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# Fault detection, diagnosis, and performance assessment scheme for multiple redundancy aileron actuator

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A B S T R A C T

This paper presents a prognostics and health management (PHM)[2] scheme for a multiple redundancy aileron actuator (MRAA),[3] which includes fault detection, fault diagnosis, and performance assessment. The scheme utilizes the system input, system output, force motor current (FMC),[4] and aerodynamic loads for fault detection, diagnosis, and performance assessment. Fault detection is implemented using a two-step radial basis function (RBF) neural network. The first RBF neural network is employed as an observer and generates the residual error, and the second RBF neural network synchronously generates the adaptive threshold. Fault diagnosis is carried out using a system observer and an FMC observer. First, a force motor observer is used to estimate the FMC. Then, the FMC ratio of each channel can be calculated using the estimated FMC and actual FMC. Finally, a fault diagnosis is achieved by comparing the FMC ratios for the channels. For performance assessment, the system observer is adopted to generate the residual error. Then, time-domain features of the residual error are extracted. Finally, the features are input into a pre-trained self-organizing map neural network to realize the performance assessment. The effectiveness of these approaches is demonstrated using several tests at the end of this paper.



## 1. Introduction

Research and development of fault detection and diagnosis methods for a MRAA mainly involves enhancing the reliability and safety [1,2]. An MRAA can have numerous faults, including sensor, force motor, and leakage faults [3], whose early detection and timely handling contribute to the efficient operation of aircrafts and increase their safety [4,5]. Therefore, it is critical for an MRAA to take fault detection and diagnosis into account to ensure safe operation [6]. Meanwhile, the prognostics and health management (PHM) for the F-35 Fighter leads to condition-based maintenance (CBM) as a replacement for time-based or scheduled maintenance [7,8]. As the key technique of CBM, PHM, which includes fault

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[2] PHM, Prognostic and Health Management.
[3] MRAA, Multiple Redundancy Aileron Actuator.
[4] FMC, Force Motor Current.

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detection, fault diagnosis, and performance assessment, has attracted increased interest [9,10].

An aileron actuator is a key component of a flight control system (FCS); a variety of fault detection and diagnosis studies on FCSs have been conducted, including studies on aileron actuators. These studies can be classified into model-based and data-driven methods. As an example of a model-based method, Varga and Ossmann proposed an LPV model-based method to realize flight actuator diagnosis [11]. Van Eykeren proposed an approach involving actuator fault detection with aerodynamic model identification [12]. M. Samadani proposed a fault detection and severity analysis method of servo valves based on recurrence quantification analysis, the effectiveness of the proposed method was validated with mathematical model, and the results were promising [13]. In X. Yang's research, a fault detection and diagnosis scheme for recursive actuator based on unscented Kalman filtering and Bayesian classifier was proposed, and typical single actuator fault can be detected and isolated effectively [14]. Compared with model-based methods, more studies have been conducted on data-driven methods, because they do not depend on the governing equations of the FCS or aileron actuator. Zhang proposed fault diagnosis for an FCS based on a fuzzy neural network [15]. Similarly, Meng and Jiang studied observer-based fault diagnosis methods [16]. However, the aileron actuators used in these studies were single redundancy systems, whereas in practice, to improve the reliability and safety of airplanes, MRAAs are commonly used. The increased redundancy corrects the error output of the fault control channel, which makes fault detection and diagnosis more difficult. Only a few studies have focused on the fault detection and diagnosis of an MRAA. In addition, most approaches proposed in these studies are limited to some specific aspects of PHM for an aileron actuator [17], and do not synthetically cover the fault detection, diagnosis, and performance assessment [18,19].

To solve the aforementioned problems, this study proposed an entire PHM scheme for MRAAs, including fault detection, diagnosis, and performance assessment methods. For fault detection, a two-step neural network is used, which comprises two radial basis function (RBF) neural networks. The first one is used to track the MRAA and generate the residual error, and the second one is used to synchronously output the corresponding adaptive threshold. MRAA faults can be detected by comparing the residual error and adaptive threshold. Another RBF neural network is employed to estimate the force motor current (FMC), after which the FMC ratio of the estimated FMC to the actual FMC is calculated. Then, fault localization and classification can be achieved by comparing the channel ratios. Finally, a self-organizing map (SOM) neural network, which is trained by using normal data, is used to assess the performance of the MRAA. The result of this performance assessment, i.e., the confidence value (CV) [20], which ranges from zero to one, can be used to make maintenance decisions [21].

Compared with existing research, this study proposed an entire PHM scheme for Multiple redundancy aileron actuator, including fault detection, diagnosis, and performance assessment, which is beneficial to the conduction of PHM in engineering field; another highlight of this study is the fault diagnosis method for MRAA based on the significant control parameter (FMC), which can localize fault channel and fault component, with data-driven method.

The remainder of this paper is organized as follows. In Section 2, the architecture of the approaches used in this study is presented. In Section 3, the MRAA simulation model is established. In Section 4, a detailed description of the proposed method is presented. In Section 5, the effectiveness of the proposed approaches is demonstrated using simulation data with different faults.

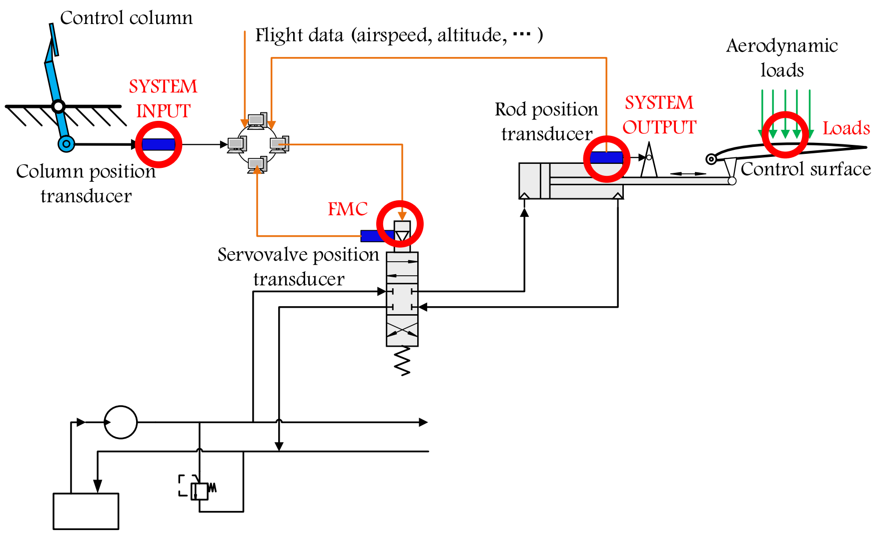


**Fig. 1.** Flight-by-wire flight control system.