Realization of obstacle evaluation system for airport clearance area based on MATLAB

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Abstract. As China's civil airport clearance management system is not perfect, the implementation schemes of civil airport clearance management issued by various regional administrations are different, there are many departments involved in clearance management, and the degree of automation and digitization of airport clearance management is low. This paper analyzes the shortcomings of clearance management in China. In view of the difficulties faced by airport clearance management and the lack of effective clearance evaluation software, starting from the basic theory, this paper establishes the mathematical model of obstacle limit surface, and develops a set of obstacle evaluation system in airport clearance area by using MATLAB. An example shows that the accuracy and evaluation conclusion of the system are reliable, the calculation speed is fast and the interface is friendly. It is helpful to promote the transformation of airport clearance management from manual drawing to scientific, digital and intelligent, and has high theoretical significance and practical value to ensure the safe operation of civil aviation.

Keywords: Flight procedure, Airport clearance, Obstacle limiting surface modelling, MATLAB.

1 Introduction

With the development of economy, cities have been further expanded and more and more airports have been built. The contradiction between the safe operation of airports and urban development has become more and more prominent. In 2010, Guangzhou TV Tower was lowered by 14.6 meters due to breaking through obstacles, and the demolition cost was as high as 17 million yuan. In 2012, Mianyang Airport was forced to stop night flights due to the ultra-high Wanda Square. In 2017, Luzhou Lantian airport was "crushed" by the building due to clearance problems and had to be relocated. A series of cases showed the contradiction between urban development and airport clearance management and the difficulty of clearance management. The main reason for the above facts is that there are many departments involved in clearance management. According to the notice on the management measures for clearance audit of construction projects in the clearance area of transport airport issued by the Civil Aviation Administration of China in January 2021 [1], clearance management involves airport management institutions, air traffic control units, airport offices, communication offices, air traffic control offices, meteorological offices and government planning departments, The construction units belong to different competent departments, involving a wide range of disciplines and poor communication. At the same time, China's clearance management level needs to be improved, and there is a lack of appropriate clearance evaluation software. Many factors increase the difficulty of clearance management objectively and subjectively.

Airport clearance protection has attracted more and more attention, and it is also a research hotspot in recent years. Li Qingdong et al. Studied the composition and mutual relationship of civil aviation airport clearance limit surface, and proposed the solution method and clearance planning program of key location points of airport clearance reserve based on Gaussian mean argument [2]. Yang Shu et al. Studied the relationship between obstacle restriction surface and obstacle height requirements of flight procedures, and simplified the evaluation process according to the relationship between them, so as to improve the approval efficiency of construction projects [3]. Wang Wei and others, taking Taiyuan airport as an example, proposed that the traditional clearance area management and prevention is too small to ensure the safe operation of airport flight procedures [4]. Wei Zhiqiang et al. Designed an obstacle evaluation software in takeoff path area from the perspective of aircraft performance, which provides ideas for the development of airport clearance evaluation software [5]. Hao bin used super map to establish the data set of obstacle restriction surface and realized the three-dimensional visualization of obstacle restriction surface in GIS software [6]. Shao Jiaping analyzed the relationship between airport clearance and urban development and put forward suggestions on clearance management [7]. Sheng Yun et al. Analyzed the main factors affecting the clearance environment level, and established the airport clearance evaluation model and evaluation system. Taking Mianyang southern suburb airport as an example, this paper analyzes the risk of obstacles within the clearance protection area of Mianyang Airport, and considers the influence of obstacle density, and establishes the clearance environment grade evaluation system of Mianyang Airport [8, 9].

The above research covers the main problems involved in clearance management and lays a foundation for this research. However, due to the various difficulties of clearance protection, there is also a lack of an effective clearance evaluation system suitable for various institutions. In view of this, combined with the actual needs, this paper develops a set of clearance obstacle evaluation system. The system developed in this paper will help to promote the transformation of airport clearance management from manual drawing to scientific, digital and intelligent, and has high theoretical significance and practical value for ensuring the safe operation of civil aviation.

2 Obstacle restriction surface modeling

The clearance area is an area designated over the airport to ensure flight safety. The traditional clearance area generally refers to the obstacle restriction surface, which is formulated according to annex 14 - airports of the Convention on International Civil Aviation [10].

Different from previous studies, considering the compatibility and scalability of the system. We did not draw the obstacle limit surface directly on the geographic information system, but based on the bottom principle, we established the Cartesian coordinate system with the center of the airport runway as the origin, the magnetic north as the positive direction of the Y axis and the due east as the positive direction of the X axis. In this paper, taking class I precision approach runway with benchmark code of 3 and 4 as an example, the obstacle limit surface model is established.

2.1 Mathematical model of approach surface

According to annex 14 to the Convention on International Civil Aviation - airports, the approach surface is defined as a combination of several planes with a total length of 15000 meters, 60 meters from the runway entrance, an inner edge of 300 meters, a divergence rate of 15%, a length of 3000 meters and a slope of 2%, a length of 3600 meters and a slope of 2.5%, and a horizontal section. It can be expressed by formulas (1) and (2).

$$\begin{cases} 1.4019x - y + 27828 > 0 \\ -0.9667x - y - 46.767 > 0 \\ -0.5088x - y + 37.727 < 0 \\ 1.4019x - y + 1997.6 < 0 \end{cases} \tag{1}$$

$$\begin{cases} 1.4019x - y - 27828 < 0 \\ -0.9667x - y + 46.767 < 0 \\ -0.5088x - y - 37.727 > 0 \\ 1.4019x - y - 1997.6 > 0 \end{cases} \tag{2}$$

The height limit of the approach surface is expressed by formula (3), and are the coordinates of the points to be evaluated.

$$z = \min\left(\frac{|1.4019 * x_o - y_o + 1997.6|}{\sqrt{1.4019^2 + 1}}, \frac{|1.4019 * x_o - y_o - 1997.6|}{\sqrt{1.4019^2 + 1}}\right) \times \alpha \tag{3}$$

Where α is the slope of each section of the approach surface, and the value is as follows:

$$\alpha = \begin{cases} 2\%, & \sqrt{x_o^2 + y_o^2} \leq 4160 \\ 2.5\%, & 4160 < \sqrt{x_o^2 + y_o^2} < 7760 \\ 0, & \text{others} \end{cases} \tag{4}$$

2.2 Mathematical model of takeoff climb surface

According to annex 14 to the Convention on International Civil Aviation - airports, the take-off climb surface is defined as a plane 60 meters from the end of the runway, 180 meters long on the inner side, 12.5% divergence rate, 2% slope, 1200 meters wide and 15000 meters long. It can be expressed by formulas (5) and (6).

$$\begin{cases} 1.4019x - y + 27828 > 0 \\ -0.7133x - y + 1105.5 > 0 \\ -0.7133x - y - 1105.5 < 0 \\ -0.9204x - y - 74.171 > 0 \\ -0.5401x - y + 62.027 < 0 \\ 1.4019x - y + 1997.6 < 0 \end{cases} \tag{5}$$

$$\begin{cases} 1.4019x - y - 27828 < 0 \\ -0.7133x - y + 1105.5 > 0 \\ -0.7133x - y - 1105.5 < 0 \\ -0.9204x - y + 74.171 < 0 \\ -0.5401x - y - 62.027 > 0 \\ 1.4019x - y - 1997.6 < 0 \end{cases} \tag{6}$$

The height limit of take-off climb surface is expressed by formula (7), and x_o, y_o is the coordinate of the point to be evaluated.

$$z = \min\left(\frac{|1.4019*x_o - y_o + 1997.6|}{\sqrt{1.4019^2+1}}, \frac{|1.4019*x_o - y_o - 1997.6|}{\sqrt{1.4019^2+1}}\right) \times 2\% \tag{7}$$

2.3 Mathematical model of conical surface

According to annex 14 to the Convention on International Civil Aviation - airports, a conical surface is defined as a surface inclined upward and outward from the periphery of the inner horizontal plane, with a slope of 5% and a final height of 100m. It can be expressed by formulas (8) and (9).

$$\begin{cases} (x+859.5271)^2 + (y-638.7733)^2 - 6000^2 < 0 \\ (x-859.5271)^2 + (y+638.7733)^2 - 6000^2 < 0 \\ -0.7133x - y - 7370 < 0 \\ -0.7133x - y + 7370 > 0 \end{cases} \tag{8}$$

$$\begin{cases} (x+859.5271)^2 + (y-638.7733)^2 - 4000^2 > 0 \\ (x-859.5271)^2 + (y+638.7733)^2 - 4000^2 > 0 \\ -0.7133x - y - 4913.3 > 0 \\ -0.7133x - y + 4913.3 < 0 \end{cases} \tag{9}$$

The height limit of conical surface is expressed by formula (10), and x_o, y_o is the coordinate of the point to be evaluated.

$$z = 45 + \left[\min(d_0, d_1, d_2) - 4000\right] \times 5\% \tag{10}$$

In equation (10), d_0, d_1 and d_2 respectively represent the distance from the obstacle to the north end, center and south end of the runway, and are represented by equations (11), (12) and (13).

$$d_0 = \sqrt{(-895.5271 - x_o)^2 + (638.7733 - y_o)^2} \tag{11}$$

$$d_1 = \sqrt{x_o{}^2 + y_o{}^2} \tag{12}$$

$$d_2 = \sqrt{(895.5271 - x_o)^2 + (-638.7733 - y_o)^2} \tag{13}$$

2.4 Mathematical model of inner horizontal plane

According to annex 14 to the Convention on International Civil Aviation - airports and Part 6 of the airport service manual [11] (DOC 9137), the horizontal plane is defined as one of the horizontal planes above the airport and its surroundings, with a height of 45 meters. It can be expressed by formula (14).

$$\begin{cases} (x+859.5271)^2+(y-638.7733)^2-4000^2<0 \\ (x-859.5271)^2+(y+638.7733)^2-4000^2<0 \\ -0.7133\text{x}-\text{y}-4913.3<0 \\ -0.7133\text{x}-\text{y}+4913.3>0 \\ -0.5088\text{x}-\text{y}+37.727<0 \\ -0.9667\text{x}-\text{y}-46.767>0 \\ 1.4019\text{x}-\text{y}+1997.6<0 \\ -0.5088\text{x}-\text{y}-37.727>0 \\ -0.9667\text{x}-\text{y}+46.767<0 \\ 1.4019\text{x}-\text{y}-1997.6>0 \end{cases} \quad (14)$$

The height limit of the inner horizontal plane is expressed by formula (15). Since the inner horizontal plane is a plane with a height of 45 meters, the height limit of any point in the plane is 45 meters.

$$z=45 \quad (15)$$

2.5 Mathematical model of transition surface

According to annex 14 to the Convention on International Civil Aviation - airports, the transition surface is defined as a composite surface inclined upward and outward to the inner horizontal plane along the slope of the edge of the landing strip and part of the approach surface. Considering that the internal approach surface, internal transition surface and lifting belt are not involved in the actual evaluation, these planes are integrated with the transition surface in one plane when modeling the transition surface, and these surfaces are "not excavated". The mathematical model of the transition surface is expressed by formula (16).

$$\begin{cases} 0.7133\text{x}-\text{y}+586.53>0 \\ 0.7133\text{x}-\text{y}-586.53<0 \\ -0.5088\text{x}-\text{y}+37.727>0 \\ -0.9667\text{x}-\text{y}-46.767<0 \\ 1.4019\text{x}-\text{y}+1997.6>0 \\ -0.5088\text{x}-\text{y}-37.727<0 \\ -0.9667\text{x}-\text{y}+46.767>0 \\ 1.4019\text{x}-\text{y}-1997.6<0 \end{cases} \quad (16)$$

The height limit of the transition surface is expressed by formula (17), and x_o, y_o is the coordinate of the point to be evaluated.

$$z = \max(100 - 14.3\% \times \frac{|-0.7133x_o - y_o - 586.53|}{\sqrt{0.7133^2 + 1^2}}, 100 - 14.3\% \times \frac{|-0.7133x_o - y_o + 586.53|}{\sqrt{0.7133^2 + 1^2}}) \quad (17)$$

3 Implementation of obstacle evaluation system in clearance area

According to the mathematical model established in part 2 of this paper, we convert obstacle evaluation into linear programming. The first step is to judge whether the obstacle is in the limiting surface, that is, to judge whether the obstacle coordinates (x, y) are the solutions of each limiting surface expressed by the linear equations. If it is a feasible solution, it is in the surface, otherwise it is outside the corresponding limiting surface. The second step is to calculate the limit height according to the height limit equation of the corresponding limit surface, and then compare it with the obstacle height to draw the corresponding conclusion, which is programmed by MATLAB. The principle of the evaluation system is shown in Figure 1 as follows.

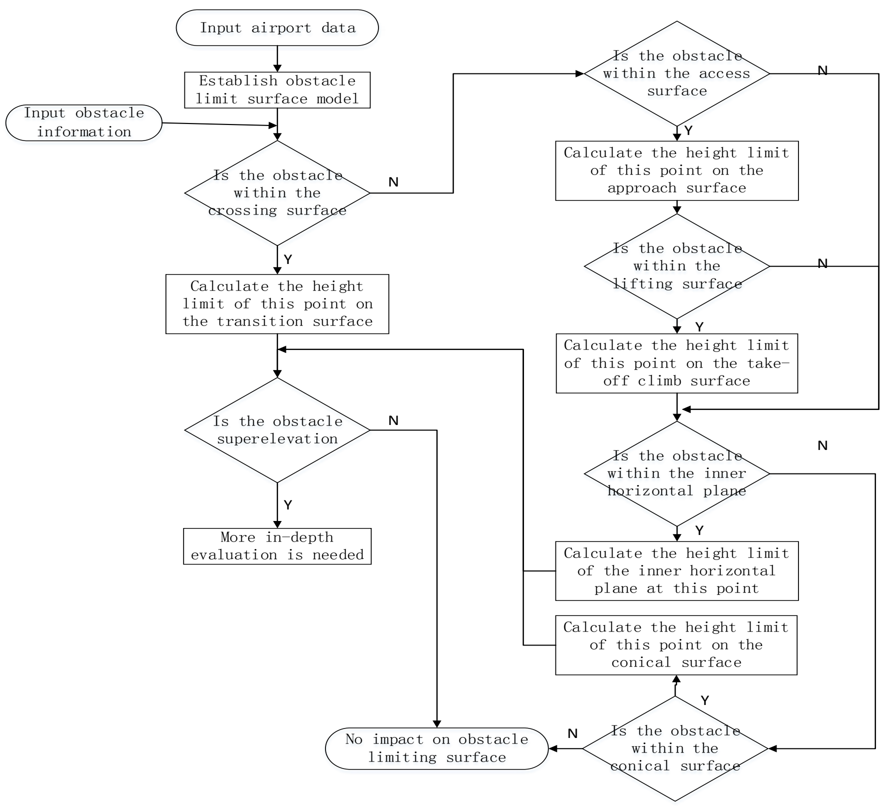

Fig. 1. Schematic diagram of obstacle height control.

Use matlab to draw the linear equations corresponding to the obstacle limit surface, as shown in the left half of Figure 2, and the right half of Figure 2 is drawn manually by AutoCAD. As can be seen from Figure 2, there is no difference between the obstacle limit surface parameterized by the mathematical model and the obstacle limit surface manually drawn by AutoCAD, which can be used for obstacle evaluation in the clearance area.

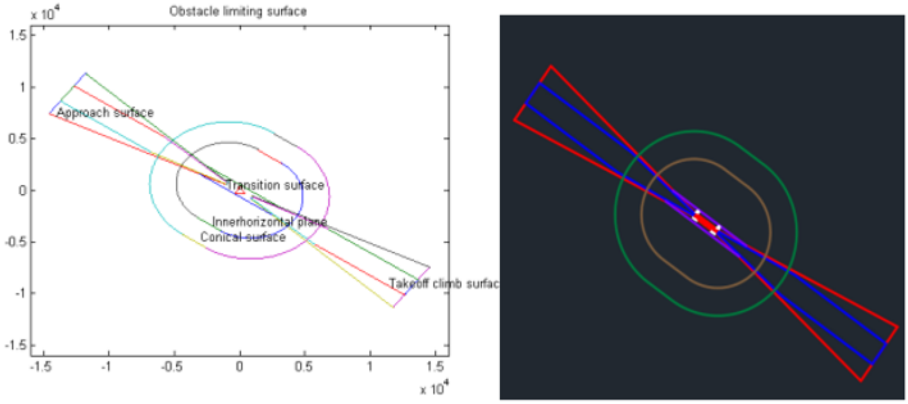

Fig. 2. Comparison of obstacle restriction surfaces.

4 Example verification

In order to verify the reliability of the mathematical model and software system proposed in this paper, we randomly select two obstacles for manual evaluation through AutoCAD drawing and the clearance evaluation system developed in this paper.

The magnetic orientation of an airport runway is 127°~307°, and the runway is 2200 meters long. There are two obstacles at the north end of the runway, 435.5198 meters and 4527.7202 meters away from the extension line of the runway center, 2110.8104 meters and 2134.3108 meters away from the extension line of the runway north end, and the obstacle heights are 51.4 meters and 82.6 meters respectively. We record them as obstacle A and obstacle B respectively. According to the coordinate system established in the second part of the article, the coordinates of obstacles can be expressed as a (- 2319.7246, 2189. 6041) and B (- 3.8421, 5564. 2611).

4.1 Matlab automatically evaluates obstacles

As shown in Figure 3, using the obstacle evaluation system in the airport clearance area developed in this paper, you only need to input the obstacle coordinates and height information in the system and click to run to get the evaluation results and picture display. It has fast calculation speed and convenient operation.

4.2 Manual evaluation of obstacles

At present, the evaluation of obstacles in the clearance area by civil aviation management agencies, design units and consulting companies is mainly divided into the following four steps: first, draw the obstacle limit surface with AutoCAD; Then, draw the obstacles on the basis of the previous drawing; The third step is to manually check the position relationship between the obstacle and each restriction surface, and finally calculate the height limit of the obstacle surface, and give the evaluation conclusions and suggestions.

Draw the obstacle restriction surface and obstacle with AutoCAD, as shown in Figure 4. Obstacle A is located on the approach surface and obstacle B is located on the conical surface.

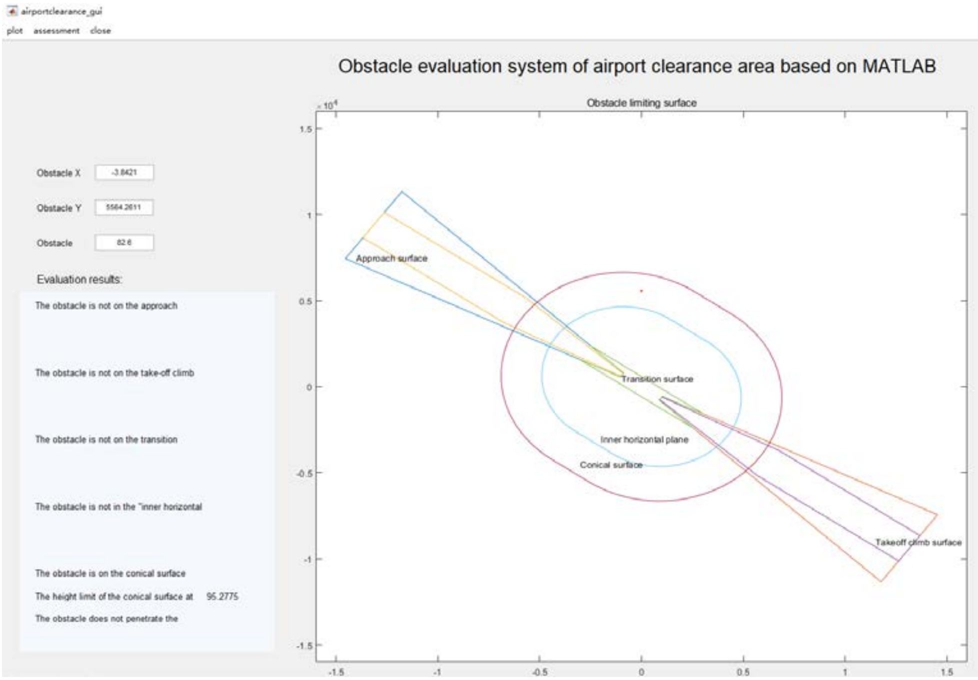

Fig. 3. Obstacle evaluation of airport clearance area based on MATLAB.

Obstacle A is located in the approach plane and inner horizontal plane. The distance from the inner edge of the approach surface is: 2060.0333 - 60 = 2000.0333 meters, less than 3000 meters. The fault obstacle A is located in the first section of the approach surface, where the height limit of the approach surface is: 2000.0333 * 2% = 40.0006 meters; The inner horizontal plane is a plane with a height of 45 meters, and the height limit here is 45 meters; Therefore, obstacle a breaks through the approach plane and inner horizontal plane.

Obstacle B is located on the conical surface, which is a surface inclined upward and outward with a gradient of 5% from the periphery of the inner horizontal surface. Through AutoCAD measurement, obstacle B is 1105.8546 meters away from the outer boundary of the inner horizontal surface, and the height limit of the conical surface at this point is: 45 + 1005.5502 * 5% = 95.2775 meters. Therefore, obstacle B does not break through the conical surface.

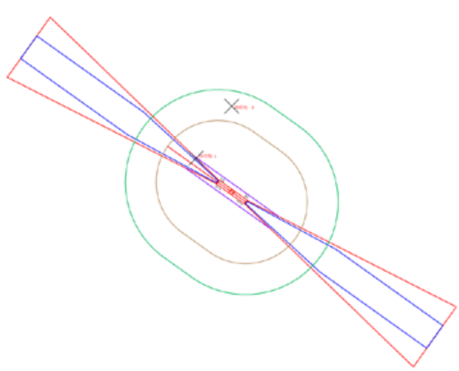

Fig. 4. Location relationship between obstacles and Airport.

5 Summary

Airport clearance protection is very important for flight safety. With the development of civil aviation transportation business and the demand for land and high-rise buildings in urban construction, the contradiction between airport clearance protection and urban development is becoming more and more intense. Aiming at the problems of wide range, great difficulty and high professional requirements of clearance protection, this paper establishes the mathematical model of obstacle restriction surface from the bottom principle. Using MATLAB programming, a set of airport clearance obstacle evaluation system is developed. An example shows that the system can evaluate obstacles accurately and quickly. Compared with the current evaluation methods, it has the advantages of fast, convenient and error proof, and does not require too much professional knowledge for operators. The system reduces the complexity of airport clearance evaluation, avoids cumbersome obstacle inspection and human errors, can effectively improve work efficiency and improve clearance management level.

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