Research on Measuring Method of RVSM Regional Waviness

Wang Ru
Shanghai Aircraft Design and Research Institute, SADRI, Shanghai, China
E-mail: wangru@comac.cc

Abstract—The increased accuracy of RVSM (Reduced Vertical Separation Minimum) can increase the flight level and airspace capacity of the aircraft, optimize the route, improve the operational efficiency of the aircraft, and improve the operating efficiency of the airline. The skin waviness near the aircraft's full static pressure probe has an important effect on RVSM. This article mainly studies several methods that can be used to measure the aircraft skin waviness, including advanced optical methods and spline curve method based on field work experience. In addition, the article also compares the advantages and disadvantages of these methods.

1. Introduction
RVSM (Reduced Vertical Separation Minimum) is the minimum vertical separation standard in the airspace where RVSM is allowed to be used. The vertical separation standard between 29,000 feet (8,850 meters) and 41,000 feet (12,500 meters) is reduced from 2000 feet to 1,000 feet [1]. The number of flight levels in this space range has been increased from 7 to 13. The flight activities carried out according to such standards are called RVSM operations.

There are many advantages in reducing the vertical separation. First it can increase the flight level and airspace capacity in the available space, the route is optimized, and the operational efficiency of the aircraft is improved. Second, the standard is helpful for airlines to reduce flight delays. Third, it is beneficial to Airport control personnel deploy flight conflicts to reduce the workload of air control. Fourth, that will improve the efficiency of jet fuel utilization to save fuel and protect the ecological environment. Fifth, it connects domestic airline with international airline networks to reduce the difficulty of transitioning from non-RVSM areas to RVSM areas, and reduce probability of accidents [2].

2. The effect of skin waviness on RVSM
Waviness, known as waviness, is one of the shape error components that form the surface features of workpieces or parts. In the aviation industry, it refers to those caused by the influence of factors such as pressure and deformation when the parts are stretched or heat-treated during the processing process, and they are periodically repeated on a surface of the workpiece in a certain wave shape. The contour height and spacing of a smaller shape error are larger. Small, generally between macroscopic geometric shape error and roughness. Waviness is the main parameter for checking the undulation of the outer surface of the aircraft, reflecting the macroscopic state of the undulation of the outer surface of the aircraft, as shown in Fig. 1. The length of the wavelength L, the minimum half-wavelength X (that is, the minimum distance between the valley point and the two nearby peak points) and the intensity of the wave (slope) K=B/X, giving the tolerance of the amplitude B and the slope K to check the control.
undulations on the outer surface of the plane. The magnitudes of the amplitude B and the slope K directly reflect the waviness of the outer skin of the aircraft.

![Figure 1. Schematic diagram of waviness](image)

RVSM operation requires that the aircraft can measure the flight altitude of the aircraft accurately by itself, which requires that the static pressure probe will not be greatly affected when measuring air pressure. The errors which influence aircraft altitude measurement include systematic errors and manufacturing deviation errors. The manufacturing deviation error includes the manufacturing installation error of the airspeed tube and the manufacturing deviation of the body surface skin. In the case of the body shape without a large overall deviation and a large step difference, the manufacturing deviation of the body surface generally manifests as no near the theoretical shape Regular fluctuation, that is, the ripple phenomenon on the surface of the body, the concept of measuring the ripple phenomenon is called waviness. Near the static pressure probe (the RVSM area is shown as Fig. 2), the waviness on the surface of the airframe affects the quality of the airflow nearby and affects the air pressure measurement, which leads to errors in flight height measurement. In order to ensure the accuracy of height measurement, the waviness of RVSM area must be controlled.

![Figure 2. RVSM area of an aircraft](image)

### 3. Measuring method of skin waviness

At present, the fuselage skin of the RVSM area of various types of aircraft at home and abroad is mainly a single-curved shape or plane, and the waviness measurement is only to measure the distance between the outer surface of the skin and the measuring scale to reflect the fuselage The waviness of the skin. Several methods of measuring waviness introduced in this article are mainly for airplanes with a hyperbolic profile in the RVSM area of the fuselage skin.

#### 3.1 Optical photography

In the process of measuring waviness using optical photography, how to choose the measurement software and how to process and analyze the various data obtained by measurement is a very important link. In all kinds of CAD software, all kinds of spline curve functions can be realized. For the spline curve envelope based on the measured shape data of the aircraft skin, so as to accurately analyze and check the shape and obtain the specific data of the shape waviness, offers the possibility.

First of all, the outer skin of RVSM area is measured by optical photographing scanning instrument to obtain the shape data, photographic measurement uses the MAX scan laser scanning and photogrammetric system for positioning, and EXA scan self-positioning reference point technology.
scanning system for surface scanning (see equipment for Fig. 3), the data collected by the measurement is transferred to the CATIA system through a special data interface to generate a data point cloud.

![Image](image1.png)

Figure 3. Optical photogrammetry instruments

Use the software function of the optical measuring instrument to divide the point cloud data into several segments at a certain interval, using multiple planes parallel to the horizontal plane. The point cloud data obtained by the segmentation is the actual situation of the skin at the location (as shown in the Fig. 4). After the point cloud data is cut, the actual roughness of the resulting skin is shown in Fig. 5 and table1. Perform artificial convex hull analysis on the data cloud line to extract the convex hull feature points, then use the spline method to generate the curve, and use the point cloud analysis function to analyze the points The distance between the cloud and these curves, the valley far away from the curve is the peak, and the peak close to the curve is the peak depth, and the distance between the peaks is judged as the depth of the valley, that is, the amplitude B, as the wavelength L, and the depth and wavelength of the valley are recorded. The slope can be calculated K, through the above data to analyze the waviness of the aircraft shape.

![Image](image2.png)

Figure 4. Point cloud and cutting plane obtained by optical instruments

![Image](image3.png)

Figure 5. Projection after a cutting line
Table 1. Point cloud data

| Measuring point | 3D deviation | Theoretical value | Measured value |
|-----------------|--------------|-------------------|----------------|
|                 | X            | Y                 | Z              | X              | Y           | Z               |
| A               | 0.097        | -1157.672         | 1176.97        | -50            | -1157.763   | 1176.938        | -50             |
| B               | 0.058        | -1245.443         | 2038.56        | -50            | -1245.46    | 2038.56         | -50             |
| C               | 0.173        | -1056.586         | 1055.74        | -50            | -1056.747   | 1500.685        | -50             |

Considering the measurement accuracy, the accuracy of photographic scanning method is much higher than the general physical measurement. However, because of the high cost of the measuring instrument, the operation process and the analysis process are too cumbersome, the measurement method is not suitable for many times in the production process. Measuring and widely used, accurate measurements can only be made when the final product is delivered or when high accuracy is required to ensure the skin's waviness requirements.

### 3.2 Spline curve method

The spline originates from the production practice of ship and aircraft manufacturing. It was originally a tool for drawing the shape curve. It is generally a flexible thin strip. The spline is pressed to a series of specified types of value points (interpolation points) by iron weight and then we trace the curved shape line of the spline as drawing, this curve is called the spline curve.

The spline curve has very good convexity retention and supportability (shown as Fig. 6). It is widely used in aircraft shape design. Due to the convexity-preserving characteristics of the aircraft's profile design, it is naturally associated with the spline when performing the waviness inspection of the aircraft's manufacturing profile. Facts have proved that the good shape fits the spline well while the uneven shape can be clearly checked. After finding the concave and convex characteristics of the shape of the aircraft skin, you can use the ruler to determine the gap between the outer skin of the aircraft and the spline, so as to determine the amplitude data of the aircraft skin. It is the most suitable and convenient as well as simple method to check the waviness in aviation manufacturing by using spline method to check waviness in process of production. It has been used in western countries and the former Soviet Union for a long time.

![Figure 6. Conservation of splines](image)

Plexiglass is generally used as the raw material for the production of splines in the production site. This material generally only produces elastic deformation and is easy to bend. So, it is easy to fit with the aircraft skin as well as with certain rigidity. Generally, a plane parallel to the structural horizontal plane is selected at a certain distance in the RVSM area, and the two ends of the spline are attached to the skin surface along the measurement section. The end of the spline is compressed firstly, and then the spline is smoothed along the measurement section to make sure the spline clings to the skin. After smoothing, press both ends of the spline and the skin tightly and use certain lateral force on both ends to make the spline fit better with the aircraft skin (as shown in Fig. 7). With using a wedge feeler gauge to measure the spline and the skin and The maximum gap of the skin is recorded as the maximum amplitude of the profile, the contact point of the skin and the spline corresponding to the maximum...
amplitude is marked, the surface distance between the two contact points is measured, and the wavelength corresponding to the maximum amplitude of the profile is recorded.

![Spline measurement method](image)

Figure 7. Spline measurement method

Compared with the laser scanning measurement method, the spline measurement method has a lack of achievable accuracy. If it is necessary to accurately reflect the waviness of the fuselage skin, this method cannot be achieved, and only the laser scanning measurement method can be used. However, the spline measurement method also has its own advantages. It can be easily implemented in field operations, and can also intuitively reflect the problems of skin waviness, which is suitable for multiple simple operations on the production site.

3.3 Short steel ruler measurement

Due to the special structural form of dense frame structure in some aircraft RVSM areas, it will have a short wave length ripple on the fuselage skin. In view of this situation, the spline measurement method was modified to develop a method similar to the spline curve method, which is more practical and more convenient to operate in the actual situation, the steel ruler measurement method.

This method is to use 300mm or 150mm steel ruler to quickly measure the position of the fuselage skin that may have amplitude, and obtain the rough measurement data of the fuselage skin waviness in the shortest possible time. This method also takes into account the spline measurement method. At the same time, it also simplifies the operation process for the special structure of certain aircraft. However, this method has a relatively small scope of application, and can only be applied to the skin surface of a dense frame structure, and the measurement accuracy is not high, and only a rough measurement can be performed.

4. Conclusion

The above-mentioned methods for measuring the waviness on the surface of the fuselage can be adjusted and selected according to the actual situation on the site. At the same time, the existing resources can be tapped, and the theoretical knowledge and production practice can be combined to measure the RVSM area waviness in the production process. The measurement is more convenient and more accurate, so as to ensure that the height measurement of the aircraft in the sky is also more accurate, and the RVSM operation is truly realized.

References

[1] YuJingyu, LuYao and ShuXiaohua, “A survey of the RVSM flight in Chinese civil aviation,” in Proceedings of 2010 Annual Conference on Aircraft Airworthiness and Air Traffic Management, 2010.

[2] WuYong, ZhangXu and YangYing, “RVSM (reduced vertical separation minimum),” in Intelligence, vol. 27, pp. 68–69, 2012.