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On-Line Optimization for Fault Tolerant Flight Control

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Abstract

In this communication the case in which an aerodynamic actuator failure occurs to an aircraft while it has to perform some guidance maneuver is considered. This problem is dealt with the reassignment of remaining operational actuators in order to perform the required maneuver while maintaining the structural integrity of the aircraft. Nonlinear Inverse Control technique is used to generate online nominal moments along the three axes of the aircraft. Taking into account all material and structural constraints as well as the redundant effects from other actuators, a mathematical programming problem to be solved on-line which related to control reallocation can be formulated. Solution techniques, based on dynamic neural networks, active set methods and interior point methods are discussed and the respective performances are compared.

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Keywords: active set, interior point, neural network, on-line optimization, fault tolerant flight control

1. Introduction

In this study we consider a transportation aircraft in the situation in which a main aerodynamic actuator failure can occurs while it has to perform some guidance maneuver. Here through a nonlinear dynamic inversion (NLI) of the flight dynamics, the necessary moments to perform a given guidance maneuver are computed. It is supposed that a fault detection and identification (FDI) module is monitoring on-line the whole set of control channels and actuators. In this study it is supposed that this FDI module presents high standards of reliability, accuracy and timeliness, so its design characteristics and operations principles are not discussed in this paper. References [1-3] present up to date achievements in this area.

So when an actuator failure occurs, is detected and correctly identified, an on-line reassignment and resetting of the remaining redundant actuators must be performed with the aim of achieving anyway the

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planned maneuvers. The question is tackled here by formulating on-line optimization problem whose solution will provide continuously new reference values for these actuators, therefore allow performing the planned maneuver in a nominal or a degraded way. This represents the main difference with other previous approaches to actuator fault management [4-6].

In this study, is adopted a linear quadratic programming formulation of the optimization problem to be solved on-line since many optimization methods exist to solve it rather efficiently. Among these methods, active set methods, interior point methods and neural network dynamic solvers, described in [7-9], have been considered and compared. The main issue is to check if the performances of these techniques are compatible with their on-line operation onboard aircraft to deal with the actuator reassignment and resetting problem under failure.

2. Effectiveness of Aerodynamic Actuators

The effectiveness of the control surfaces appears through the contributions of their angular deflections to the dimensionless coefficients present in the expressions of aerodynamic forces and torques [10]. These control surfaces produce a collective external effect over the whole aircraft as well as internal efforts which should satisfy structural constraints. The global dimensionless coefficients used to express aerodynamic forces are assumed to be given by:

$$C_x = C_{x0} + k\,C_z^2 \quad (1)$$

$$C_y = C_{y\beta}\beta + C_{yp}\,pl_A/V + C_{yr}\,rl_A/V + \underline{C}_{y\delta p}'\underline{\delta}_p + \underline{C}_{y\delta r}'\underline{\delta}_r \quad (2)$$

$$C_z = C_{z0} + C_{z\alpha}\,\alpha + C_{z\delta ths}\,\delta_{ths} + \underline{C}_{z\delta q}'\underline{\delta}_q \quad (3)$$

where k is a positive coefficient and the C_{ij} are dimensionless aerodynamic derivatives, V is the airspeed, δ_{ths} is the angular position of the trimmable horizontal stabilizer and l_A is a reference length. Here p, r are respectively the roll and yaw rates, α is the angle of attack, β is the side slip angle, $\underline{\delta}_p$, $\underline{\delta}_q$, $\underline{\delta}_r$ are respectively the aileron, elevator and rudder deflections.

The dimensionless coefficients of the main axis aerodynamic torques can in general be expressed such as:

$$C_m = C_{m0} + C_{m\alpha}\,\alpha + C_{mq}\,ql_A/V + C_{m\delta ths}\,\delta_{ths} + \underline{C}_{m\delta q}'\underline{\delta}_q \quad (2.1)$$

$$C_l = C_{l0} + C_{l\beta}\beta + C_{lp}\,pl_A/V + C_{lr}\,rl_A/V + \underline{C}_{l\delta p}'\underline{\delta}_p + \underline{C}_{l\delta r}'\underline{\delta}_r \quad (2.2)$$

$$C_n = C_{n0} + C_{n\beta}\beta + C_{np}\,pl_A/V + C_{nr}\,rl_A/V + \underline{C}_{n\delta p}'\underline{\delta}_p + \underline{C}_{n\delta r}'\underline{\delta}_r \quad (2.3)$$

where q is the pitch rate. According to the relationship between aerodynamic derivatives and aerodynamic torque, the expression of the different aerodynamic torques generated by the control surfaces can be approximated by an affine form with respect to the corresponding deflections of the different aerodynamic actuators, so that we get expressions such as:

$$M_{ik}(t) = M_{ik}^0(t) + \mu_{ik}(t)\,\delta_k(t) \quad (3)$$

where $M_{ik}(t)$ is the i^{th} considered torques (roll, pitch, yaw, bending, flexion), $\delta_k(t)$ is the deflection of the k^{th} aerodynamic actuator ($k \in K$={aileron, flap, right spoilers, left spoilers, elevator, rudder}) and $\mu_{ik}(t)$ is the current effectiveness of actuator k to produce moment i. The current values $M_{ik}^0(t)$ and $\mu_{ik}(t)$ depend on the airspeed V, the flight level and on the values of α, β, p, q and r. Global aerodynamic torques generated by aircraft aerodynamic actuators can be rewritten in a global affine form as: