Available online at www.sciencedirect.com
ScienceDirect
Chinese Journal of Aeronautics 23(2010) 194-197
Chinese Journal of Aeronautics
www.elsevier.com/locate/cja

Decision-making of Aircraft Optimum Configuration Utilizing Multidimensional Game Theory

Peng Runyan*, Wang Heping, Wang Zhengping, Lin Yu

School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China

Received 5 March 2009; accepted 18 May 2009

Abstract

As multi-discipline coupling and components interference often affect the aircraft configuration decision-making and analysis during conceptual design process, this article presents an approach of multidimensional game theory based on aircraft components to deal with this problem. The idea is that the configuration decision-making process is regarded as the game for different disciplines and technologies, and the aircraft components are players. The payoff function with highest total gain means that according to the game protocols and multidimensional theory, the optimal aircraft configuration within the strategy set will be chosen. The decision-making model is applied to conceptual design process of the high altitude long endurance (HALE) unmanned aerial vehicle (UAV) based on the assessment of technological risk. The obtained optimum configuration is quite consistent with the current HALE UAV development trends. Thus, taking into account the coupling and interference factors, the multidimensional gaming model based on aircraft components will be an effective analysis method in the decision-making process of aircraft optimum configuration.

Keywords: decision making; optimum configuration; components; interference; multidimensional game theory; disciplines coupling; technological risk

1. Introduction

From the relationship between the degree of freedom and cost of design in the aircraft design process[1], we can see that the configuration decision-making has an important influence on the design progress. At present, the selection of aircraft configuration is mainly based on the experiences of senior experts or expert systems. The aircraft is a huge system, many factors such as classical mechanics, aerodynamics, structural mechanics, control theory, aesthetics, etc. need to be considered during its design, so the configuration inference and decision-making process based on experts or expert systems is very complicated and the efficiency is often degraded.

As a branch of applied mathematics, the game theory has been applied widely to the areas of economics, biology, politics, etc., such as "Prisoners Dilemma" and "Pigs Payoffs". Game theory is a decision-making method between players who interact with and depend on each other. Based on the comparability between aircraft design and game theory, some researches on gaming in aircraft design and analysis process have been made[2-3]. These researches are mainly focused on the issues of multi-discipline optimization and tactics flight. But few are concerned with the conceptual configuration decision-making. So according to the influences of the component design, location and interferences on the performances of key disciplines and technological risk, a multidimensional gaming model is established for the aircraft optimum configuration decision-making process in this article.

2. Multidimensional Game Theory

2.1. Definition

Game theory is a game in which the individuals or teams chose possible strategies synchronously or successively to achieve high payoff income according to the known information in certain circumstance or constrained condition[4]. It has five factors: player, strategy, decision-making order, payoff function and information. When the decision is made in several fields, the game is called multidimensional game theory.

*Corresponding author. Tel.: +86-29-88494855.
E-mail address: pry20032003@yahoo.com.cn

doi: 10.1016/S1000-9361(09)60204-1

The gaming model including two players is $G = (S_1, S_2; u_1, u_2)$, where S_i (i=1,2) is the strategy space of each player and u_i (i=1,2) is the payoff function of each player.

2.2. Protocol and equilibrium

According to the factors and characters of game, the gaming process can be depicted in several types. In this article, the aircraft components are regarded as the game players, so based on different players, the cooperative, non-cooperative and leader/follower protocol will be introduced.

(1) Cooperative protocol

In this protocol, both players have the information of each other and they work together to find a Pareto solution. A pair (x_{1p}, x_{2p}) is Pareto optimal if no other pair (x_1, x_2) exists, such that

$$\left.\begin{array}{l} u_i(x_1,x_2) \le u_i(x_{1p},x_{2p}) \quad i=1,2 \\ u_j(x_1,x_2) < u_j(x_{1p},x_{2p}) \\ \quad\quad \text{For at least one,} \quad j=1,2 \end{array}\right\} \tag{1}$$

(2) Non-cooperative protocol

This protocol occurs when the full coalition of players is not possible being emerged due to organization, information, or process barriers. Players must make decisions by assuming that the choices of other decision makers are made. In an iterative approach, the final Nash equilibrium solution will be obtained. A strategy pair (x_{1N}, x_{2N}) is a Nash solution if

$$\left.\begin{array}{l} u_1(x_{1N},x_{2N}) = \max\limits_{x_1} u_1(x_1,x_{2N}) \\ u_2(x_{1N},x_{2N}) = \max\limits_{x_2} u_2(x_{1N},x_2) \end{array}\right\} \tag{2}$$

The Nash equilibrium solution has the property of being the fixed points of two subsets of the feasible space:

$$(x_{1N},x_{2N}) \in S_{1N}(x_{2N})S_{2N}(x_{1N})$$

where

$$S_{1N}(x_2) = \left\{x_{1N} \mid u_1(x_{1N},x_2) = \max_{x_1} u_1(x_1,x_2)\right\}$$

$$S_{2N}(x_1) = \left\{x_{2N} \mid u_2(x_1,x_{2N}) = \max_{x_2} u_2(x_1,x_2)\right\}$$

are called the rational reaction sets (RRSs) of the two players. The RRS of a player is a function that embodies his reactions to the decisions made by other players.

(3) Leader/follower protocol

When one player dominates another, they have a leader/follower relationship. This is a common occurrence in a design process when one discipline dominates the design (when one discipline plays a large role), or in a design process that involves a sequential execution of interrelated disciplinary processes. P1 is said to be the leader if he/she declares his/her strategy first by assuming that P2 behaves rationally. Thus the model of P1 as a leader is as follows

$$\begin{array}{ll} \text{Max} & u_1(x_1, x_2) \\ \text{s.t.} & x_2 \in S_{2N}(x_1) \end{array} \tag{3}$$

where $S_{2N}(x_1)$ is the RRS of P2.

For exactly describing game theory, the above mentioned protocols are represented by functions. The normal game is usually represented by a matrix which shows the players, strategies and payoffs.

3. Decision-making Model

From the traditional viewpoint, aircraft has the main components such as wing, fuselage, empennage, engine, undercarriage, etc. Each component has its own function, e.g. wing is the main lift surface, fuselage contains payload, empennage plays an important role in stabilizing and controlling the aircraft, engine provides the propulsion during flight, and undercarriages support the aircraft in takeoff and landing processes. When the design requirements are known, then what components should be chosen, how the chosen components should be designed and what kind of interferences exist between them form the gaming issues between aircraft components.

The optimum configuration decision-making of aircraft is also related to the development level of key technology. For example, the developments of computational fluid dynamics (CFD), new material, intelligence control and electronic technology may result in advanced aircraft configuration and bring the opportunity and challenge to the design. As a long period engineering, it is necessary for aircraft designers to look into the developments of these key technologies and their developmental trends. So identifying the levels of key technology and design risk is the prerequisite for optimum configuration decision-making. In conceptual design phase, to obtain the optimum aircraft configuration, the important disciplines and the coupling between them need to be considered too. Based on the methods of quality function deployment (QFD) for key technology identification[5] and performance index allocation principle[6-7], the performance weights will be assigned to each important discipline field.

From above analysis, the components design, location, interference, disciplines coupling, technological risk, etc. are considered and the optimum configuration decision-making process is simulated utilizing the multidimensional game theory in this article. The decision-making flow chart is shown in Fig.1.

The idea of aircraft configuration decision-making is that the aircraft components are the players and the strategies or strategies combination for each important discipline and technological risk are evaluated, and then get the one dimensional payoff income. All important disciplines will be synthesized to achieve the optimum configuration that has total highest payoff income by multidimensional game theory[8] combined with the assigned performance index weights.