Improved State Space Model Using Iterative PSO for Unsteady Aerodynamic System at High AOA

Guiming Luo, School of Software, Tsinghua University, Beijing, China
Boxu Zhao, School of Software, Tsinghua University, Beijing, China
Mengqi Jiang, School of Software, Tsinghua University, Beijing, China

ABSTRACT

Due to the complex hysteresis phenomenon at a high angle of attack (AOA), modeling of unsteady aerodynamic coefficients usually encounters the problem that the parameter vector is too long and the simulation accuracy is not high. The article proposes an improved state-space model based on aerodynamics, applying Fourier analysis and the principal component analysis for model optimization. The likelihood criterion and GOIPSO (Iterative Particle Swarm Optimization Based on Genetic Operator) algorithm are established under the Gaussian assumption. The iterative PSO, into which the genetic algorithm’s operators are integrated to calculate the optimization of the likelihood function, greatly reduced the probability of local optimization. Experiments show that the algorithm and model proposed in this paper greatly improves the model-fitting accuracy.

KEYWORDS

High Angle of Attack, PSO Algorithm, State Space Model, Unsteady Aerodynamic System

1. INTRODUCTION

When the Wright brothers conducted the first controllable flight, the flight control system was born (Jakab, 2014). Aerodynamic coefficients are important parameters during the operation of an aircraft and in the process of establishing a dynamic model in a flight control system. They are also of great significance in the research and design of new aircraft. Along with the development of aircraft technology, research on identification of aerodynamic coefficients has not stopped.

Currently, the flight envelope of an aircraft has expanded from a smooth movement state at a low angle of attack to an unsteady flow state at a high angle (Gad-el-Hak, & Ho, 1986; Lutze, & Fan, 1998). Aerodynamic force data and oscillatory data at a high angle of attack can be obtained through wind-tunnel experiments. The data shows strong inconsistency and time-related complexity compared to that of a low angle of attack. Therefore, aerodynamic coefficients of a flight system have become a focus of the present research. By analyzing the data obtained from wind-tunnel experiments, different aspects of the aircraft system can be modeled. Through computer modeling and simulation experiments, the model is improved to enhance the accuracy of aerodynamic coefficients and provide effective support for aircraft design and control.

The study of identifying aerodynamic coefficients is conducted from static data to dynamic unsteady data, from the initial linear model to the nonlinear model. At present, static pneumatic experiments and linear aerodynamic coefficient model can meet the basic industrial requirements.
(Baker, Yuan, & Goggin, 1998) Under the flight conditions of a high angle of attack, aircraft flights demonstrate a high degree of non-linearity and strong hysteresis performance, which have uncovered phenomena calling for new research. To identify the aerodynamic coefficients in complex situations, many aspects of the experimental process and modeling studies have been improved (Denoël, 2009; Meng, Li, & Veres, 2010). This paper is based on the experimental data generated by a wind tunnel in large amplitude oscillation.

In view of the non-linear and unsteady phenomena of aircraft at a high angle of attack, the research addresses mainly three aspects. First, from the perspective of mathematical research to establish a corresponding algebraic model directly for the aircraft, the main idea is to approximate the wind tunnel experimental data or real flight data by using an algebraic model, such as a polynomial model (Lin et al., 1997). Because the length of the parameter vector is guaranteed, a pure algebraic model is generally more accurate, and the model is also simple. In recent years, such methods have been often used at a low angle of attack or in static wind tunnel data modeling.

The second model category is established based on aerodynamics research. For example, in the 1970s, Tobak proposed step theory (Tobak, & Schiff, 1981) to model unsteady aerodynamic coefficients; here, the variation of the aerodynamic coefficients is regarded as a set of a series of step responses. The feature of this model is the viewpoint of physical analysis: using hydrodynamics to analyze the flight processes which result in non-linear aerodynamic phenomena at a high angle of attack and using mathematical expressions to represent the physical phenomena that occur during flight. In addition to an integral model based on step theory, there are also a pure step-response model and a model of differential forms in such models (Wang, Lan, & Brandon, 2000). Additionally, the state space is an important research point for the modeling of aerodynamic coefficients (Taha, Hajj, & Beran, 2014).

Further, regarding the flight process of an aircraft as a “black box” is also a class of modeling ideas. This method is based mainly on a strong adaptive algorithm and the machine learning ability, belonging to the modern artificial intelligence modeling methods in which neural network models are prominent (Nivison, & Khargonekar, 2017). An improved model was also developed for unsteady nonlinear aerodynamics on the basis of the standard boosting approach, which also demonstrates good results (Zhao, Luo, & Zhu, 2017). This modern modeling approach considers the flight dynamic process as a complex physical process and does not refine the study. Using these methods, a model can be directly established and identified for the nonlinear system. Therefore, it is difficult to define the physical meaning of the model. In recent years, this method has become an area of active research for studying aerodynamic coefficients.

After establishing the corresponding flight model for the experimental data, the authors need to identify the unknown parameter vector in the model and obtain the quantified model to carry on the corresponding aerodynamic study. Then, the authors establish the criterion function for the target model and select the appropriate optimization algorithm to find the global optimal solution based on the criterion function. In the 1990s, swarm intelligence based on the behavioral characteristics of biological groups in nature emerged to solve optimization problems. With an unknown objective function, genetic algorithms such as the particle-swarm and ant-colony optimization algorithms (Deb, Pratap, Agarwal, & Meyarivan, 2002) (Kennedy, 2011) can provide good approximations to the optimal solution. This kind of intelligent optimization algorithm research focuses mainly on aspects of the algorithm, the evolutionary process, fusion technology and social applications. For genetic algorithms and the particle swarm algorithm with wide-ranging applications, the dynamic adaptive method (Zhan, Zhang, Li, & Chung, 2009), cross-evolution fusion (Juang, 2004; Naka, Genji, Yura, & Fukuyama, 2003) and other improved algorithms have been proposed in recent years. It is particularly important to mention that this type of intelligent optimization algorithm has its advantages in its convergence rate and in the search for the overall situation. Therefore, the fusion of different intelligent optimization algorithms is also currently a much-researched area. Many of these improved algorithms have been successfully applied to optimization problems and actual domains and have played an important role in the industry (Ratnaweera, Halgamuge, & Watson, 2004).
Seeing for Knowing: The Thomas Effect and Computational Science
Jordi Vallverdú (2010). *Thinking Machines and the Philosophy of Computer Science: Concepts and Principles* (pp. 280-293).
[www.igi-global.com/chapter/seeing-knowing-thomas-effect-computational/43703?camid=4v1a](www.igi-global.com/chapter/seeing-knowing-thomas-effect-computational/43703?camid=4v1a)

Fuzzy Causal Patterns of Humor and Jokes for Cognitive and Affective Computing