Aircraft Guidance-System Logic Design for a Fully Autonomous Mission

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Abstract: In the aircraft guidance-system design-process, a number of autopilots are designed at certain flight conditions. An autopilot is responsible for a certain task not the whole mission, e.g., an autopilot can be responsible for the a/c to have a certain rate of climb, velocity, or altitude…etc. And a need arises for a supervisory control system that manages the engagement and disengagement of each designed autopilot, passing the command inputs to them for the a/c to accomplish the whole mission. It looks like the supervisory control system existing in DCS's (*D*istributed *C*ontrol *S*ystems). In this paper, the logic of the online-software for such systems is presented, clarifying the inputs, outputs, and timing of the system. Also the logic of the *G*round *C*ontrol *S*tation (GCS) software is presented. A realistic mission is adopted to clarify the operation of the guidance system.

Keywords: Aircraft Guidance, and Autonomous Flight

1. Introduction

One of the techniques used in a/c guidance along a prescribed trajectory is to design certain autopilots at some flight conditions. Then the a/c is kept stable and under command at these flight conditions, i.e., if the a/c is required to have a certain velocity, altitude, or heading…etc. the responsible autopilot can be engaged to accomplish this task. Then a supervisory control system is to be designed to engage and disengage each autopilot at the appropriate times, feeding them with the appropriate command inputs. This system has two programs; GCS software which deals with the a/c operator in a user friendly way, receives the a/c mission description, and saves this data in an appropriate manner. And the online software which is the main system component; it receives the saved data from the GCS software, manages the engagement and disengagement of each autopilot, and feeds them with the desired command inputs. These two components are to be discussed in this paper.

2. Mission Profile

An air-to-surface mission for a fixed target is planned, [1]. This mission represents a simple striking mission that can be either training or real mission. The mission consists of climb, cruise, descent, releasing bomb, climb, cruise, descent, and steering at each necessary point. The overall mission runs about 30 minutes. The plane view of the mission is illustrated in Fig. 1, while the altitude and speed information at each steering point are provided in Fig.2 and Table 1.

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Table 1   Altitude, velocity, and heading angle at each steering point

Steering Point	Altitude (m)	Velocity (m/sec)	Heading (deg)
Steering Point 1	300	70	100
Steering Point 2	10,000	350	165
Steering Point 3	10,000	350	224
Steering Point 4	300	200	253
Steering Point 5	13700	650	293
Steering Point 6	10,000	350	293
Steering Point 7	180	70	0

The target is in an air base which is 98.175 nm away from the take-off base and 2° off to the east. The altitude of the base air field is assumed to be 150 m. The FOXTROT a/c (a twin engined, jet fighter/bomber a/c), [2], was selected to be the example a/c, in this paper, for designing the guidance system. The usual cruise condition of this a/c is known to be 10,000 m altitude at 350 m/sec. The simulation starts from just after take-off condition at 300 m altitude, and finishes at little lower than 180 m altitude. After the take-off, the vehicle has to climb to the cruise altitude, 10,000 m, and makes a 100° turn. At steering point 2, the a/c makes 65° turn. Steering for the final target approach is made at steering point 3, and the altitude is dropped to 300 m which is the bomb release altitude. When releasing the bomb, the CCIP (Continuously Computed Impact Point) delivery mode is considered. As soon as the bomb is released, the vehicle rapidly increases its altitude to 13700 m (steering point 5) to avoid any anti-aircraft fire. At steering point 6, the altitude is returned to the cruising condition, and the vehicle approaches the original base. The take-off and landing are not included in the mission.

3. Guidance System Operation

Prior to identifying the operation of the guidance system, recall the flight conditions at which the FOXTROT a/c data are available, [2], and the autopilots are designed. There are four flight conditions illustrated in Table 2. At each flight condition, there are four designed autopilots; ROC, altitude, velocity, and heading. The designed auto pilots at each flight condition are responsible for delivering the a/c to the neighboring flight conditions where other autopilots take the responsibility, e.g., the autopilots designed at flight condition (2) is responsible for delivering the a/c to flight conditions (1) and (3). Also the a/c can not transfer from a certain flight condition to a non-neighboring one directly, i.e., the a/c can not speed up from 70 m/sec (flt. Cond.1) to 350 m/sec (flt. Cond.3) directly, the guidance system will divide this process into two steps, from 70 m/sec to 265 m/sec (flt. Cond.2), and then from 265 m/sec to the desired 350 m/sec.

Table 2   Altitude and velocity at each flight condition

Flight Condition	Altitude (m)	Velocity (m/sec)
(1)	Sea level	70
(2)	10,000	265
(3)	10,000	350
(4)	13700	650

The guidance system software is divided into two programs. The first which has the interface table (Table 3) is considered the connection between the a/c operators and the guidance system; it runs on the ground for catching the data table row by row, and saving them to be used by the main program. The second is the main program which runs online to perform the main guidance system task.

Table 3 shows how the GCS software is to be filled by the operator for the a/c to accomplish the mission stated previously.

Table 3   Guidance system software interface

Index	Priority	Condition Variable	Condition Value	Autopilot Type	Command Value	Disenabling Condition Index
1	0	Initial	———	ROC (m/sec)	30	4
2	0	Initial	———	Velocity (m/sec)	265	5
3	0	Initial	———	Heading (deg)	100	6
4	1	Altitude (m)	10,000	Altitude (m)	10,000	8
5	2	Velocity (m/sec)	265	Velocity (m/sec)	350	8
6	3	X-Y Distance (m)	173,162	Heading (deg)	165	7
7	4	X-Y Distance (m)	190,520	Heading (deg)	224	11
8	5	Just After Previous	———	ROC (m/sec)	- 90	9
9	6	Altitude (m)	300	Altitude (m)	300	12
10	6	Altitude (m)	300	Velocity (m/sec)	200	13
11	6	Altitude (m)	300	Heading (deg)	253	18
12	7	External Signal	CCIP signal	ROC (m/sec)	50	16
13	7	External Signal	CCIP signal	Velocity (m/sec)	265	14
14	8	Velocity (m/sec)	265	Velocity (m/sec)	350	15
15	9	Velocity (m/sec)	350	Velocity (m/sec)	650	19
16	10	Altitude (m)	10,000	ROC (m/sec)	50	17
17	11	Altitude (m)	13,700	Altitude (m)	13,700	19
18	12	X-Y Distance (m)	162,420	Heading (deg)	293	22
19	13	Just After Previous	———	ROC (m/sec)	- 50	20
20	14	Altitude (m)	10,000	Altitude (m)	10,000	.
21	15	Just After Previous	———	Velocity (m/sec)	350	.
22	16	X-Y Distance (m)	122,232	Heading (deg)	0	.
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Now the interface table will be identified:

- Each row represents a task that the a/c has to perform.
- The index field is a counter that is filled automatically by the software.
- The priority field is filled in a chronological order to tell the system which task has to be accomplished first.
- The condition variable is a pull down menu containing seven choices; initial, altitude, velocity, heading, x-y distance, external signal, and just after previous. This column tells the guidance system when the task of this row has to be started; initially just after running the program, when the altitude reaches certain value, the velocity, the

heading, the x-y distance, when an external signal arrival, or just after the previous task settles.

- The condition value field represents the value when the condition variable specified above reaches, the guidance system starts performing the task.
- The auto pilot (A/P) type is a pull down menu containing the four types of the existing auto pilots; it represents the task of this row that should be done.
- The command field asks about the set point (command input) of the specified autopilot.
- The disabling-condition-index field is filled after filling all the rows; it represents the index number of the condition at which it is intended to disable this task.
- Each row has an *add* button that should be clicked after entering the row data, and the system software checks for the a/c ability to perform this task. If it is not able, the software suggests appropriate alternative series of tasks.

The take off autopilot delivers the a/c to 300 m altitude, 70 m/sec velocity. At then the a/c has to perform three tasks; climbing with 30 m/sec ROC to 10,000 m altitude, increasing the velocity to 350 m/sec, and turning to 100° heading. The following lines illustrate some of the operators' task row by row, and the way by which the guidance system software (s/w) responds:

First row: the priority fields were filled by zeros and the conditions were chosen initially in the three tasks to be performed firstly. The autopilot type was selected to be ROC, the command value set to 30 m/sec, and the *add* button was then clicked. The s/w then asks about the altitude to be reached, it is set to 10,000 m, so it suggested the next row data to be filled with priority: one, condition: altitude, value: 10,000 m, A/P type: altitude, and the command value: 10,000, i.e., the s/w suggests altitude hold when the a/c reaches the desired altitude.

Second row: the A/P type was chosen to be velocity, the command value set to 350 m/sec, and the *add* button was then clicked. The s/w checks the validity of this command, the selected condition at which this task should be done is initially (300 m altitude, 70 m/sec), so the a/c cannot reach 350 m/sec (flt. Cond.3) from 70 m/sec (flt. Cond.1) as stated before. Therefore, the s/w refused, suggested the command of this row to be 265 m/sec (flt. Cond.2) and suggested the next row to have apriority: two, condition: velocity, value: 265 m/sec, A/P type: velocity, and the command value: 350, i.e., the s/w suggests reaching from 70 to 350 m/sec in two steps.

Sixth row: to understand the condition which was selected "x-y distance". After studying the mission profile in the x-y plane, it is found that the turning at steering point 2 is done when the a/c is at an x-y distance from the base equals 93.5 nm (173,162 m), so it is the condition for turning to 165°.

Eighth row: The condition here is selected "just after previous". Every designed auto pilot gives a signal after setting its mission. In this row it is intended to descend to the target air base field after the heading angle reaches the desired value, i.e. the heading auto pilot settles, so it's the condition for descending.

Twelfth row: In this row it is intended that the a/c climbs increasing its velocity after the bomb has been released, therefore the condition for the a/c to start doing so is the external signal coming from the CCIP mode telling us that the bomb release has finished.

The a/c operators fill the data table to the end of mission, and then they enter the disenabling condition for each row task, and click finish. The system s/w runs a simulation for the whole mission to be checked by the operators, if they are not satisfied with the simulated mission, they can edit the mission rows and check again. Going to the design step of the main program, which is responsible for the a/c to accomplish the entered mission.

4. Guidance System Design

The guidance system input is the mission data (Table 3), its output is the switching on/off signals to the specified autopilots at the appropriate times. Figure 3 illustrates the flow chart of the guidance system s/w, Fig. 4, 5 represent the flow charts of the functions used in the main guidance system program, and Fig. 6. shows the disenable subroutine used in the disengage function.

5. References

[1]   Yu, Si-bok, "Life-extending control for a highly maneuverable flight vehicle", Ph.D. Thesis, Old Dominion University, 2003.
[2]   Donald McLean, "Automatic Flight Control Systems", Prentice Hall International Ltd, UK, 1990.
[3]   J. C. Neidhoefer and K. Krishnakumar, "Intelligent Control for Near-Autonomous Aircraft Missions", IEEE, Jan 2001.
[4]   Gary B. Lamont, "UAV Swarm Mission Planning Development Using Evolutionary Algorithms", Air Force Institute of Technology, OH, USA.
[5]   Mario Andres Cordoba, "Autonomous Intelligent Fuzzy Logic Guidance, and Flight Control System for the EFIGENIA EJ-1B Mozart UAV", 17th IFAC Symposium on Automatic Control in Aerospace, Toulouse.
[6]   Djaber Boukraa, Yasmina Bestaoui, and Naoufel Azouz, "3D Trajectory Tracking for a Fixed Wing UAV Using Dynamic Inversion", 17th IFAC Symposium on Automatic Control in Aerospace, Toulouse.
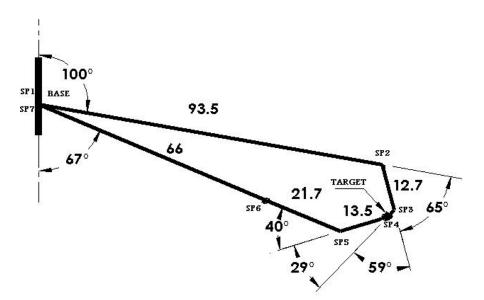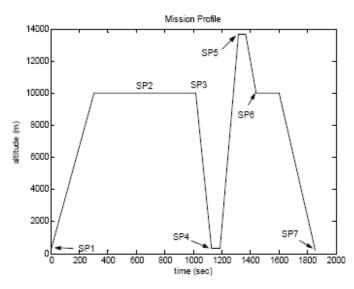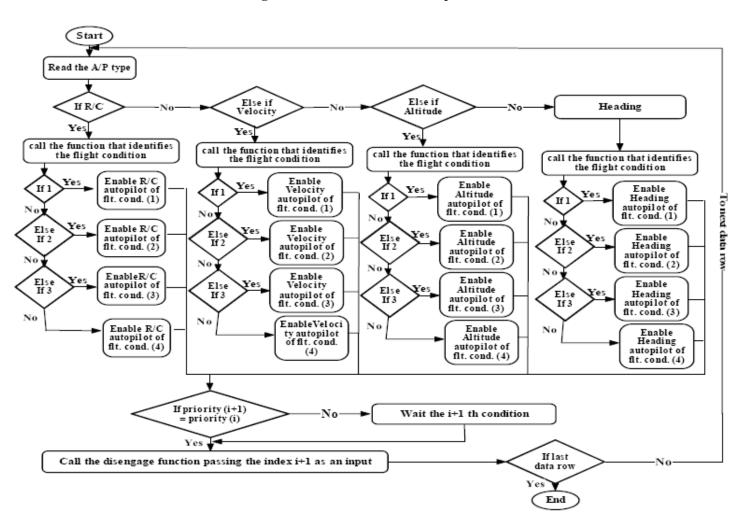
Fig. 1   Plane view of the mission.
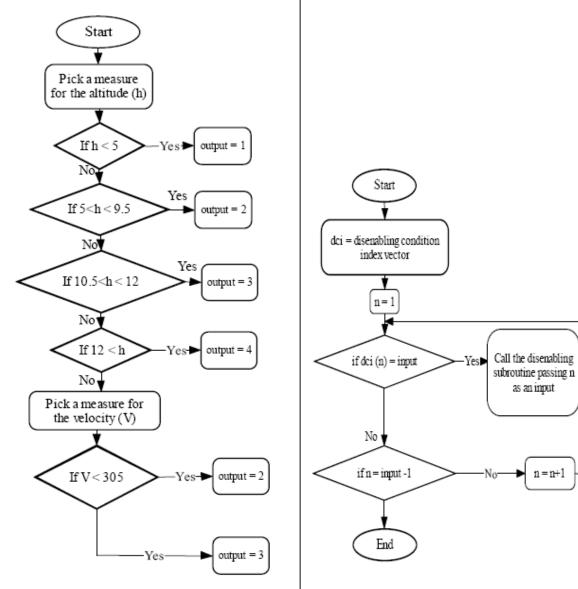
Fig. 2   Altitude of the mission profile.

Fig. 3   Guidance system software

Fig. 4   Flow chart of the function that identifies the flight condition, used in the main program of the guidance system.

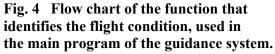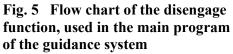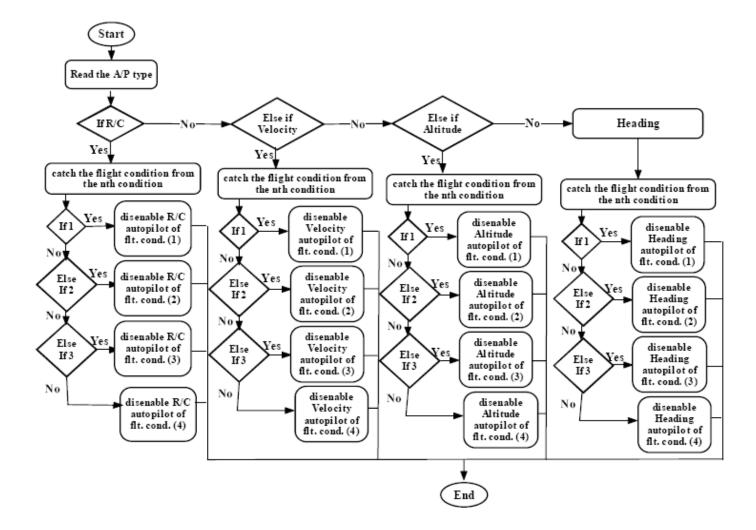**Fig. 5   Flow chart of the disengage function, used in the main program of the guidance system**

Fig. 6   Disenable subroutine, used in the disengage function