行政院國家科學委員會補助專題研究計畫成果報告

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※　　晴空亂流與陣風時飛機最佳飛行軌跡之探討　　※
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□赴國外出差或研習心得報告一份

□赴大陸地區出差或研習心得報告一份

□出席國際學術會議心得報告及發表之論文各一份

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一、中文摘要

在現代空中交通中，晴空亂流仍然是對飛行安全和飛行品質造成危害的重要因素之一。在本研究論文中，我們以真實風場的特性為基礎，使用 MATLAB 創造一個三維的風場，並且提出三個晴空亂流預測參數 T1、T2 以及 T3。其中 T1 參數用於定義亂流的強度，T2 和 T3 分別是飛機於直線加速度和角加速度方面的反應。最後我們分別使用基因演算法和結合退火神經網路的基因演算法來解算這個問題，結果顯示有明顯的成效，在相同品質的解答下，解題用的計算時間縮短約 25%。並且希望本文的成果能在將來應用在新型都普勒雷達的研發與飛行模擬的訓練中。

在本文中，我們首先將建立三個方向的風場模型，我們採用的方法是使用 MATLAB 軟體結合五十個以上的三角函數波形，並與真實的風場資料比較，結果顯示風場模型在強度與行為模式上都相當接近真實風場，且方便於使用飛行模擬程式中。

其次，為了定義亂流的強度，我們提出三個亂流參數 T1、T2、T3 來判定亂流的強度與飛機的反應。T1 參數用於定義三維亂流的強度，T2 是飛機在亂流中的直線加速度反應，T3 則是飛機在亂流中的角加速度反應，我們將模擬的風場的 T1 值與真實的風場的 T1 值作比較，發現兩者相當吻合。

第三我們使用剛體運動方程式建立 747-100 型的飛行模型，並用四階的 Runge-Kutta 來解飛行力學方程式，為了要求出在亂流中的飛行軌跡，我們使用兩種方法來求解，第一種是基因演算法(GA)第二種方法是基因演算法結合退火神經網路(ANN)。在本論文中所採用的基因演算法是實數型的基因演算法，理由是實數型的基因演算法的計算效率較高，且對系統的環境要求較不嚴苛。本文中所訂定的目標函數(OBJECTIVE FUNCTION)有二：其一是 T1+T2+T3，其二是 T1+T2+T3 加上三個方位角的均方根，分別針對飛行安全與同時考慮飛安和飛行品質兩者。用上述的兩種方法求兩個目標函數的最小值即為最佳飛行軌跡。

最後，為了增進計算效率，我們將基因演算法結合退火神經網路求解最佳化問題，成果顯示計算效能有明顯的提升，在相同品質解的情況下，計算時間可以縮短約 25%。在最佳飛行軌跡之情況下，飛機將會受到最小的亂流擾動，且機身姿態也維持最小的改變，幾近於水平飛行，因此無論對於飛行安全與飛行品質都可以達到我們的要求。

關鍵詞：晴空亂流、基因演算法、類神經網路

Abstract

In modern airline’s operation, clear air turbulence (CAT) remains one of the most influential factors in flight safety and flight quality consideration. In this research we use Matlab to create 3-D turbulence based on the real turbulence profiles, and prediction parameters (indices) T_1, T_2 and

T_3. The T_1 factor is to define the turbulence intensity, the T_2 and T_3 factors are the response of aircraft in linear acceleration and three angular accelerations. Finally we use the genetic algorithm and combining the genetic algorithm (GA) and annealed neural network (ANN) methods to search the optimum escape trajectory. Results show moderate success that the computational time was shortened by 25% and with the same quality of solutions. It is hoped that the concepts and techniques implemented in this work could be used in future airborne Doppler radar research and flight simulation practice.

In this work we first simulate turbulence/gust like three-dimensional wind profiles. The method is to use the Matlab tool and directly combine more then fifty trigonometric function waves. Comparing with real wind velocity profiles, the simulated wind show similar fluctuating behavior and can be used in our flight simulation. Secondly, to quantify the severity of CAT phenomenon, a set of prediction parameters（T_1, T_2, T_3）have been proposed, T_1 is three-dimensional turbulence acceleration, T_2 is aircraft response in linear translation, and T_3 is aircraft response in angular motion. These simulated T values show excellent agreement with real turbulence/gust T values.

Thirdly, the classical rigid body, mass/mass distribution fixed flight dynamics equations are solved by standard 4th order Runge-Kutta method. To achieve an optimum flight trajectory in order to avoid the severity of CAT, two methods are employed as the steering tools, namely, the genetic algorithm and the genetic algorithm plus annealed neural network modification method. In our work the real-value GA approach is chosen due to its computation efficiency and similarity it the natural world. Our GA process is implemented as follow: both of T_1+ T_2+ T_3, and T_1+ T_2+ T_3+root mean squares of three Euler angles are assigned as the objective functions.

And in the last, to further improve the computation efficiency of our work, the neural network method is added to our GA scheme. The model we selected is annealed neural network. It is relatively new and gives accurate data in a less timely fashion. Results show that this combination of GA and annealed neural network do improve the computation efficiency by 25%. When the CAT avoidance strategy is implemented and optimum flight trajectory achieved, it is obvious that direction attitude angles are also kept minimum. Thus represent a high degree of ride comfort and flight quality. It is hoped that the concepts proposed in this work will improve future passenger flight safety, and we no longer need to worry about clear air turbulence influence in our journey.

Keywords: Clear Air Turbulence, Genetic Algorithm, Neural Network Method

二、計畫緣由與目的

Clear air turbulence (CAT) is probably one of the most influential factor in flying quality consideration, one unique thing about CAT is that it basically can not be seen or predicted, the blue clear sky may lead to some severe turbulence situation. Generally speaking, turbulence or gust has random fluctuating behavior, associated with strong vorticity and mixing effect. Thunderstorm, vertical convection, mountain lee waves, non-uniform heating, etc. are the most common causes of turbulence. Among the many different kinds of turbulence, CAT may be the most severe one and difficult to predict. It is believed that CAT is directly caused by high altitude jet stream phenomenon, it can lead to unexpected severe vertical/lateral motions and pitching moments, and disastrous effect on flight attendants and/or passengers. Statistics shown that there are hundreds of aircraft injury/death accidents caused by CAT phenomenon.

Flight safety and flying quality both are

extremely important to modern day aviation industry. While the air transportation has become the most important travel way in present days, accidents and incidents still remains, and people begin to pay more attention in flight safety. The factors that cause accidents and incidents could be divided into three kinds: human factor, mechanical failure and the weather. The human factor could be eliminated by well-trained crews, and the mechanical failure could be prevented by well maintenance and quality assurance. But the only hazard that still out of human control is the weather, and the two most hazardous weather phenomena to flight safety/quality are probably the low level wind shear and the high level clear air turbulence (CAT). Due to the large amount of research efforts put into wind shear alert awareness in last fifteen years [1] [2] [3] [4] [5] [6] [7], the wind shear related accidents have greatly reduced. But as the amount of civil aviation transport increase by 6 percent annually, the incidents caused by turbulence phenomenon become more frequent, and the public's expectation in flying quality and ride comfort is also higher than ever before.

Recently, the FAA plan focuses on the critical problems that limit the National Airspace System's capacity, and severe weather en route (i.e. CAT) is still on the list. Clear air turbulence basically could not be seen or predicted. It can only be known by receiving local area flight information broadcast, which means that one or more aircraft already flown into turbulence. In most cases, turbulence brings no harm but only uncomfortable flutter, but in more serious cases, it could causes damage to the aircraft structure and injuries to the passengers. It shows that both aircraft structure and passengers are primary concern of flight safety in modern days aviation.

The weather hazard has become the popular subject for flight safety consideration. In some recent studies, wind field and flight path reconstruction using genetic algorithm and neural network method were developed for accident investigation. For several years, Lu and his students have devote much effort to flight safety studies[8], their focus is on wind field and flight path reconstruction, and the technique is very useful for accident investigation. By acquiring flight data and information from Flight Data Recorder (FDR), they can reconstruct the wind profiles of the turbulence that caused the aircraft crashed. They can also rebuild the flight path of the crashed aircraft. The technique that they used is genetic algorithm, which is a fairly good solution to the optimization problems and will be introduced later. But all their works are focus on low-level wind shear and in landing phase.

There are many studies and researches focus on gust load in last few years, and many organizations like FAA and NASA Langley has published many reports. They focus on gust loads effects on aircraft structure. The gust load means that stresses and aerodynamic forces causes by the gust applied on the aircraft's structure. The aircraft flown through turbulences suffer unsteady gust loads, which may not destroy aircraft immediately. But those extra loads caused by gusts and turbulence may damage the aircraft's structure, which may cause wing or fuselage to fatigue. Thus the durability and damage analyses of an aircraft structure have become major concern, either to validate an existing design or to establish a new design. Generally speaking, the method of analysis for gust load needs gust load spectra, which often measured from the aircraft acceleration during flight.

In the FAA report [9], they use acceleration data from the accelerometer to evaluate the gust load factors. The acceleration data from the accelerometer could be divided into two different signals, one is the acceleration caused by maneuver and the other is caused by gust. What we wish to get is the acceleration caused by gust, then they can develop the wind profiles for acceleration applied on an aircraft. This type of wind profiles is used in our research too.

The gust load is a critical factor to an aircraft. It could apply extra stress on aircraft structure, which causes fatigue and cracks on structure. In most situation, the gust load of an aircraft in within the tolerance range of the original design. However, the maneuvers will apply extra loads on the aircraft structure too. The combination of both loads might exceed the maximum load tolerance of the aircraft. This might cause accidents, even the detrimental in-flight break up. As in the NASA Langley report [10], they focus on the situation we mentioned above, investigate the gust load effects on an Airbus A310 aeroelasticity using nonlinear system theory.

The aviation industry has been developed nearly a century, and the achievement today is admirable. The air traveling in modern days is much safer than twenty years ago, and the accident has been reduced to minimum. The low level wind shear, once being the most terrible hazard to flight safety, can now be avoid by airfield wind shear monitor. But until today, there is still no perfect solution to clear air turbulence. Maybe in the future, with the help of more powerful Doppler radar, we can detect the clear air turbulence ahead, and initiate the avoidance maneuvers before encounter.

In our research, first we will develop the turbulence parameter T_1 to define the turbulence intensity using the similar definition of the gust load. Then using T_2 and T_3 to measure the aircraft's response in linear and angular motions. Finally we will use genetic algorithm (GA) and annealed neural network (ANN) to calculate the optimum avoidance flight path based on T_2 and T_3 information to procure for flight safety and ride comfort.

三、結果與討論

The two different results show that the convergence status of the neural network combined GA method is more efficient and suitable for solving the optimization problems. In this case the objective function is easier to converge and the convergence speed is faster than the GA method. However, we still do not sure that if the convergence speed of GA method could be improved (personally my answer is YES, but the question is how much time would we spent to get a few minutes faster?). What we did in this research is by using the annealed neural networks to speed up the convergence speed, which will shorten the computer time by 25%, but it still takes too much computer time, and still could be reduced theoretically by further use of the annealed neural algorithm and networks.

In Fig 1 we can see the comparison between GA and GA+ANN method. The result shows that the computer cycle is reduced to 69% and the computational time is reduced to 75%, the reason that these two values do not match each other is that the computational time for a single cycle of each method are different. The GA+ANN method takes more time for every single cycle, but it needs fewer cycles to converge. So the summation of time is less than GA method.

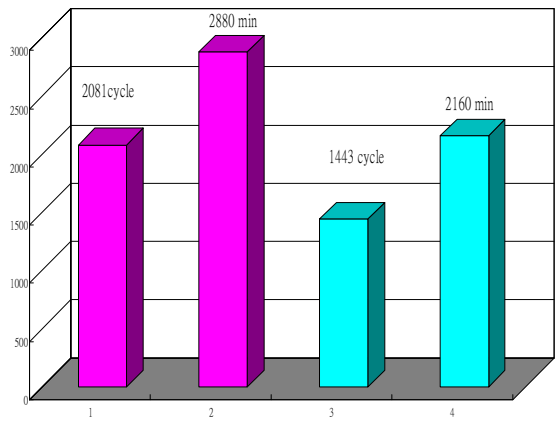

Fig 1 Comparison between GA and GA+ANN efficiency

Basically, the three layers of neurons can solve almost any problems, but in our case, the convergence status is not as good as four layers neurons, so we choose four layers neurons in our program, and because we have four species, with four layers neurons we can get a four by four matrix,

which makes the neural network programming a little easier. And in my opinion, the convergence speed is highly related by the neuron structure, so by improving the neuron structure the convergence speed could even faster. For further improvements, the PC cluster is recommended, which is more efficiency than spent huge work hours in reconstructing the neuron structure. I believe this is the best and easiest way to shorten the computer time. Also, the programming language is an important factor to the computer speed, if someone intent to use this program on a PC cluster, he who must first parallelize this program. This means rewriting this program into FORTRAN or C language which support parallel computing. The MATLAB is not the most efficient language and do not support parallel computing, but it has some toolbox that is useful to GA programming. So it is our first choice to establish this research.

The clear air turbulence is still a hazard to flight safety, we hope that the results of this research could be used in flight simulation or crews training in the future. And mostly, we humbly hope that the concepts or analytical methods developed in this research could be used in the future airborne Doppler radar development and to accomplish the real time avoidance strategy computing.

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