CURVED AND STEEP APPROACH FLIGHT TESTS OF A LOW-COST 3D-DISPLAY FOR GENERAL AVIATION AIRCRAFT

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Abstract

A low-cost display and navigation system for visual guidance information in a 3-dimensional format is presented. The basic constituents of the 3D-display are a tunnel image for presenting the command flight path in a 3-dimensional format and a predictor for indicating the future position of the aircraft at an appropriately selected time ahead. Optionally, an image of the outside world can be displayed in an integrated form. The low-cost 3D-display is directed at an application to small aircraft in order to provide this type of vehicle with improvements for guidance and control. Results from flight tests involving curved and steep approaches are presented for showing the performance of the system.

1 Introduction

Recent developments in the field of cockpit displays are concerned with the presentation of visual guidance information in a 3-dimensional format. The displayed information comprises the command flight path in an appropriate form and the aircraft position indicated by a predictor at a specified time ahead. Such a display type has gained great interest since it offers the possibility to improve the guidance information for the pilot. This is because it provides the pilot with command and status information, including preview. A further improvement is possible due to the pictorial and descriptive manner in which the visual information is displayed. Thus, an intuitive access becomes feasible, yielding a reduction of the mental effort for reconstructing the spatial and temporal situation. Research on displays with a 3-dimensional presentation format shows promising results (Refs. 1-11).

In this paper, results from flight testing a 3D-display for curved and steep approaches are presented. The purpose is to show how efficient the pilot can be supported in such demanding control tasks.

2 Display with Predictor-Tunnel Configuration

The configuration of the 3D-display which was used in the flight tests is depicted in Fig. 1. It comprises a tunnel image for showing the command flight path and a predictor for indicating the position of the aircraft. They form central perceptual and cognitive constituents of the displayed visual information. The following considerations are concerned with the lateral motion, giving details on the manual control issues. Similar considerations apply for the longitudinal case.

The tunnel provides command information and preview. Basically, the pilot can structure a control feedforward. With proper transfer characteristics of the pilot in relation to those of the aircraft, it is possible to use the advantages of the feedforward for the control task.

The predictor indicates the position of the aircraft at a specified time ahead, the prediction time, which has to be appropriately selected. The position of the predictor symbol in the 3D-display can be related to a command reference which is given by the cross section of the tunnel at the prediction time ahead and is especially marked (Fig. 1). Thus, a precise reference is available. The pilot can act in response to deviations of the predictor symbol from the described command reference for minimizing system errors in the presence of command and/or disturbance inputs. This is a compensatory control task for the pilot.

The predictor can be considered to have two functions:

1. Indicator of aircraft position
2. Element of control system

The first function which relates to the original purpose of the predictor is based on kinematical and geometrical relationships (Fig. 2). It is also of pictorial nature to comply with the general characteristic of the display as a device presenting visual information in such a manner. The aircraft position at the prediction time ahead is determined using an appropriate mathematical model for describing the continuation of the flight path. There are various models of different complexity. A proven model is referenced to a circular continuation of the flight path. This yields for the predictor deviation

$$\Delta y_{PR} = \Delta y - y_C^* + \Delta\chi V T_{PR} + \dot{\chi} V T_{PR}^2 / 2 \qquad (1)$$

The goal of the first function is to yield an indication of the predicted aircraft position corresponding with the motion in a realistic manner. Such a feature relates to what may be termed face validity which concerns the correspondence between status information presented by the predictor in the 3D-display and the actual situation. The presented status information has a high degree of face validity if there is a clear correspondence. This means for the predictor which indicates the aircraft position at the prediction time ahead that the relation between its position and the tunnel has to be realistic in a geometrical and kinematical sense. The face validity issue is considered important since the predictor is an element of a perspective flight path display which presents guidance information to the pilot in a pictorial and 3-dimensional format.

The second function of the predictor concerns its role as an element of a control system, within the framework of the manual control task of the pilot (Fig. 3). The predictor comprises several inputs which correspond with quantities used for describing the continuation of the flight path, according to Eq. (1). Thus, the following relation holds for the transfer characteristic of the predictor-aircraft system

$$Y_{PR} Y_C = \frac{e_{PR}(s)}{\delta_a(s)} = K_{PR} L_{\delta_a} \frac{K_{\dot{\phi}} s^3 + [g T_{PR}^2 / 2] s^2 + g T_{PR} s + g}{s^3 (s + 1/T_R)} \qquad (2)$$

This relation describes the transfer characteristic of the controlled element which is made up of the aircraft, Y_C, and the predictor, Y_{PR}. Proper selection of the gains yields a transfer characteristic of the controlled element given by (Fig. 4)

$$Y_{PR} Y_C = \frac{K}{s} \qquad (3)$$

over an adequately broad region centreed around the pilot system crossover frequency. Thus, a controlled element is achieved which requires minimum pilot compensation.

The relation described by Eq. (2) accounts for a roll rate feedback. This is an expansion with regard to a predictor based on a circular flight path continuation. It may be introduced to improve the system characteristics at higher frequencies.

3 Research Aircraft and Test Equipment

The 3D-display is installed in the research aircraft of the Institute of Flight Mechanics and Flight Control of the Technische Universität München, Fig. 5. The following components are used to operate the predictor-tunnel display and to generate the 3-dimensional imagery:

- LCD display
- Display computer
- Navigation system

The LCD display presents the 3-dimensional guidance information. As shown in Fig. 6, it is mounted at the right side of the cockpit instrumentation panel for the test pilot. The LCD display has a screen size of 10.4", a resolution of 640 × 480 pixels and a brightness of 1600 cd/m², with a refresh rate of 60 Hz. The predictor-tunnel configuration corresponds with the one shown in more detail in Fig. 1. The original instrumentation is at the right side of the panel, for the safety pilot (Fig. 6).

The 3-dimensional imagery is generated using a low-cost computer which is based on slot-card PC hardware, with the following data: 1,7 GHz, Pentium IV OS Linux, 256 MB. A 3D-accelerated graphics-card is applied (*n*VIDIA GeForce4 MX420 PCI), capable of a performance of about 30 million polygons per second.

The low-cost navigation system consists of the following components:

– Attitude and heading reference unit
– Air data measurement unit
– Magnetic heading sensor
– D/GPS receiver

The D/GPS receiver (with a satellite based augmentation system signal, a differential code and real time kinematic capability) shows the following performance data for position accuracy: 1.8 m CEP for stand alone operation, 0.8 m CEP for EGNOS and 0.45 m CEP for differential.

A CAN bus connection is used to exchange data between the 3D-display computer and the navigation system. It is a two-wire multi-transmitter serial data bus for real-time data transmission. Position data is exchanged via a RS-232 connection between the 3D tunnel display computer and the GPS receiver.

An essential contribution for achieving the low-cost goal is due to an efficient software for generating and displaying the 3-dimensional imagery presented in the 3D-display. It provides a real-time capability and a high update rate (30 frames per second).

4 Flight Test Results

The predictor-tunnel display is subject of a comprehensive flight test program, concerning demanding guidance and control tasks to exploit its capabilities. The flight tests include basic tasks related to straight flight and curved trajectory following as well as more complex flights like curved and steep approaches, low level flights in a difficult terrain environment (mountainous area), etc. Flight test results on curved and steep approaches are presented in the following, providing a representative insight into the performance achieved with the system.

The approach trajectory is graphically illustrated in Figs. 7. and 8 which show the vertical profile and the horizontal projection of the command flight path (with markings A to I). There are changes in the trajectory at points B to H. At B and F, simultaneous changes in the vertical and lateral directions take place. The descent angle shows different values, up to 10 deg.

The command flight path was indicated to the pilot in the 3D-display in the form of a tunnel which corresponds with the configuration depicted in Figs. 1 and 6. The tunnel is 40 m in width and 30 m in height.

Results form the flight tests are presented in Figs. 9 and 10 which give the time histories of the vertical and lateral deviations from the command approach trajectory. The results show that the pilots closely followed the command trajectory. There are only small deviations from the command flight path in both the vertical and lateral directions. The aircraft stayed within the tunnel boundaries which are also indicated in Figs. 9 and 10 using an area with a grey shading (± 15 m distance from the centre line in the vertical and ± 20 m in the lateral direction).

Precise control of the command flight path was also achieved in the segments in which changes in the trajectory take place. These segments relate to points B to H indicated in Figs. 9 and 10.

Results on the predictor control are presented in Figs. 11 and 12. In these Figs., the vertical and lateral deviations of the predictor position from the command flight path at the prediction time ahead are shown. There are larger deviations when compared with the actual deviations from the command flight path.

5 Conclusions

A 3D-display comprising a tunnel-predictor configuration in a 3-dimensional format is considered a means to improve the visual guidance information of the pilot. The tunnel presents the command flight path and the predictor indicates the position of the aircraft at an appropriately selected time ahead. Results from flight tests involving curved and steep approaches with several trajectory changes in the vertical and lateral directions are presented. They show that the pilots can closely follow the command trajectory using the displayed 3-dimensional guidance information.

6 References

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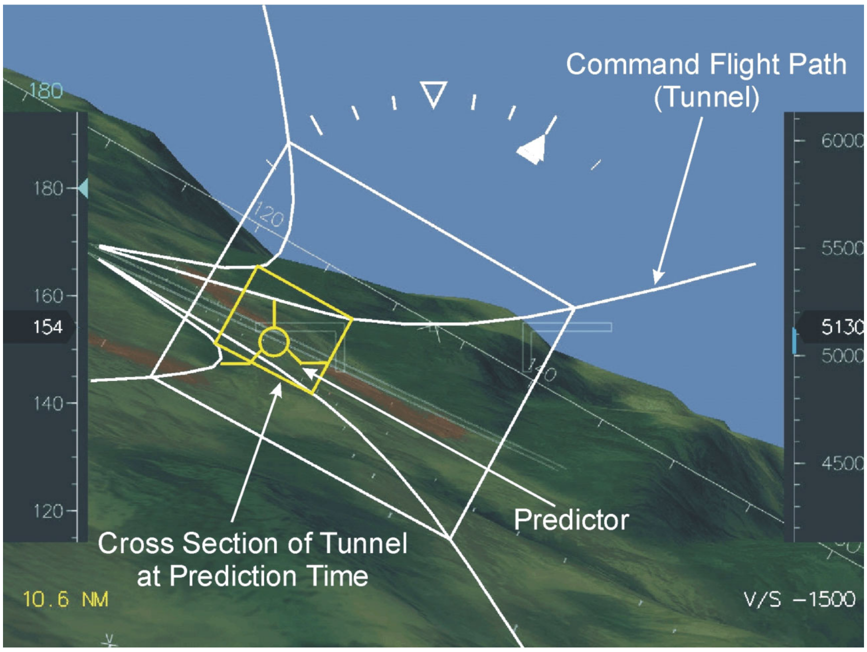

Fig. 1: Display presenting predictor-tunnel configuration in 3-dimensional format

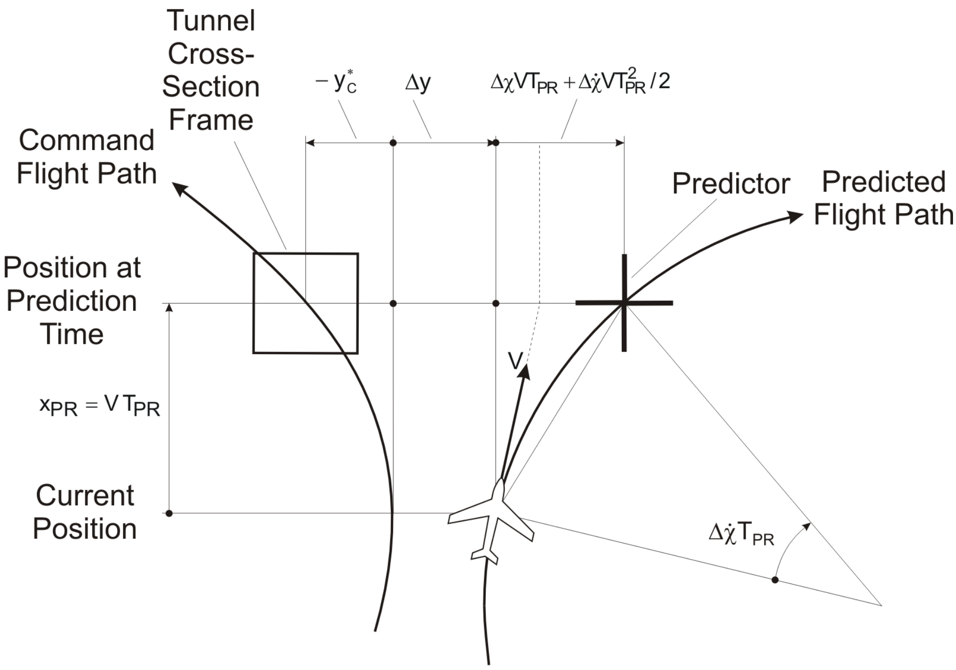

Fig. 2: Predictor indicating aircraft position at prediction time ahead

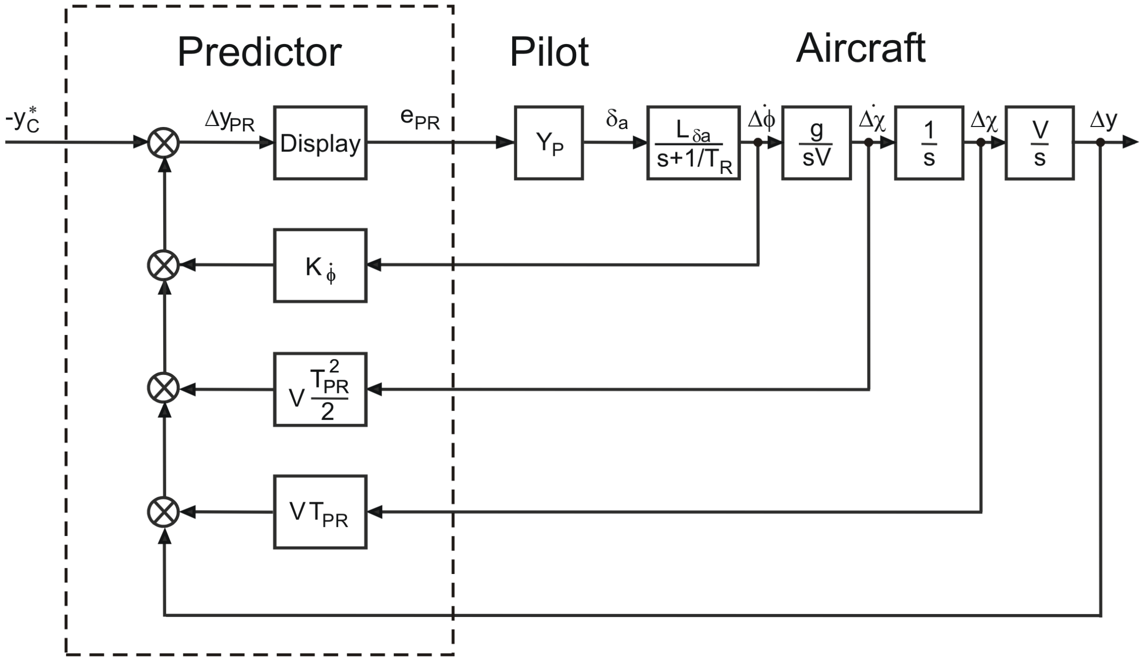

Fig. 3: Control loop with predictor

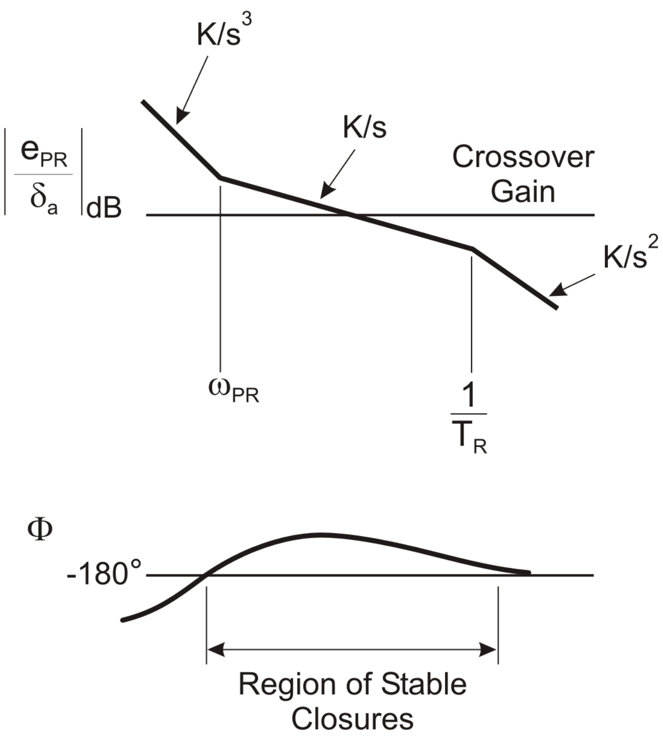

Fig. 4: Asymptotic Bode plot for lateral predictor-aircraft system

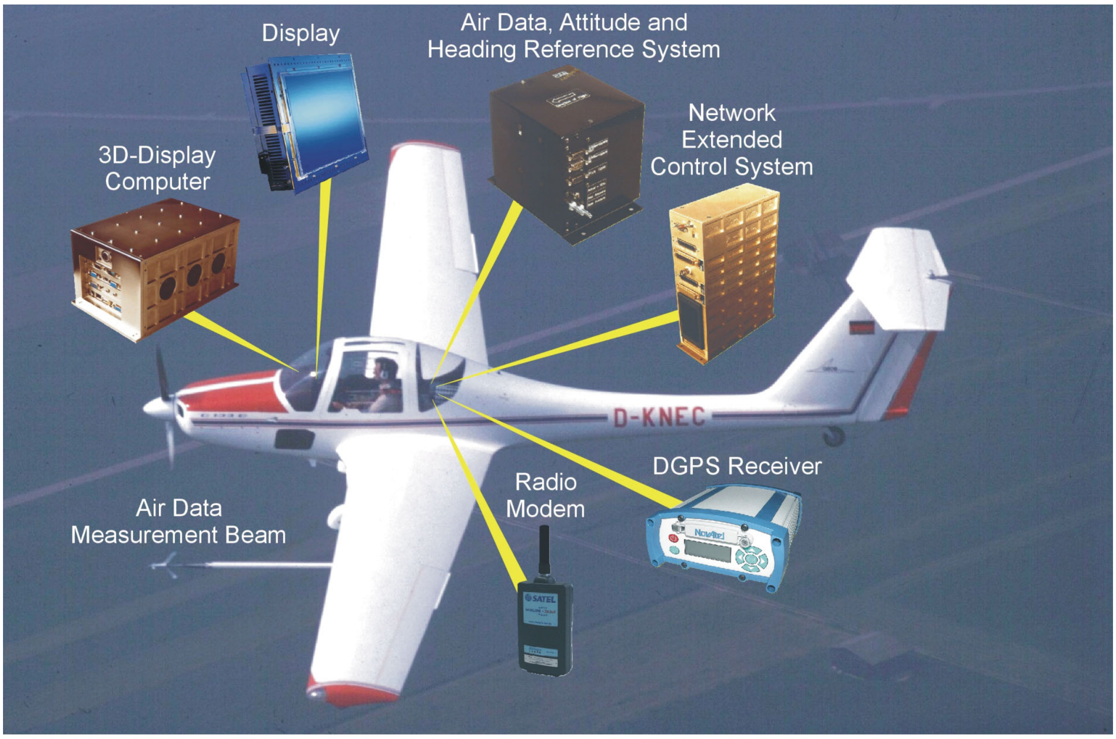

Fig. 5: Research aircraft for testing of 3Ddisplay

Fig. 6: Cockpit instrumentation with predictor/tunnel display (banked flight condition)

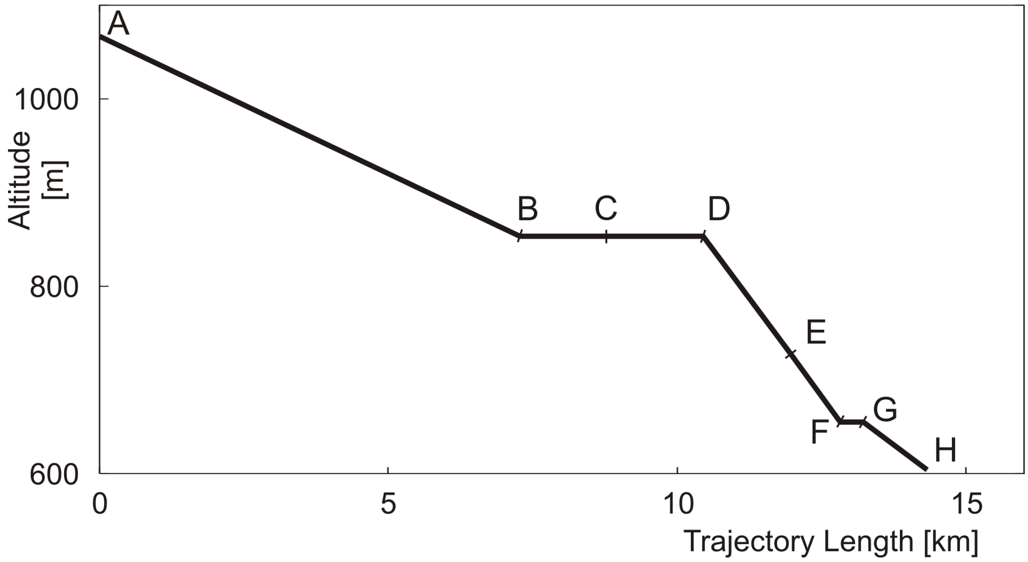

Fig. 7: Vertical profile of approach trajectory

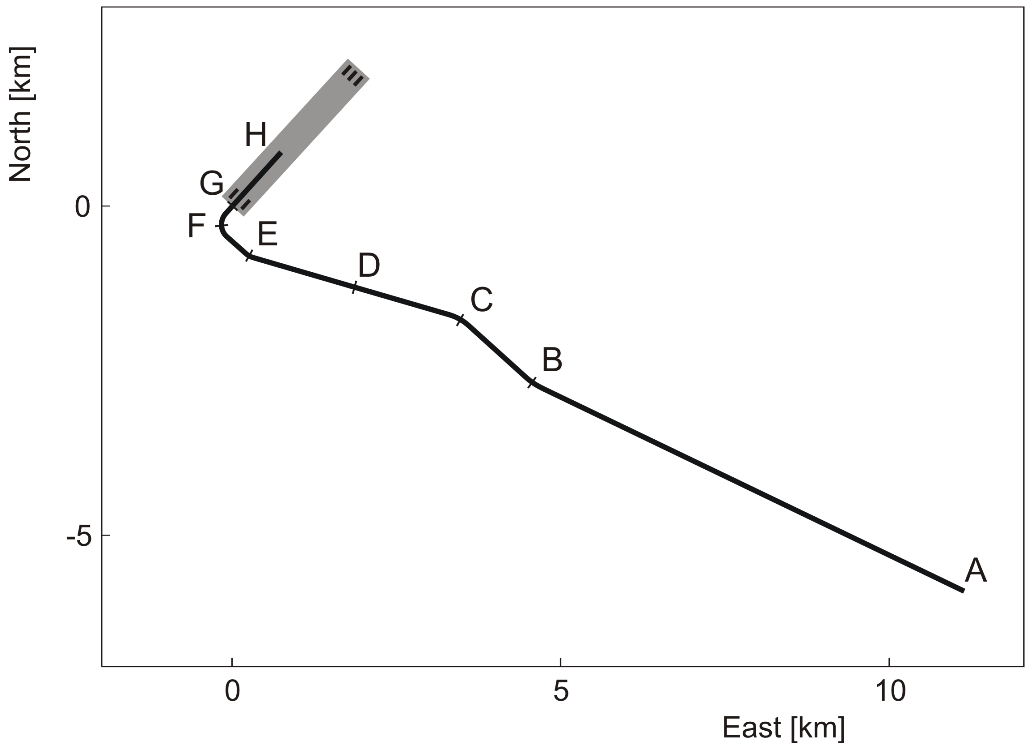

Fig. 8: Horizontal projection of approach trajectory

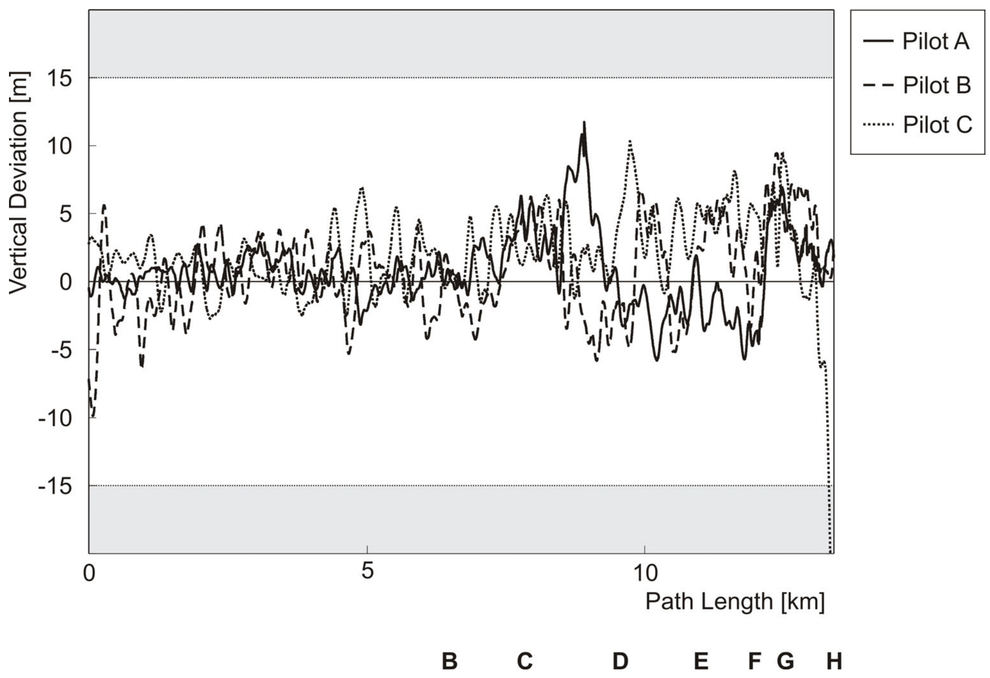

Fig. 9: Vertical deviation from command flight path

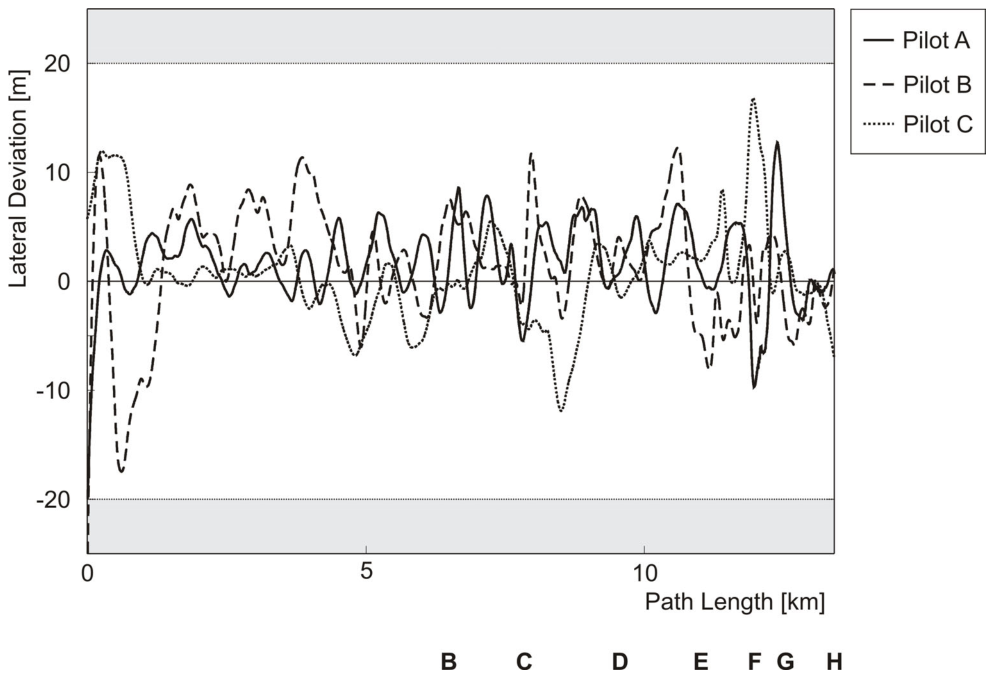

Fig. 10: Lateral deviation from command flight path

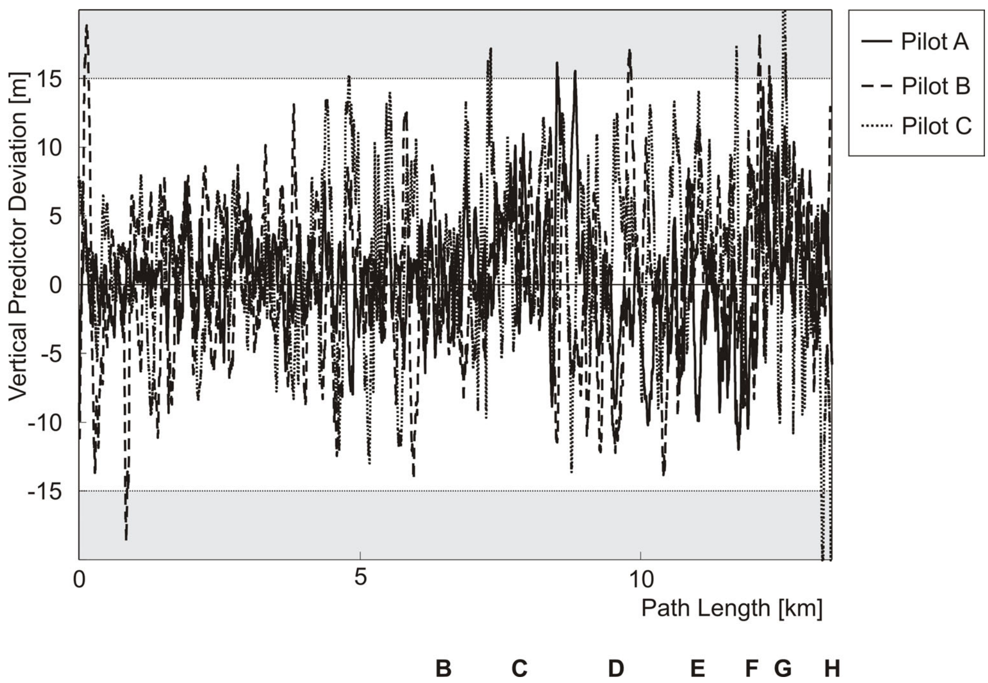

Fig. 11: Vertical predictor deviation from command flight path

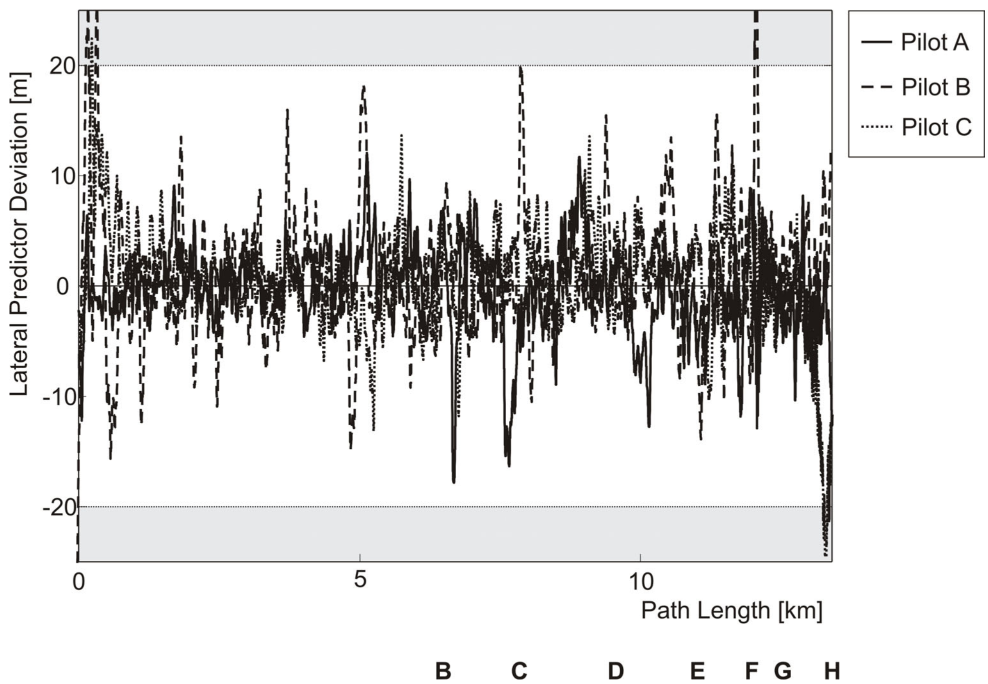

Fig. 12: Lateral predictor deviation from command flight path