Research on the Continuous Descent Approach (CDA) Operational Error of Pilot Base on Cloud Model and Uncertainty Theory

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Abstract. Through the Cloud model and uncertainty theory research on Continuous Descent Approach (CDA) procedures is a simple and rapid method. This paper analyzed aircraft's required time of arrival (RTA) in CDA process with the Cloud model, meanwhile the six operational errors of pilot were defined. From uncertainty theory, the probability distribution of the CDA operational error of pilot will be faintly determined. Although data for CDA operating experience are sparse in China, further research will continue.

Keywords: Continuous Descent Approach, Cloud model, required time of arrival, operational error, uncertainty theory.

1 Introduction

As an important part of the Next Generation Air Transportation System (NextGen), CDA procedures can be effective at reducing aircraft noise in the airports, meanwhile, results of the experiments of economic and environmental benefits indicate that the CDA provides fuel burn and emissions impact reductions. Although CDA are beneficial for reducing aircraft noise and fuel savings, related uncertainties to these operations can cause terminal area capacity to be reduced. For this reason, CDA arrival routes have only been operated during low-density traffic operations.

Continuous Descent Final Approach (CDFA) is the name of CDA in China, but it was still in the stage of theoretical research. Civil Aviation Administration of China (CAAC) issued advisory circular about CDFA, and put forward the concepts about it. CDFA is a significant technology for civil aviation of China in future.

With the conventional aircraft approach, an aircraft would be given clearance by Air Traffic Control from the bottom level of the holding stack (normally an altitude of 6000 or 7000 feet) to descend to an altitude of typically 3000 feet. The aircraft would then fly level for several miles before intersecting the final 3 degree glide path to the runway. During this period of level flight, the pilot would need to apply additional engine power to maintain constant speed. [1]

In contrast to a conventional approach, when a CDA procedure is flown the aircraft stays higher for longer, descending continuously from the level of the bottom of the stack (or higher if possible) and avoiding any level segments of flight prior to

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intercepting the 3 degree glide path. A continuous descent requires significantly less engine thrust than prolonged level flight. As illustrated in Figure1, because the aircraft flying a CDA is higher above the ground for a longer period of time, the noise impact on the ground is reduced in certain areas under the approach path. [1]

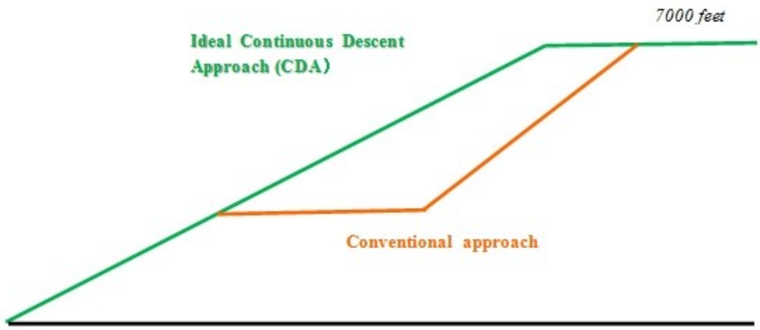

Fig. 1. Comparison between a CDA and a conventional approach

2 Research Model

2.1 The Cloud Model

Cloud model is proposed by Deyi Li who is a member of the Chinese Academy of Engineering to represent the uncertainty transition between qualitative concept and quantitative description in 1995.

Researcher establish a cloud model about the arrival routes of CDA, based on a lot of flight trajectory survey data. Because of the characters of fuzziness and randomness, the required time of arrival (RTA) could be described by a cloud model. From the model, the number of sample set will be increasing and the persuasion of data will be enhancing.

2.2 The Normal Cloud Model

Suppose U is a domain of definition expressed by precise value, in the quantity concept C corresponding to U, there be a stable tended random number to a random element x in the domain of definition, which is defined as follows:

$$\mu : U \to [0,1]$$

$$\forall x \in U, x \to \mu(x)$$

The distribution of x in the domain of definition is called C(X), x is called a cloud drops, and C(X) is combined by many Cloud drops.

Cloud model has three digital characteristics: Expected value (Ex), Entropy (En) and Hyper-Entropy (He), which will integrate the fuzziness and randomness of spatial concepts in unified way. Expected value (Ex) is the center value of concept in the domain of definition, and it's the representative value of the qualitative concept. Entropy (En) is the measuring of the fuzziness of qualitative concept, reflects the numerical range which can be accepted by this concept in the domain of definition, and reflect the uncertain margin of the qualitative concept. The bigger the entropy is, the bigger numerical range can be accepted by the concept. Hype Entropy（He） reflects the dispersion of the cloud drops. The bigger the Hyper Entropy is, the bigger of its dispersion and the randomness of degree of membership.

Backward cloud generator (BCG) is a generator between quantitative values and qualitative concept, which is a mapping mode about backward cloud. A certain number of data be translated into the cloud's digital character C (Ex En, He) which is model as follows. (figue2)

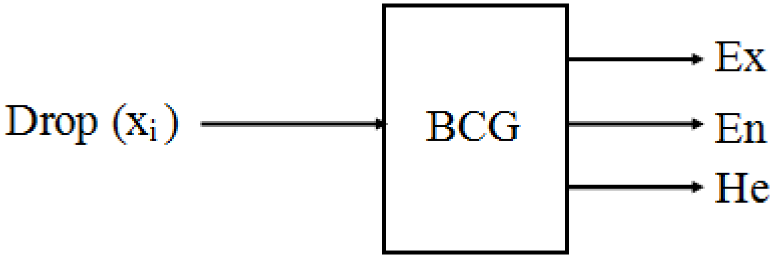

Fig. 2. Backward cloud generator

2.3 Backward Cloud Generator Procedure Code

The input of the backward cloud generator is the quantitative value of N cloud drops Xi, and the output is three digital characteristics Ex, En, He. The backward cloud generator BCG in details is:

INPUT:

Cloud drops $x_i (i = 1, 2, ..., n)$

OUTPUT:

Three digital characteristics Ex, En, He

Algorithm:

(1) Calculate: $Ex = \frac{1}{n}\sum_{i=1}^{n} x_i$

(2) Calculate: $En = \sqrt{\frac{\pi}{2}} \times \frac{1}{n}\sum_{i=1}^{n} |x_i - Ex|$

(3) Calculate: $He=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i-Ex\right)^2-En^2}$

To calculate the errors of required time, system uses four-dimensional (4D) trajectories, which are generated for the estimated times of arrival (ETAs) for both aircraft. Through a lot of experiments calculate each aircraft's required time of arrival (RTA), which a large proportion of RTA be caused by the operational error of pilot.

From the experiments of Federal Aviation Administration (FAA), we know system can calculate each aircraft's required time of arrival with a ground-based sequencer and scheduler. The aircraft's time error and final approach speed would be received through the experiment of FAA. Same aircraft type is the first condition of experiment and the trajectory be selected for the 3∘-CDA arrival routes.

Through the data of FAA, we know the 4,000 assigned RTA errors (100-aircraft streams and 40 repetitions), however, the valid data have only 3,960. The distribution of RTA error are shown in Figure3.

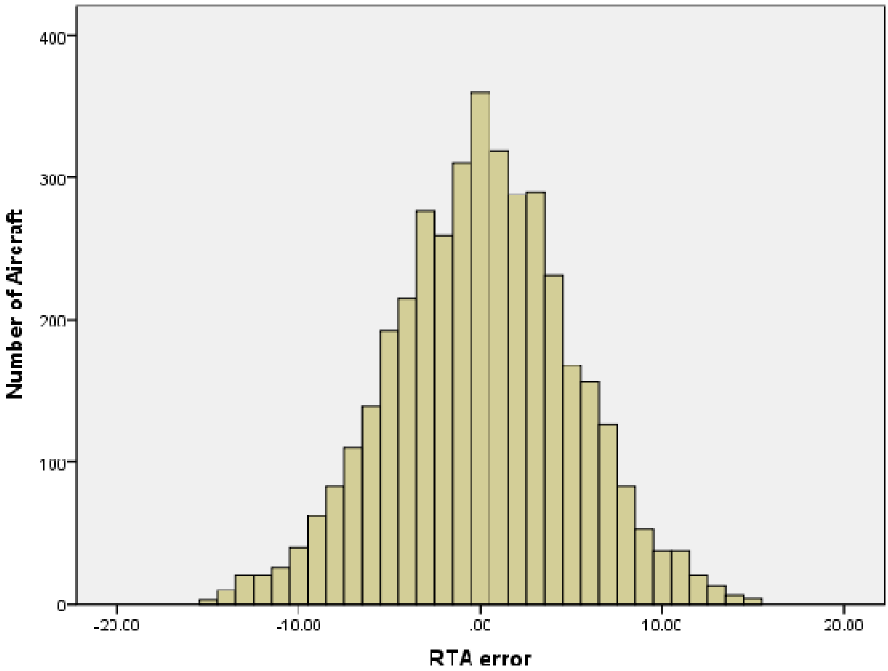

Fig. 3. The distribution of RTA error

Each aircraft of RTA error can be viewed as a cloud drop in the model, which can constitute a trend of error. According to the parameter of model, the figure of cloud model will be established by the matlab, and the procedure code of cloud model as follow.

```
%generate a cloud model(Ex=0.04,En=4.912,He=0.519,n=3960)
Ex = 0.04;
En =4.912;
n = 3960;
cloud_drop=1:n;
u=1:n;
for i=1: n
    cloud_drop(i)=0;
    u(i)=0;
end
He =0.569;
    for i=1: n
        Enn = normrnd(En,He);
        cloud_drop(i) = normrnd(Ex,abs(Enn));
        u(i)=exp(-(cloud_drop(i)-Ex)^2/(2*Enn^2));
    end
    plot(cloud_drop,u,'r.');
    xlabel('RAT error');
    ylabel('Certainty');
```

2.4 The Cloud Model of RTA Error

The trend of cloud model (Ex=0.04, En=4.912, He=0.519, n=3960) is shown in Figure 4.There is an obvious differences between the figure of cloud model and the veritably distribution of RTA error. The histogram of RTA error is only used as a statistical result, those errors would represent just one specific of an aircraft, but the figure of cloud model is a likely trend for the future development. Because the ability of cloud model, we can estimate the trend of RTA error when the aircraft to reach large numbers.

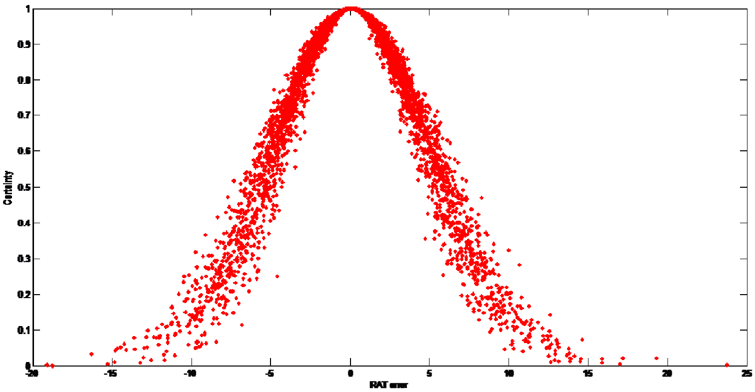

Fig. 4. The cloud model of RTA error (N=3960)

Nowadays, the capacity of terminal airspace increasing is a necessary trend, for example, Tianjin International Airport's aircraft movements reach the number of 100,151 in 2013. To reply the increasing the capacity requirement of terminal airspace, large sample analysis will be used in future study for the RTA error in CDA. The cloud model of RTA error when the number of sample attain10, 000 or50, 000.The model is shown in Figure 5 and Figure 6

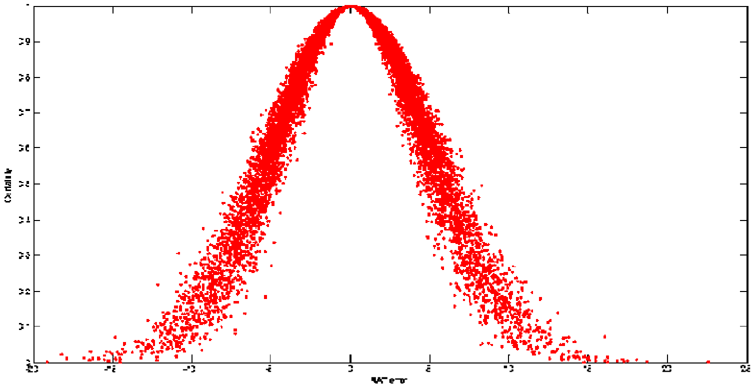

Fig. 5. The cloud model of RTA error (N=10000)

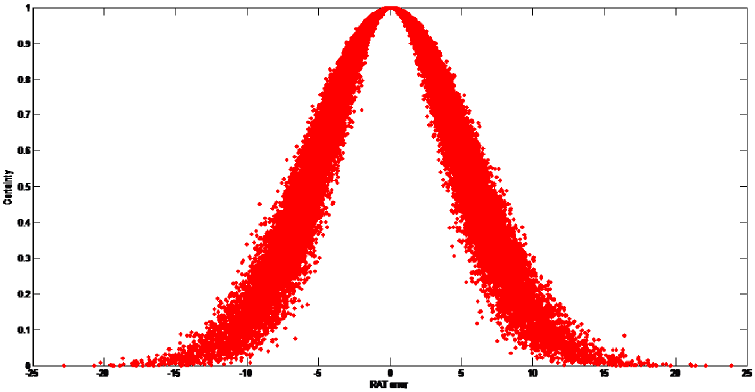

Fig. 6. The cloud model of RTA error (N=50000)

There are a group of cloud drops△X in the dimensional domain U, which is a contribution degree△C for the qualitative concept A, which is defined as follows:

$$\Delta C \approx \mu_A(\mathrm{x}) * \Delta x / \sqrt{2\pi} En$$

Obviously, contribution degree C is a relevant concept about all the element in the dimensional domain the equation C is

$$C = \frac{\int_{-\infty}^{+\infty} \mu_T(x)\,dx}{\sqrt{2\pi}En}$$

For

$$\frac{1}{\sqrt{2\pi}En}\int_{Ex-3En}^{Ex+3En} \mu_T(x)dx = 99.74\%$$

Therefore, all the cloud drops about the qualitative concept included in the interval [Ex-3En, Ex+3En].

2.5 The Risk Layer of RTA Error

According to calculation we know, the percentage of interval [Ex-0.67En, Ex+0.67En] is 53.11% in all the cloud drops, and the percentage of contribution degree about qualitative concept of the interval is 50%, cloud drops in the interval be known as the core of interval. Similarly, the percentage of interval [Ex-En, Ex+ En] is 73.46% in all the cloud drops, and the percentage of contribution degree about qualitative concept of the interval is 68.26%, cloud drops in the interval be called basic interval. The percentage of interval [Ex-2En, Ex- En] U [Ex+ En, Ex+2En] is 22.50%, but the percentage of contribution degree about qualitative concept of the interval is 27.18%, cloud drops in the interval be called outside the range. Meanwhile, the percentage of interval [Ex-3En, Ex-2En] U [Ex+2En, Ex+3En] is 4.04%, but the percentage of contribution degree about qualitative concept of the interval is 4.3%, cloud drops in the interval be called outside the weak range.

According to the theory of cloud scale, a cloud model can be divided into four intervals, the core of interval, basic interval, outside the range and outside the weak range. Because the different of distribution, there is a huge difference that the contribution degree of the four intervals. About the RTA error when operating the process of CDA, we can build four layers, absolute safety layer, basic safety layer, slight danger layer and danger layer. In the course of studies, where absolute safety layer is the core of interval, basic safety layer is basic interval, slight danger layer is outside the range and danger layer is outside the weak range, respective.

Table 1. The risk layer of RTA error

Layer	Interval	RTA Error（s）
Absolute Safety Layer	[Ex-0.67En, Ex+0.67En]	[-3.25,3.33]
Basic Safety Layer	[Ex-En, Ex+ En]	[-4.86,4.96]
Slight Danger Layer	[Ex-2En, Ex- En] U [Ex+ En, Ex+2En]	[-9.78,-4.87]U[4.97,9.87]
Danger Layer	[Ex-3En, Ex-2En] U [Ex+2En, Ex+3En]	[-14.69,-9.79]U[9.88,14.779]

As is shown in Table 1, the critical value of RTA error is - 9.79 seconds, which is a spacing buffer. The buffer can ensure the safety of the process of CDA, it is significant that research operational error of pilot. From the study of cloud model we know that RTA error is an inevitable trend in CDA process, the uncertain RTA error factor may affect precise aircraft spacing at the runway and increase the risk of accident.

3 Research on Operational Error of Pilot

3.1 Operational Error of Pilot

Operational error of pilot is a very significant element in RTA error, this is one reason why reducing the operation of pilot is so important in the process of CDA. Research on possible cause of pilot operational can against inadvertent operation, this type of error can occur for various reasons, such as a pilot accidentally bumps a control when intending to CDA process, or accidentally actuates one control when intending to actuate a different control.

The operational error of pilot in CDA process can be divided into the following categories

- Lack of training
- Fatigue of pilot
- Data entry error
- Slippage Resistance of control
- Habit of pilot
- Communicative disorders

1. Lack of training. The process of CDA is a complex operation for a pilot who lack of specialty training. For ensure the safety of CDA, the pilot need to undertake training activities before execute the process of CDA.
2. Fatigue of pilot. The reason of pilot fatigue has many aspects. Sleep-deprived, disease, and work overload are all included. The research shows that the fatigue will cause such problems as sight, hearing and attention decrease, respond time extension and operation error increase in the CDA process.
3. Data entry error. Because a variety of environments, use conditions, and other factors, pilot may input error data in the CDA process, these abnormal operations will influence the accuracy of CDA process and the safety of approach.
4. Slippage Resistance of control. The physical design and materials used for controls can reduce the likelihood of finger and hand slippage. However, a pilot is likely to slip out of the hand in CDA process.
5. Habit of pilot. Each pilot has its own operating habits, for example, CDA process should be operated by both left-handed and right-handed pilots. If the controls designed to be not operated with left-handed pilot, the probability of making mistakes will be increase a threshold.
6. Communicative disorders. Pilots and controllers were asked to speculate the accuracy meaning of each other, because of the reason of language, information and different meaning, some pilots may be given a wrong meaning in the CDA process.

3.2 Research Prospect of Uncertainty Theory

Uncertainty theory was founded by Liu and refined by Liu. Nowadays the uncertainty theory has become a branch of mathematics for modeling human uncertainty.

First, in order to acquire the data of operational error, we have to invite some domain experts to evaluate their error rate that each human error will occur. Since human beings usually overrate human error, the error rate may have much larger variance than the real frequency. However, the result of uncertainty theory still reflect the situation of the CDA operational error of pilot.

Second, according to the score that domain experts grade on the basis of experience, Set up ξ is an uncertain variables, $\Phi(x; \theta_1, \theta_2 ... \theta_n)$ is a form of uncertain distribution, $\theta_1, \theta_2 ... \theta_n$ is a series of unknown parameter. The data is $(x_1, \alpha_1), (x_2, \alpha_2), \cdots, (x_n, \alpha_n)$from the domain experts, the x, it's going to be the harm extent of the CDA operational error of pilot, the α, it's going to be the probability of operation, then

$$\hat{a} = \left\{ 3 \left[\frac{\alpha_1 + \alpha_2}{2} \mathrm{x}_1 + \sum_{i=2}^{n-1} \frac{\alpha_{i+1} - \alpha_{i-1}}{2} x_i + (1 - \frac{\alpha_{n-1} + \alpha_n}{2} \mathrm{x}_n \right] \right\}^{-\frac{1}{2}}$$

Third, because of the expert's data is$(x_1, \alpha_1), (x_2, \alpha_2), \cdots, (x_n, \alpha_n)$, $\hat{a}$ is the result of computational formula. Similarly, the numeric of $\widehat{b}$ could be calculated. The density of operational error of pilot probability formula, then

$$\Phi(\mathrm{x}; \mathrm{a}, \mathrm{b}) = \hat{a}\, x + \hat{b}$$

Because of the lack of CDA operating experience in China, it is difficult to find the suitable expert to assess the six operational errors of pilot and obtain accurate data, so we unable to get basic data for uncertainty theory in short period of time. Further research will continue.

4 Conclusion

The computed result of the CDA operational error of pilot is an important part of the research about human factor. It's still show great reference significance in the layer of air traffic management. As a process of human-computer interaction (HCI), the operation of pilot is a core direction in the study of civil aviation safety.

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