Homework 2

Fault Tolerant Control (SC42130)

May 2, 2024

Below is an overview of the electronic flight control system (EFCS) as depicted in Figure 7 from (Goupil, 2011).

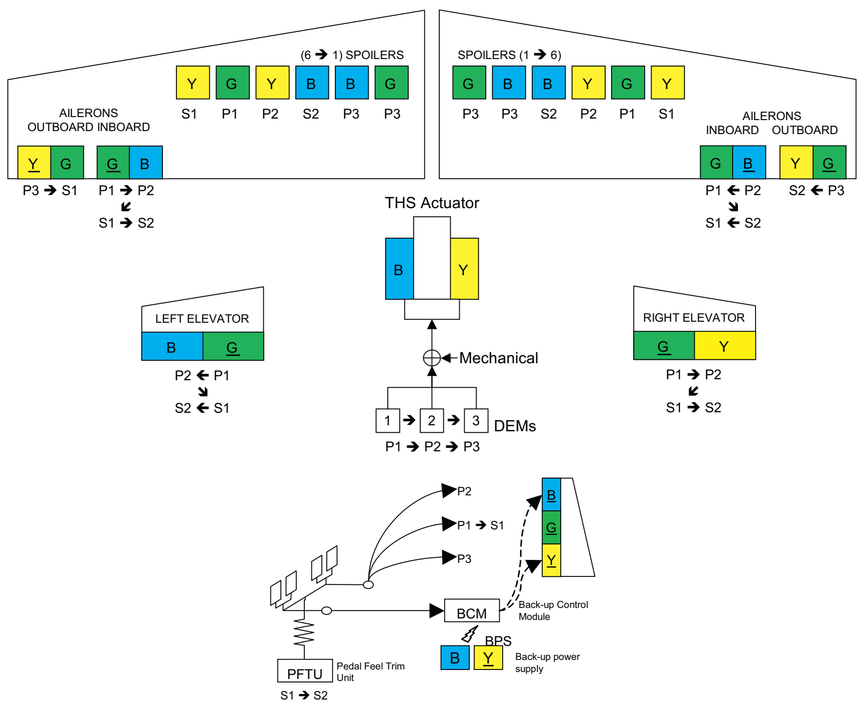
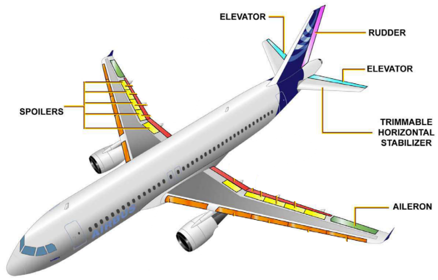


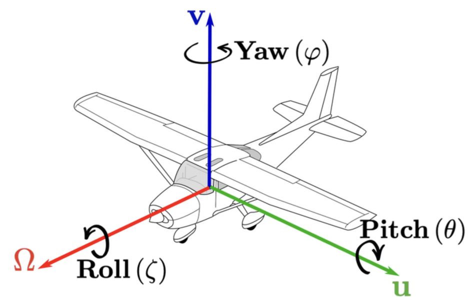
Fig. 7. A340 EFCS architecture.

Figure 1: A340 EFCS architecture: the unlabeled component on the bottom right denotes the rudder.

An overview of these component can be seen below (Hangar MMA, n.d.) in Figure 2a. Note that Figure 2a is for illustrative purposes only. Names, types and number of components (i.e. ailerons, spoilers) should be taken from Figure 1. The plane can make the following maneuvers: yaw, pitch and roll, which are depicted in Figure 2b.



(a) Overview of where components are located.



(b) Pitch, yaw and roll angles

Figure 2: Descriptive representation

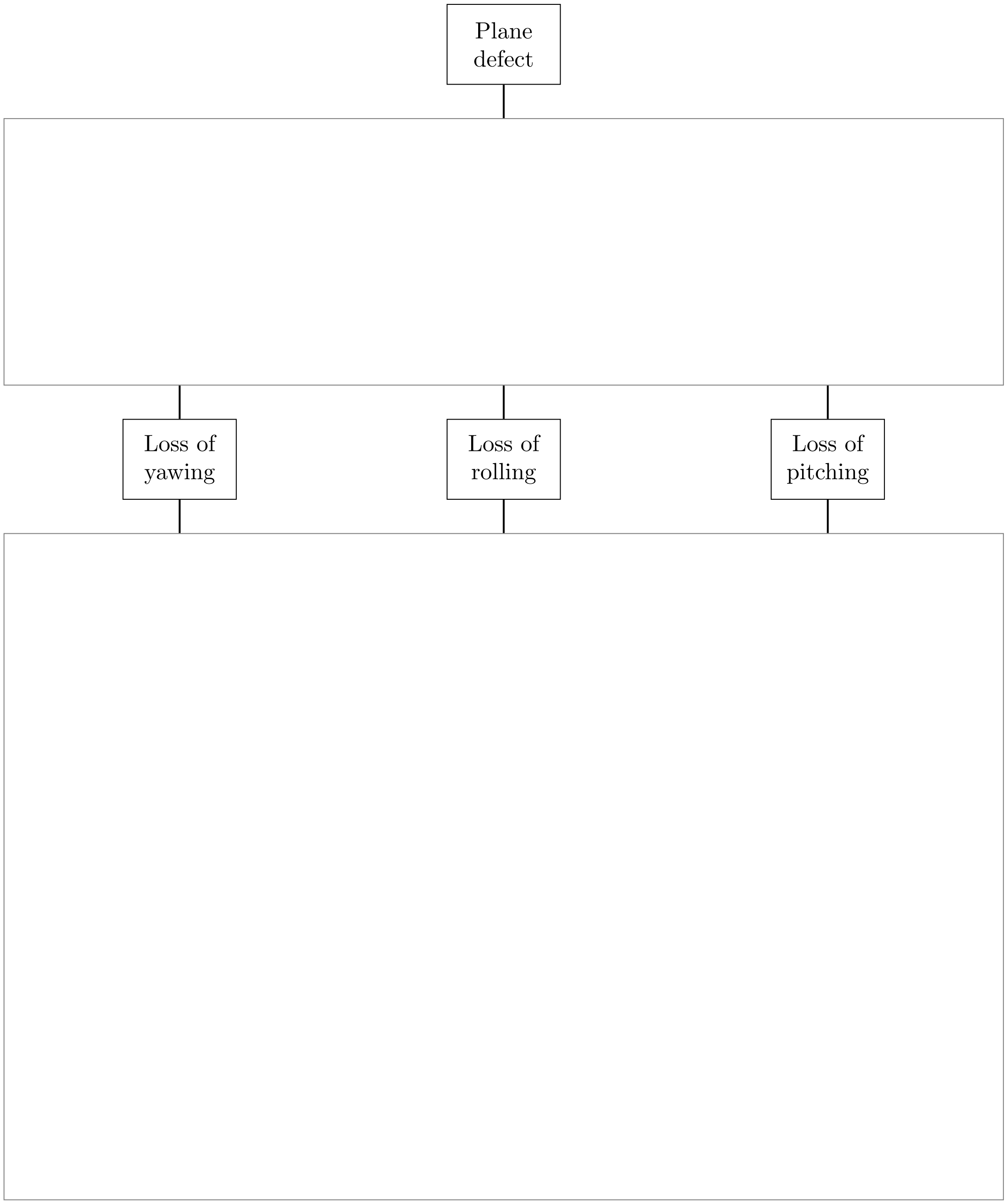
In this first question we consider the entire plane as a component. The plane is deemed uncontrollable (i.e. defective) if either a change in the altitude (i.e. going up or down) or a change in heading (i.e. turning left or right) is no longer possible. To accommodate a change in altitude a plane needs to pitch either up or down. Both the elevators and the Trimmable Horizontal Stabilizer (THS) can provide a change in pitch angle, but the elevators are vital as the THS on its own does not provide a large enough control surface to facilitate all the necessitated pitches to adequately change height. However, losing either one of the two elevators is not detrimental in providing sufficient pitch, as long as the THS is usable as well. Having both the left and right elevator can overcome any defect that the THS might have. A change in heading can be accommodated by either yawing or rolling (a.k.a. banking) the plane. Yawing can be accomplished by any control surface which can move to the left and right (when viewing the plane from above as in Figure 1). Rolling is usually facilitated by the ailerons, but it can also be facilitated by using at least half of the spoilers, as together they provide just enough drag. As both ailerons are positioned further outwards on the wing they allow for greater maneuverability: as long as at least one of the ailerons on each wing is operational the aircraft can freely bank.

1) Carry out a Fault Tree Analysis (FTA) of the plane. The fault tree can be completed by filling in the following diagram.

Hint: when writing the Minimal Cut Sets (MCSs) of fault trees which include a k/N majority-voting gate $G : \{0,1\}^N \to \{0,1\}$, you can use the following notation. Suppose the input to the gate are the events $e_1, e_2, \ldots, e_N$, and define $\mathcal{E} \coloneqq \{e_i, i \in \{1, 2, \ldots, N\}\}$ as the set of all input events to the gate. Recall the definition of a power set $\mathscr{P}(\mathcal{E})$ as the set of all subsets of $\mathcal{E}$. We define the set of all minimal cut sets of G as $\mathscr{P}_k(\mathcal{E}) \subset \mathscr{P}(\mathcal{E})$, where

$$\mathscr{P}_k(\mathcal{E}) \coloneqq \{\mathcal{E}_\ell \subseteq \mathcal{E} : |\mathcal{E}_\ell| = k\}.$$

So long as you include a "token" set $\mathcal{E}_\ell$ in the (correct) definition of the MCS, and show your understanding of the definition of $\mathcal{E}_\ell$ by providing two examples, you will be awarded full marks.



Note: for the naming of the basic events, use the acronyms R (Rudder defect), LE (Left Aileron defect), RS2 (Right Spoiler 2 defect), etc. in your FTA for readability. You can draw the diagram by hand or for increased flexibility use a digital flowchart tool like `draw.io`.

2) The physical structure of the plane has reflectional symmetry along the longitudinal axis, as for each left component their exist a corresponding right component, as seen in Figure 1. Therefore, we might be temped to simplify our analysis and focus solely on for instance all components situated on the left half of the plane. Through examination of Figure 1, please explain why this simplification is incorrect, and provide an explicit counterexample showing how component placement symmetry does not lead necessarily to having symmetric fault propagation.

> The rudder is located at the back of the plane and provides a change in yaw angle φ over time, given some reference yaw angle φ_{ref}. This desired yaw angle is provided either by means of a pedal deflection, of given as an EFCS signal. In order for the rudder to properly function it needs both electric power and hydraulic power. The rudder angle α of the control surface (i.e. the rudder blade) is mapped to the derivative of the yaw angle $\dot{\varphi}$ through some known dynamics f_{plane}. The actuation signal α is computed by a PI controller located on a microprocessor, with gains K_{p} and K_{i}, which is fed the error term e (the difference between the current yaw angle and the desired one). The rudder blade (i.e. the control surface) is mounted to the plane using a hinge system. Finally, in order for the rudder to function properly the relative wind speed V_{rel} needs to exceed 360 km/h.

3) Define the service provided by the rudder component as a 6-tuple.

Note: the request and enable need to be conditions which are either satisfied or not satisfied (i.e. boolean functions). For request, we assume that this is a set of binary variables which are OR'd whilst for enabled, we assume these are binary variables that are AND'd.

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4) **(Bonus)** Give the FTA of the left elevator, where the basic events are failures of the relevant primary and secondary computers, and the failures of the different hydraulics groups.

References

Goupil, P. (2011, June). AIRBUS state of the art and practices on FDI and FTC in flight control system. *Control Engineering Practice*, *19*(6), 524–539. Retrieved 2024-04-21, from https://www.sciencedirect.com/science/article/pii/S0967066110002704 doi: 10.1016/j.conengprac.2010.12.009

Hangar MMA. (n.d.). *Family A330/A340 to A318/319/320/321 ATA 27 - FLIGHT CONTROLS.* Mecânico de Manutenção Aeronáutica.