding air relative to the airships speed. In the proposed concept, the adaptivity is provided by varying the width of the fuzzy sets of the controller output "elevator deflection" depending on the true airspeed v. According to Figure 2 a steering factor f is evaluated, where the relationship between f and v is derived by the fact that for a static consideration the overall amplification of the closed loop has to be constant for all airspeeds. Because of the higher effectivity of the elevator deflection during higher speeds the relationship has to be inverse proportional. The width of the output fuzzy set is multiplied by this factor f. The quality of the control is proved by simulation of a reacceleration manoeuvre. For that first the airship is cruising with a pitch angle of -30° for landing. Then the Zeppelin is to be controlled on a pitch angle of 20° simulating reacceleration. The robustness of the controller concept is to be seen in Figure 3, where the pitch angle during this manoeuvre is depicted.

Now, in this paper this cruising controller structure is extended to the vertical take off/landing manoeuvre and the transition phase to cruising. For performing this manoeuvre for the pitch angle control two correcting variables are disposal: In the take-off or landing phase a horizontal speed through the air is missing, so the aerodynamic forces at the flaps have no effect. Therefore the pitch angle is adjusted through the vertical force of the stern drive, turned around 90 degrees. This drive is to be controlled independent of the thrust of the drives on side of the hull. As soon as the airship gathers speed the effect of the elevator flap begins and influence of the vertical force of the stern drive becomes less importance. The controller has to react appropriately and has to switch between the two correcting variables continuously. For this task a fuzzy controller based on a hyper-inference concept as shown in Figure 4 is designed.

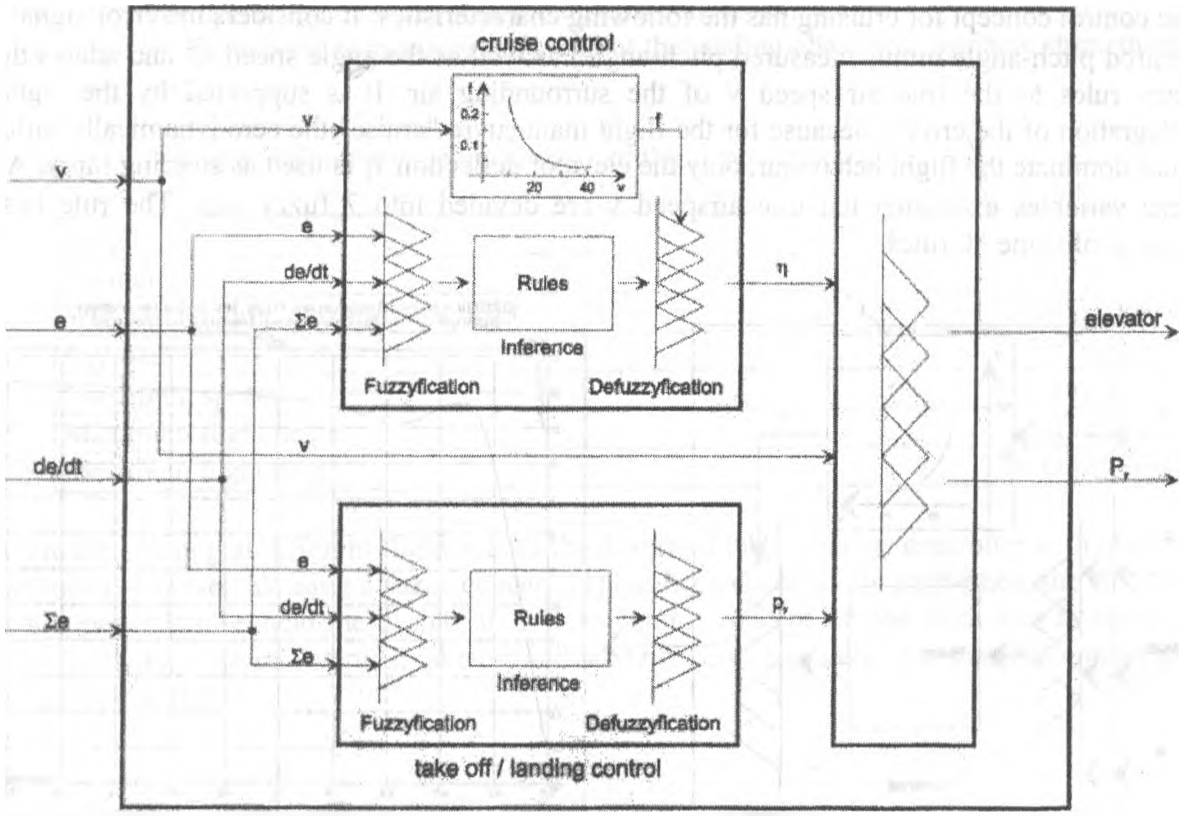

Figure 4: Controller structure for take-off/landing and cruise and the transition phase

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