



## Engineering method to build the composite structure ply database



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### ARTICLE INFO

#### Article history:

Received 6 June 2016

Accepted 30 June 2016

Available online 5 July 2016

#### Keywords:

Composite ply database

VBA program

Structure design

Stacking sequence

### ABSTRACT

In this paper, a new method to build a composite ply database with engineering design constraints is proposed. This method has two levels: the core stacking sequence design and the whole stacking sequence design. The core stacking sequences are obtained by the full permutation algorithm considering the ply ratio requirement and the dispersion character which characterizes the dispersion of ply angles. The whole stacking sequences are the combinations of the core stacking sequences. By excluding the ply sequences which do not meet the engineering requirements, the final ply database is obtained. One example with the constraints that the total layer number is 100 and the ply ratio is 30:60:10 is presented to validate the method. This method provides a new way to set up the ply database based on the engineering requirements without adopting intelligent optimization algorithms.

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### Introduction

Composite materials have been widely used in military and civil aircraft. The ply number of these composite materials varies from dozens to hundreds. The laminate thickness varies from 0.1 mm to 60 mm, or even more. Due to the benefits of low weight, high strength, being corrosion-free and fatigue-resistant, composite materials have been rapidly used in load carrying structures. Unlike metal structures, a variety of design variables must be considered during the composite aircraft structural design and analysis, such as the ply number, the ply angle, the stacking sequence, the symmetry, the characteristics of the first layer and last layer, the manufacture feasibility and so on. In the practical engineering, 0°, 45°, 135° and 90° are the ply angles most widely used. Therefore, there are often 4 choices of ply angle for each ply. With the increase of ply number, the stacking sequence can be very complex. Theoretically, if ply orientation has four options and a ply stacking has 100 plies, there are 100 powers of 4 kinds of stacking sequences. The number of stacking sequences is still large even if the symmetry and other requirements are considered. Hence, it is difficult to decide which stacking sequence is the proper layout for composite materials structure design engineers. If a ply database is formed through manual operation, it's not practical to complete composite structure ply design for aircraft structures. Therefore, computer programming is introduced to meet the specific requirements of the database automatically.

Ply database must come first when designing composite aircraft structures [1–4]. There have been many researches on the composite stacking sequence optimization. Knowledge-based system or expert system has been introduced to design the composite aircraft structures. A framework of a knowledge-based system was established by Webber and Wu [5–7] to analyse and assess the structural designs. The object of the optimization is weight, the constraints are the failure criteria of local buckling, overall buckling and maximum strain or maximum stress. Kim et al. [8–10] formed an expert system for the strength and stiffness optimization of composite laminates under some rules of design heuristics. Li et al. [11] developed an expert system which can make design schemes for fiber reinforced plastics. Genetic algorithm is also widely used in the stacking sequence optimization. Akira et al. [12,13] performed stacking sequence optimization using genetic algorithm. The constraints are handled by introducing a new repair strategy. Park et al. [14] used a genetic algorithm with elitist model to optimize the stacking sequence.

In the above studies, the stacking sequence optimization is mostly based on the intelligent optimization algorithms which are time consuming. In practical engineering, we have to think of the efficiency of the methods we use. Moreover, there are many other problems such as robust and fewer options when using intelligent optimization algorithms. In this paper, a method building the ply database based on the practical engineering is proposed without using intelligent optimization algorithms. Compared to the methods above, this method can produce many more stacking sequences that satisfy certain engineering ply rules so that the stacking sequences form a ply database.

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## Method to build the ply database

A method of setting up the ply database is proposed based on practical engineering without adopting full permutation algorithms or genetic and neural network algorithms. The core ideas are as follows:

- (1) By adopting certain algorithms and satisfying the constraint conditions, the core stacking sequences are produced.
- (2) The maximum ply number is obtained based on the core stacking sequences.
- (3) By reducing the maximum number of ply stacking sequence, the ply sequence with less plies is formed.
- (4) Filter all the stacking sequences according to certain engineering ply rules so that the ply database can be set up.

The engineering ply rules of this method are as follows:

- (1)  $0^\circ$ ,  $45^\circ$ ,  $135^\circ$  and  $90^\circ$  are adopted as the basic ply orientation angles.
- (2) Each ply stacking sequence must be symmetrical.
- (3) The ply ratio should meet user requirements, for instance, 30/60/10, 40/50/10, 60/30/10, the first number is  $0^\circ$  ply ratio, the second number is  $45^\circ/135^\circ$  ply ratio, the third number is  $90^\circ$  ply ratio.
- (4) Each ply ratio must be more than 6%, less than 80%.
- (5) Four continuous plies should not have the same orientation.
- (6) The plies with the same orientation should be separated as far as possible.
- (7) The balance character is defined by users, if the balance character is required, the ply sequences in the ply database which don't meet the requirement would be removed.
- (8) The requirement of balance symmetry. The ply stacking sequence is not only symmetrical, the  $45^\circ$  ply number is also the same as the  $-45^\circ$  ply number.

The procedure of this method is as follows:

- (1) Form the core stacking table. Usually, the ply number is more than 20 in the practical design. Moreover, the number 20 can satisfy the symmetry and is widely used ply ratio 30/60/10; 40/50/10. As a result, 20 is often taken as the core ply number. In consideration of the symmetry requirement, the actual core ply number is 10. According to the ply ratio, the number of plies of  $0^\circ$ ,  $45^\circ$ ,  $135^\circ$  and  $90^\circ$  is determined. Then full permutation ply sequences with user determined ply ratio are generated. By removing the ply sequences which have four continuous layers, the core stacking sequence table is formed.

The dispersion character of the ply stacking sequence is defined as follows. If the ply orientation angle is different from the connected upper ply orientation angle, we set the penalty coefficient of the ply as 1, otherwise the penalty coefficient is  $-1$ . The sum of the penalty coefficients of each ply forms the layup penalty coefficient. We define the layup penalty coefficient as the dispersion of the stacking sequence. Take the stacking sequence in Table 1 as an example. Add up the penalty coefficients of each ply, the sum of the penalty coefficients is 8. We can evaluate the stacking sequence through the dispersion character. The larger the layup penalty coefficient is, the better the stacking sequence is.

Moreover, there is more than one core ply stacking sequence according to this algorithm. There is also more than one core ply stacking sequence with the same layup penalty coefficient accord-

ing to this algorithm. This reveals the diversity of the stacking sequences in the ply database. The user can freely decide which core ply sequence will be used to form the maximum ply sequence for the ply database based on the engineering experience.

- (2) Form the ply stacking sequences with the maximum ply number. The maximum ply number is based on the design requirement, often the integer multiple of the core ply number. One or several core layups are chosen to form the maximum ply sequence by random combination. We can choose the core ply stacking sequences with larger layup penalty coefficient. For instance, we choose A1, A2, A3, A4 these four core ply stacking sequences in the core ply stacking table. A1 ~ A4 ply stacking sequences, each has 10 plies. If the maximum ply number is 80, the stack sequence can be built as (A1, A3, A4, A2)s or (A2, A3, A1, A2)s, etc. It should be noted that according to the principle of random combination, there are many different ply stacking sequences. The users can determine the sequences of the core ply stacking and the maximum ply number according to their own needs.
- (3) Reduce the ply number of each ply stacking sequence to obtain basic ply database. For each ply stacking sequence with the maximum ply number, exclude the 2 frontal layers (the first layer and last layer of the stacking sequence) every time to obtain the next stacking sequence. This operation is continued until the last two layers are left. All the stacking sequences obtained in the operation form the basic ply database.
- (4) Check the layup with the engineering requirements. Verify and evaluate all ply stacking by the engineering ply rules such as the symmetry requirement, the ply ratio requirement; the requirement that four continuous layers should not have the same orientation angles, etc.
- (5) Obtain the final layup database. Removing the ply stacking that cannot meet all the requirements, the final layup database is then obtained.

## The software design of ply database

In order to realize the above ply database design process, we use VBA script language to write the corresponding program. The interface is shown in Fig. 1. The input parameters are: total plies number, the key plies number, the ply percentage. The main part of the procedure is as follows:

```

Sub main()
n_line = 1
  For i = 1 To 100
    core_list(i) = -100
  Next i
  Call read_for_core_list

  Call perm(core_list, 1, 10)

  Worksheets("sheet2").Cells(1, 20) = "the core ply
number:"
  Worksheets("sheet2").Cells(2, 20) = n_line - 1
End Sub
Sub read_for_core_list()
  n_ply_0 = Worksheets("sheet1").Cells(7, 2)
  n_ply_45_135 = Worksheets("sheet1").Cells(7, 3)
  n_ply_90 = Worksheets("sheet1").Cells(7, 4)
  act_all_ply = Worksheets("sheet1").Cells(2, 2)

```

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