Header

Date: 06/08/2015
Location: UMore Park Airfield
Aircraft: Baldr
Pilot: Danny Chryst
Flights: 1 Baldr
Purpose: Testing the LQG controller (with integrators) designed to use only the split elevators for stabilization & tracking.

Weather

- Clear with average wind speeds of 5mph (NW). Max wind speed of 15mph. Visibility 10 miles.
- METAR data from Lakeville (KLVN) and South Saint Paul (KSGS) reporting stations for the time period spanning the flight is given below.

Start

KLVN 081421Z AUTO 32006KT 10SM CLR 19/14 A2977 RMK AO2
KSGS 081433Z AUTO 34006KT 10SM CLR 21/13 A2976 RMK AO2 T02090133

Finish

KLVN 081521Z AUTO 33007KT 10SM CLR 21/14 A2977 RMK AO2
KSGS 081534Z AUTO 29007KT 10SM CLR 23/13 A2976 RMK AO2 T02270129

Introduction

Apurva, Brian, Chris, Danny, Julian, Laura, and Raghu arrived at the UMore Park Airfield around 8:30am for the eleventh flight of Baldr. In addition to Baldr flights, there were several Fenrir flights that are summarized in separate flight reports.

Baldr is the UAV Lab's newest UltraStick 120 airframe that will be used for aircraft reliability research. Baldr is a modified UltraStick 120 airframe that has split elevators and split rudders, each surface driven by a dedicated servo motor. Recently, efforts have been underway at the University of Minnesota to design fault tolerant control laws for UAVs. Specifically, researchers have been focusing on attempting to control Baldr using only the split elevators, with all other control surfaces locked into their respective trim positions. The key idea in this experiment is controlling a conventional aircraft with two coplanar control surfaces. There are two main motivations that drove this experiment:

1. Exploring the controllability of conventional aircraft (with an empennage) that have been severely handicapped with losses in multiple aerodynamic control channels, and
2. Drawing meaningful conclusions about the controllability of two-surface flying wing aircraft which are subject to faults in any one of the two aerodynamic control surfaces.

For this experiment, the performance objectives were tracking phi and theta commands. Hence, only phi and theta tracking control loops were synthesized and implemented. It is important to note that each of the split elevators induce both longitudinal and lateral-directional motion in the aircraft. As a

consequence, researchers were specifically interested in synthesizing multi-input, multi-output control laws (as opposed to the conventional loop-at-a-time designs). For this experiment, researchers synthesized a linear quadratic Gaussian (LQG) controller, with the primary performance objective being output regulation. A secondary performance objective was tracking phi and theta commands. In order to track commands, two integrators were added to the synthesized LQG controller on the roll and pitch channels. The integrators effectively ensure that the steady-state tracking error is as close to zero as possible. In addition, the baseline controller runs for the first 2 seconds before the LQG controller is engaged. This simulates a realistic scenario wherein the flight control law has to switch from the baseline to the backup after a fault has been detected. The LQG controller was designed in Simulink and subsequently autocoded using Simulink coder. In addition, updated input trim settings for all the control surfaces (estimated from Baldr flights 1 through 6) were used in this flight.

This experiment used ONLY the left elevator of Baldr to regulate outputs around trim and track phi and theta.

Experiment

A total of 12 runs were planned for this experiment. All 12 runs were successfully executed.

Run #	Maneuver	Duration [s]
1,2,3	Trimmed in straight & level flight at 23m/s. Pitch = 5deg. Roll = 0deg. Throttle = 65%.	30
4,5,6	Roll step of +10deg about trim roll attitude of 0deg. Maneuver started 3 seconds after autopilot initiation and lasted a total of 30 seconds.	33
7,8,9	Roll step of -10deg about trim roll attitude of 0deg. Maneuver started 3 seconds after autopilot initiation and lasted a total of 30 seconds.	33
10,11,12	Pitch doublet of +/- 5 deg about trim pitch attitude of 5deg. Maneuver started 3 seconds after autopilot initiation and lasted a total of 6 seconds.	9

Observations

All 12 planned runs were successfully executed with satisfactory tracking performance. The controller does a good job in regulating phi and theta about their trim values. The tracking performance is better during some maneuvers as compared to others; this is summarized below. In all cases, the control command sent by the flight computer to the left elevator is within the saturation limits of the actuator.

1. Straight and level flight: The worst-case tracking errors are, respectively, -20 deg in phi and -25 deg in theta. The best tracking performance is seen for run number 2, where the errors in phi and theta are within [-10, +5] deg and [-15, +5] deg, respectively.
2. Right banked turns: The worst-case tracking errors are, respectively, -25 deg in phi and -25 deg in theta. The best tracking performance is seen for run number 5, where the errors in phi and theta are within [-15, 0] deg and [-15, +5] deg, respectively.
3. Left banked turns: The best overall performance is seen for the case of left banked turns executed in runs 7, 8, and 9. Run number 9 did not go correctly and will not be discussed in this

report. Considering only runs 7 and 8, the worst-case tracking errors are, respectively, +15 deg in phi and -10 deg in theta. The best tracking performance is seen for run number 8, where the error in phi and theta are within [0, +15] deg and [-10, 0] deg, respectively.

4. Pitch doublets: The tracking performance for the pitch doublets are unsatisfactory. The worst-case tracking errors are, respectively, -15 deg in phi and -20 deg in theta. The unsatisfactory performance in pitch doublets is a result of pitch being de-emphasized in the control synthesis.

Flight code

I. Aircraft: Baldr
II. Guidance: guidance/guidance_3n4.c (3 straight & level, 3 roll steps of +10deg, 3 rolls steps of -10deg, 3 pitch doublets of +/- 5deg)
III. Navigation: navigation/EKF_15state_quat.c
IV. Control: BALDR_LQG_LEFT/(autocoded C files)