White Paper

Wind Load Test and Calculation of the Base Station Antenna

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PROSE

CONTENTS

Abstract

In recent years, with the rapid development of technology in the telecommunication industry, wireless mobile communication technology has been rapidly deployed all over the world. In order to solve the complexities between the supply and demand of wireless mobile data, new technologies have emerged to meet the growing demand for mobile data, such as new spectrum bands, new cellular technologies (i.e., LTE), and multi-antenna technologies (i.e., MIMO). However, this also leads to more antennas installed in a base station tower. Additionally, antenna becomes more integrated and more complicated as more frequency bands and ports are required in each antenna. This inevitably leads to a bigger antenna that increases the antenna wind load.

Most radomes have a rectangular or semi-rectangular cross-sectional shape. When the wind flows around the radome surface, a vortex and wind flow separation will be generated, resulting in complex aerodynamics, which will make the base station antenna vibrate. Most base station antennas are installed on a steel structure single tube communication tower because it has a small footprint, less land area required , and relatively fast construction compared to other tower structure. However, it is a less rigid structure and has a large horizontal displacement capacity on the tower top. The base station antenna is usually installed at a high elevation, where the wind speed is higher, and vortex-induced vibration is more likely to occur.

Therefore, wind load is an important parameter in the structural design of the base station antenna and determines the configuration of the tower and the auxiliary support structure. It directly affects the reliability of the antenna application and the safety of the tower. The accuracy of the antenna wind load calculation affects the tower safety and the economic impact of the project.

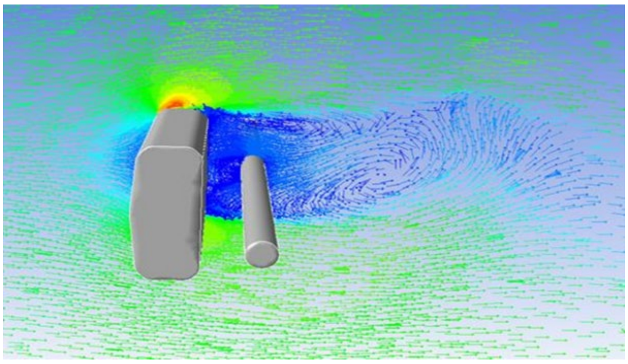


Figure 1 Karman vortex street

Figure 2 Communication tower

Prose, having accumulated decades of experience in the antenna industry, and realizing the importance of wind load very early, has worked diligently to reduce the wind load of the base station antenna. The BASTA V11.1 standard specifies the new wind tunnel test method and calculation method for the base station antennas. Prose also carries out wind tunnel testing according to the new BASTA V11.1 standard and updated the wind load calculation method in all our technical documentation. This white paper will discuss Prose's wind tunnel test process and how wind load data is updated to ensure most accurate value.

Wind Load Calculation

Generally, there are three methods to obtain the wind load of an antenna: standardized calculation, wind tunnel testing, and Computational Fluid Dynamics (CFD) simulation.

1. Standardized calculation

Standardized Calculation is a recognized and reliable method to calculate the wind load. The calculation according to the standard is to understand the major factors of the problem, establish the theoretical model, and then use mathematical tools and methods to solve equations to reveal the inherent laws of the various physical phenomena involved. This method is limited by mathematical tools and solving methods. If the physical properties and boundary shape of the problem are complex, a simplified model can only be established, and it is difficult to obtain results that simulate the actual situation. Therefore, wind load results based on standards are often too conservative.

2. Wind tunnel testing

The wind tunnel test simulates the environment similar to the actual natural environment of the product. Therefore, the wind tunnel test method is also the most accurate of the three calculation methods. It can carry out the research work under almost the same conditions as the research problems, and the results are intuitive and reliable. The disadvantages of this method are that the experimental period is long, the cost is high, and the acquisition of airflow field information in the wind tunnel is very difficult, so it is impossible to study the complex airflow phenomena and related mechanisms in detail.

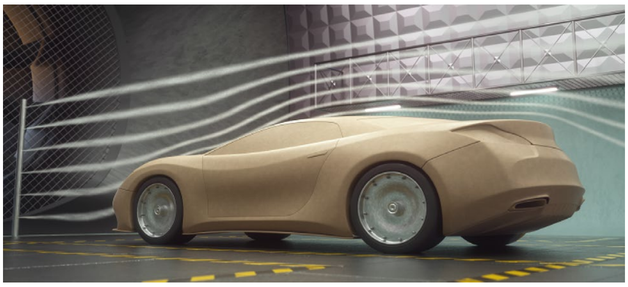


Figure 3 Vehicle wind tunnel test

3. CFD simulation

In recent years, with the development of computer software and hardware, high-quality aerodynamic numerical simulation has become possible, and this method has become more and more popular. Compared with the traditional wind tunnel test method, CFD has the characteristics of having a short cycle, low cost and wide application range. This method can overcome the influence of wall interference, support interference, model elastic deformation, flow field quality and other objective factors in the wind tunnel experiment. It can also visually simulate the whole flow field, reveal the nature of the flow clearly, and provide the direction for further theoretical analysis and experimental research. Therefore, CFD simulation method is a faster and more economical way to optimize the design of the antenna. However, numerical simulation also has some limitations. This method is a discrete approximation calculation method. The accuracy of the simulation depends on the selected turbulence model and numerical algorithm, and it also depends on the corresponding initial conditions, boundary conditions and the processing of parameters in the mathematical model.

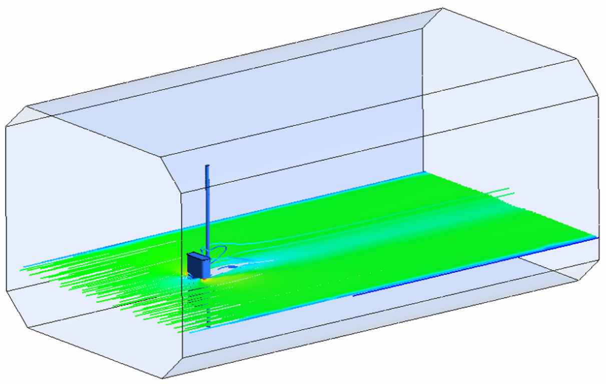


Figure 4 CFD simulation of the antenna

To summuarize the three methods of wind load calculation have their advantages and disadvantages. The formula in the calculation standard is the summary of previous experimental rules, which can guide the wind tunnel experimental research and numerical simulation. The wind tunnel test is the basis for establishing the motion law and theoretical model, and the correctness and reliability of the standard calculation formula and numerical simulation results are verified. Numerical simulation enhances the ability of wind tunnel experimentation and also enriches and perfects the method of studying antenna aerodynamics.

Prose wind load calculation is not limited to one method. All three methods are used in designing the antenna to have an optimized wind load. Prose uses EN1991-1-4 to calculate the wind load. To solve the problem of the calculation being too conservative, wind tunnel test data is used to adjust the parameters. CFD simulation is used to optimize and reduce the wind load of the antenna. In order to solve the limitation of the the CFD simulation requires experience for its settings, the simulation is calibrated by comparing with the wind tunnel results, greatly improving the accuracy of the simulation.

The standard for Prose wind load calculation

There are two standards for calculating the wind load: European standard EN 1991-1-4 and North American Standard ANSI / TIA 222. In the ANSI / TIA 222 standard, the antenna is regarded as an addition, and only the flat and cylindrical antenna forms are considered in the calculation of the wind load. However, EN 1991-1-4 takes into consideration the influence of the antenna round shape, so the wind load calculation is more accurate.

The wind load of the antenna can be calculated by the following formula：

$$F_w = 0.5 \cdot \rho \cdot (C_{dp} \cdot \psi_\lambda) \cdot v^2 \cdot A$$

Where：F_w is the wind load of the antenna. ρ is the air density, which depends on the local altitude, temperature and atmospheric pressure. C_{dp} is the shape drag coefficient, which can be estimated according to the standard or by wind tunnel testing. This value is a parameter that characterizes the aerodynamic characteristics of the cross-section. If the shape of an antenna section is more in line with the aerodynamic characteristics, C_{dp} will also be smaller. ψ_λ is the end-effect factor, which can be calculated according to EN1991-1-4 or ANSI / TIA 222 standard. This value can be used to calculate the wind load of the antennas with the same section but different lengths. v is the air velocity, which is related to terrain roughness, height, season and many other factors. According to the BASTA standard, the calculated wind speed of the antenna industry is 150 km / h. A is the windward projected area, equal to the projected area of the cross-section perpendicular to the direction of the airflow.

In practical engineering, the most important index to judge whether the design of an antenna conforms to the required aerodynamic characteristics is the drag coefficient C_d. The smaller the value is, the less the wind load is. The conversion relationship between the drag coefficient C_d and the shape drag coefficient can be expressed as follows:

$$C_d = \psi_\lambda \cdot C_{dp}$$

The wind load of the antenna can also be calculated by the following formula:

$$F_w = 0.5 \cdot \rho \cdot C_d \cdot v^2 \cdot A$$

Among all the parameters of the formula for calculating antenna wind load, only the calculation of the drag coefficient C_d is not clear. To be more specific, the shape drag coefficient C_{dp} is not defined. The value can be calculated by EN1991-1-4 or ANSI / TIA 222 standard, wind tunnel test or CFD simulation.

In the EN1991-1-4 standard, the shape drag coefficient C_{dp} can be calculated as follows:

$$C_{dp} = C_{f0} \cdot \psi_r$$

Where: C_{f0} is the force coefficient for rectangular sections with sharp corners and without free end flow. The calculation method is shown in Figure 5. ψ_r is the reduction factor for a square cross-section with rounded corners. The calculation method is shown in Figure 6. For end-effect factor ψ_λ. It can be calculated according to Figure 7.

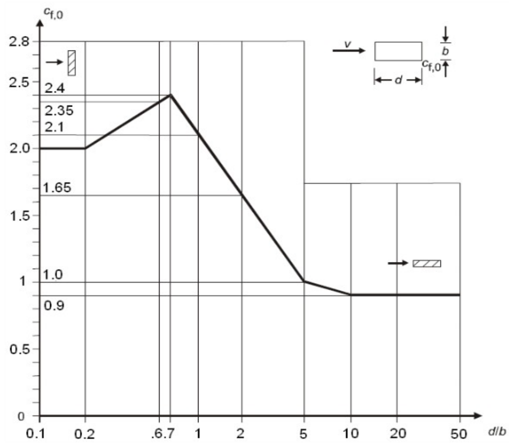


Figure 5 Force coefficient for rectangular sections with sharp corners and without free end flow

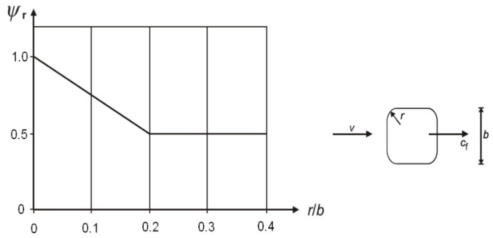


Figure 6 Reduction factor for a square cross-section with rounded corners

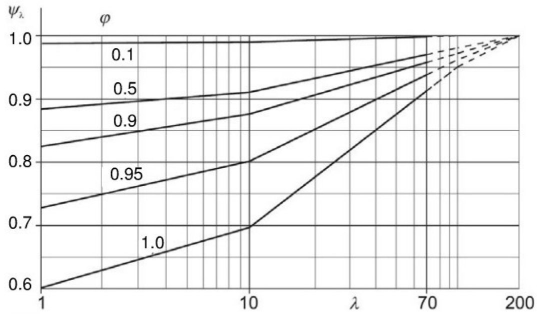


Figure 7 Indicative values of the end-effect factor

Wind tunnel test based on BASTA standard

Prose conducted the wind tunnel test of the antenna in the wind tunnel laboratory of Jilin University and completed this according to the wind tunnel test report provided by Jilin University. The wind tunnel laboratory is an open wind tunnel, which is more in line with the characteristics of natural wind. The wind tunnel has a low blocking ratio, so there is no need to modify the blockage ratio. The influence of the blockage effect on the wind tunnel test is described in detail in the appendix. The wind tunnel test is in accordance with BASTA V11.1. In addition to completing the force measurement experiment, Prose also carried out pressure measurements and Particle Image Velocimetry (PIV) experiments in order to better study the aerodynamic characteristics of the antenna and optimize the radome with lower wind load.

1. Force measurement experiment

The force balance is a key measurement to measure the wind load of the antenna. The overall accuracy of the balance sensor and data acquisition system is better than 0.05% F.S. (F.S.: full scale), which ensures the accuracy of measurement results.

As shown in Figure 8 and Figure 9, the antenna is vertically installed on the pole with a mechanical downtilt of 0°. The diameter of the pole is 100 mm. The distance between the bottom of the antenna and the bottom of the wind tunnel is 300 mm, and the top is leveled with the top of the pole. The test wind speed is 150 km/h with a 360° range. Due to the symmetry of the antenna structure, only the data with a rotation of 0-180 ° is needed. After the airflow is stable, the data is recorded. The test was performed and data was recorded for 15° increments of incident angle, and supplemental data was recorded at a 20 ° angle.

The force measured in the wind tunnel is actually the resultant force F_w of the antenna and the pole:

$$F_w = F_{antenna} + F_{pole}$$

Only the wind load of the antenna is reported on the datasheet, so it is necessary to subtract the force of the pole from the resultant force measured in the test. It is assumed that the antenna and the pole are two completely independent systems. Therefore, the wind load of the antenna can be obtained by subtracting the load of the pole placed in the undisturbed airflow.

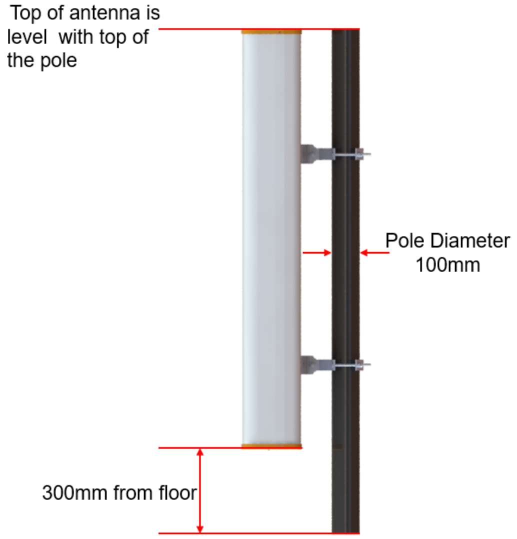


Figure 8 Installation diagram of the antenna and the pole

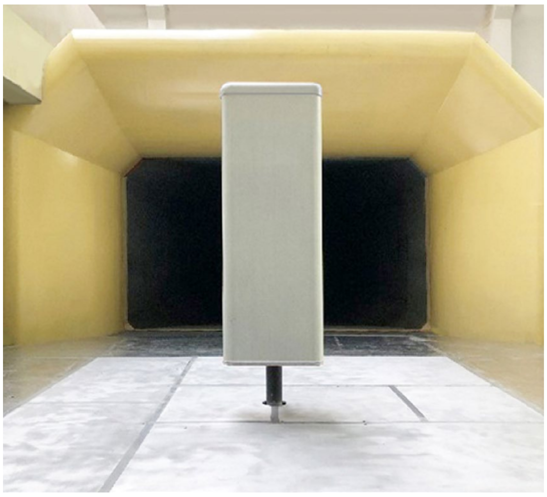


Figure 9 Wind tunnel force test of the antenna

Under different angles, the exposed length of the pole is also different. Therefore, each angle is treated separately according to the exposed length of the pole. At 0-60° and 120-180° angles, the test antenna's pole is only exposed for 300 mm below the antenna. Therefore, under these angles, only the force of the exposed part of the pole needs to be subtracted. At 75-105° angles, the pole is completely exposed, so the force on the whole pole needs to be fully deducted under these angles. The force of the antenna at different angles can be calculated according to the following formula:

0-60°and 120-180°:

$$F_{antenna} = F_w - F_{pole\_P1}$$

75-105°:

$$F_{antenna} = F_w - F_{pole\_P}$$

The drag coefficient of the antenna is calculated according to the following formula:

$$C_d = \frac{F_{antenna}}{0.5 \cdot \rho \cdot v^2 \cdot A_{antenna}}$$

Because the antenna has a different projected area $A_{antenna}$ in different wind directions, to facilitate the calculation, the windward projected area of the front is taken for the calculation. Figure 11 shows the drag coefficient of an antenna measured in the wind tunnel.

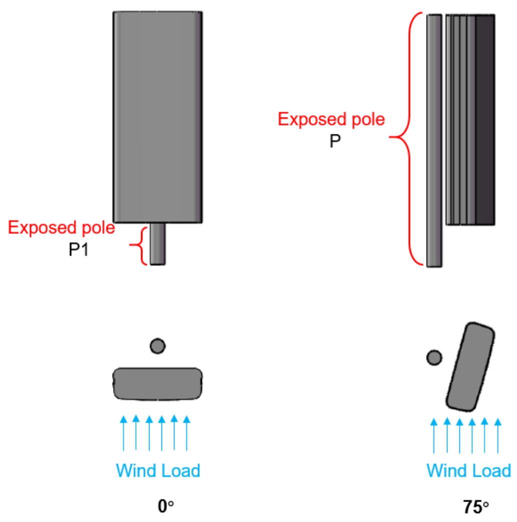


Figure 10 Different exposure degree of the pole

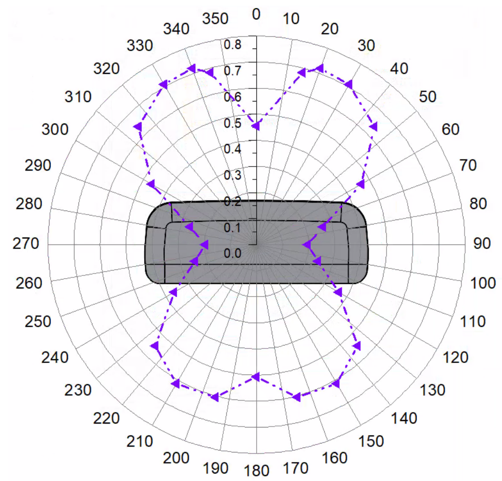


Figure 11 Drag coefficient of the antenna under different wind directions

2. Pressure measurement experiment

An electronic pressure scanning valve, plastic sleeve, hose, and a steel tube are used to measure the pressure on the radome surface. When measuring the surface pressure of the antenna, 42 pressure measuring points are set on the cross-section of the model. More dense pressure measuring points are arranged at the rounded corners and side of the model, and spare pressure measuring points are arranged at other positions. The pressure measurement experiment is shown in Figure 12.

Figure 12 Wind tunnel pressure test of the antenna

The test results show that the pressure distribution on the front and back of the antenna is uniform, while the pressure change is more severe in the rounded corners and sides. In these areas, small structural changes will lead to changes in the flow field of the whole antenna. Therefore, these areas are also key areas of antenna wind load optimization. It also shows that the definition of rounded corners correction in EN1991-1-4 standard is too broad to be applied to optimized antenna products.

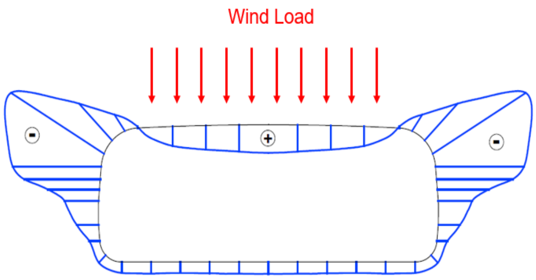


Figure 13 Pressure distribution on antenna surface at 0 degree

3. PIV experiment

PIV is a non-contact flow field analysis technology based on the principle of two-time point rapid photography. Its measurement principle is shown in Figure 14. During the experiment, tracer particles are dispersed in the flow field, and the flow field is irradiated by the laser sheet . The particle images are exposed twice or more and captured by the imaging recording system to form PIV experimental images. The PIV image is analyzed by the image cross-correlation method. The average displacement of a particle image in each small region can be obtained, and the fluid velocity on the whole flow field section can be determined. This technology can not only measure the velocity of the flow in the field, but also display the information of the flow field in real-time.

Figure 16 shows the real-time flow of the lateral surface flow field of an antenna. It can be seen from the figure that the airflow on the antenna’s lateral surface is close to the radome, without any backflow. This indicates that the radome does not have any air separation, which conforms to the aerodynamic characteristics, and the wind load of the antenna is low.

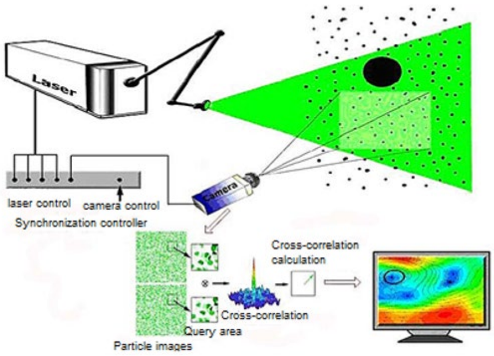


Figure 14 Measurement principle of PIV technology

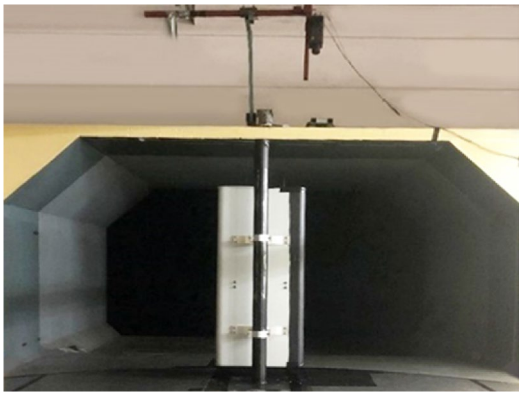


Figure 15 Wind tunnel PIV test of the antenna

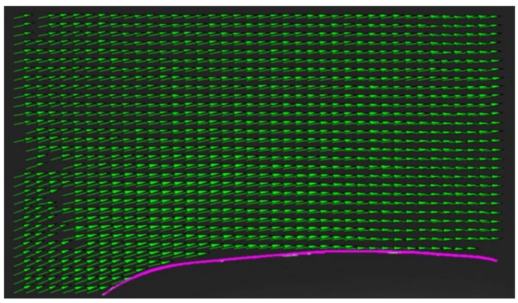


Figure16 Transient flow field of the antenna lateral surface

Conversely, flow that does not conform to aerodynamic characteristics is shown in Figure 17. It can be seen from the figure that air separation occurs when it passes by the end cap, and separation vortices are formed on the surface of the top end cap. The formation of separation vortices means that there is a violent energy exchange. Therefore, when the fluid flows near the end cap, it will require a lot of energy, which will lead to an increase in flow resistance and the increase of the wind load on the antenna.

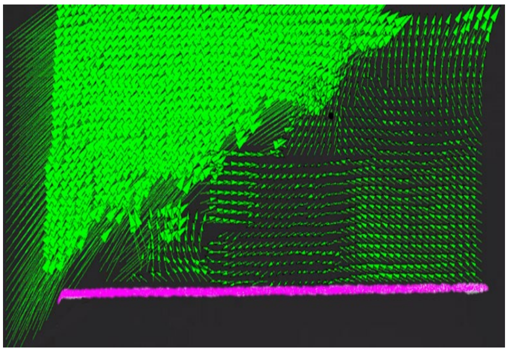


Figure 17 Transient flow field of top end cap

Prose measures the wind load of an antenna with different cross-sections through force measurement experiments, visualization of the flow characteristics of the air around the antenna through PIV experiments and makes the related qualitative and quantitative data analysis. We optimize the radome wind load based on these experiments.

Definition of Prose wind load calculation method

Figure 18- Figure 20 shows the comparison of the antenna wind tunnel test results with the calculation results of EN 1991-1-4 and ANSI/TIA 222. It can be seen from the figure that there is a big gap between the C_d calculated by EN1991-1-4 and ANSI/TIA 222 and the wind tunnel test results. Although EN1991-1-4 introduces the rounded corner correction coefficient and the accuracy of wind load calculation is relatively improved, it is still larger than the results of the wind tunnel test, and the calculation is still conservative. The conservative standard is not a good match for Prose's optimized radome products.

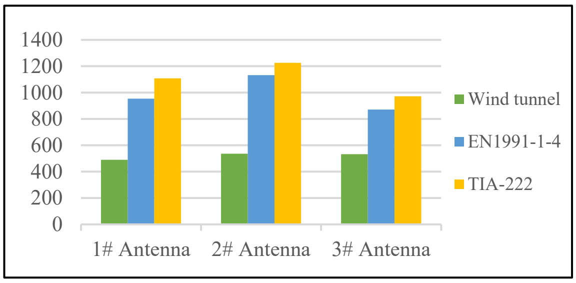


Figure 18 Comparison of the drag coefficients on front wind load

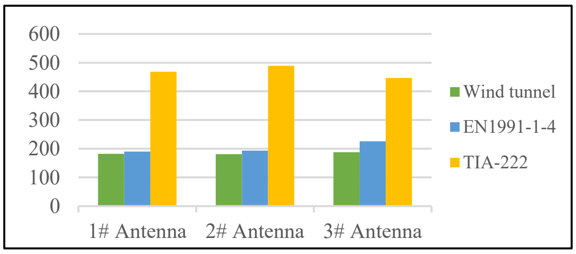


Figure 19 Comparison of the drag coefficients on lateral wind load

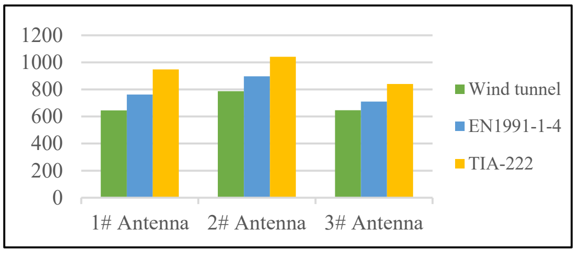
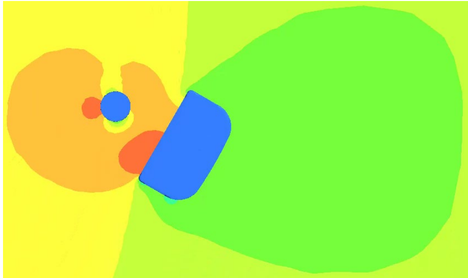


Figure 20 Comparison of the drag coefficients on maximum wind load

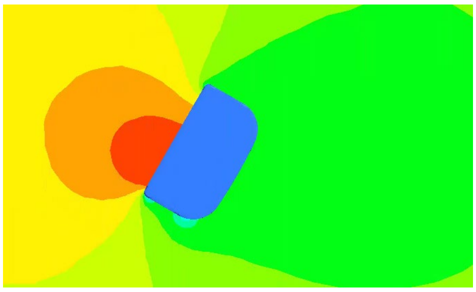
According to BASTA V11.1 standard, Prose defines the front, lateral and maximum wind load of the antenna at the wind speed of 150 km/h in our datasheets. The shape drag coefficient C_{dp} of the antenna with the same cross-section is obtained based on the results of the wind tunnel test. For the same cross-section, the length of the different antennas, multiplied by the end-effect factor ψ_λ, obtained from EN1991-1-4. According to the following formula, the wind load of antennas of different lengths can be obtained.

$$F_{antenna} = 0.5 \cdot \rho \cdot (C_{dp} \cdot \psi_\lambda) \cdot v^2 \cdot A$$

In the above equation, the antenna force $F_{antenna}$ is equal to the resultant force obtained from the wind tunnel test minus the force of the antenna. As shown in Figure 21, the whole airflow environment will become extremely complex due to the presence of the pole. At some angles, the pole not only increases the projected area of the whole system but also affects the force of the wind on the antenna. So it becomes very difficult to subtract the force of the pole from the whole system. According to the hypothesis of the treatment method of the appeal wind tunnel test, Prose adopted different deduction methods for different wind direction angles.



With pole



Without pole

Figure 21 Impact of the pole on the flow field

1. Front shape drag coefficient C_{dp_front}

Firstly, the front wind load of the antenna is calculated, and the force on the pole is deducted according to the wind tunnel test method. When the wind blows from the front of the antenna, only a small part of the length of the pole is exposed. Therefore, it is only necessary to deduct the force on the exposed part of the pole.

$$F_{antenna\_front} = F_{w\_front} - F_{pole\_P1}$$

The front shape drag coefficient C_{dp_front} can be calculated as follows:

$$C_{dp\_front} = \frac{F_{antenna\_front}}{0.5 \cdot \rho \cdot \psi_{\lambda\_front} \cdot v^2 \cdot A_{antenna\_front}}$$

2. Lateral shape drag coefficient $C_{dp\_lateral}$

When the wind blows from the lateral of the antenna, the pole is completely exposed. Therefore, it is necessary to completely deduct the force of the whole pole.

$$F_{antenna\_lateral} = F_{w\_lateral} - F_{pole\_P}$$

The lateral shape drag coefficient $C_{dp\_lateral}$ can be calculated as follows:

$$C_{dp\_lateral} = \frac{F_{antenna\_lateral}}{0.5 \cdot \rho \cdot \psi_{\lambda\_lateral} \cdot v^2 \cdot A_{antenna\_lateral}}$$

3. Maximum shape drag coefficient C_{dp_max}

Theoretically, the maximum wind load of the antenna can appear at any angle. The maximum wind load in the wind tunnel test is greatly affected by the pole, so the force of the pole cannot be accurately deducted. Approximately calculate the wind load of the antenna according to the following formula:

$$F_{antenna\_max} = F_{w\_max} - F_{pole\_P1}$$

The maximum shape drag coefficient C_{dp_max} can be calculated as follows:

$$C_{dp\_max} = \frac{F_{antenna\_max}}{0.5 \cdot \rho \cdot \psi_{\lambda\_max} \cdot v^2 \cdot A_{antenna\_max}}$$

Prose wind load update instructions

1. Update wind load calculation method

The Prose wind load calculation method and wind tunnel test method conform to the requirements of the latest BASTA V11.1 standard, and the calculation formula of EN1991-1-4 is modified according to the wind tunnel test results. The specific modification method can be referred to in the previous sections. The revised wind load is smaller than that calculated by EN1991-1-4. This is because the result of the standard calculation is conservative, and it is not suitable for Prose radome products with aerodynamic optimization.

2. Remove rear wind load and add maximum wind load

Based on the latest version of BASTA V11.1 standard, Prose datasheet removes the rear wind load of the antenna and add the maximum wind load.

3. Change of radome section

Prose realized the importance of wind load very early on and has done a considerable amount of work in reducing the wind load of the antenna. As described above, Prose has done a lot of testing in the wind tunnel, which forms the basis for optimizing the radome wind load. Based on CFD simulation technology, the wind load of the antenna is optimized, and the results of these optimizations are verified in the wind tunnel. One of the ways to reduce the wind load is to change the cross-sectional shape of the radome so that the shape of the radome is more in line with the aerodynamic characteristics to reduce the drag coefficient. Prose has also carried out in-depth research on this, shaping our characteristic radome products. Some radomes will even increase their depth after optimization.

4. Instructions of wind load data in the specification

The wind load data of Prose datasheets are calculated based on wind tunnel test results. Although Prose's wind tunnel test adopts the open wind tunnel to simulate the characteristics of natural wind as close as possible, the wind tunnel test can not completely simulate the situation of the wind in the real environment. Because the wind in a real environment is not as stable as that in wind in the tunnel, it may be pulsating, and the direction of the wind may change at any time. Even if the natural wind is stable, the wind speed cannot be completely the same as the wind speed of 150 km/h in the wind tunnel. The wind speed is related to the local terrain roughness, height, season, and many other factors. Therefore, in the actual project, site engineers should be aware of the limitation of wind load data in the datasheet, which can only be used as reference data for the design of base station antennas in the tower. Site engineers need to consider the specific factors of the location of the base station antenna tower and evaluate the wind load of the whole system in combination with the corresponding engineering specifications.

Appendix

1. Introduction to the wind tunnel laboratory of Jilin university

The automobile wind tunnel of Jilin University is the first professional automobile wind tunnel constructed in China. It was planned and designed at the end of the last century and started construction in 2002.

The wind tunnel is a low-speed open flow wind tunnel. The nozzle of the test section is 2.2 meters high and 4 meters wide. The nozzle area is 8.4 m^2, and the length of the test section is 8 meters. The maximum wind speed is 60m/s. The yaw angle is 0.023°, the pitching angle is 0.36°, and the average static pressure gradient is 0.004/m. The wind tunnel is equipped with a high-precision mechanical force decomposition six-component balance turntable system and a wide-band mobile belt ground effect simulation system.

Address: No.300 BOCAI Road, high tech Industrial Development Zone, Jilin City, Jilin Province, China

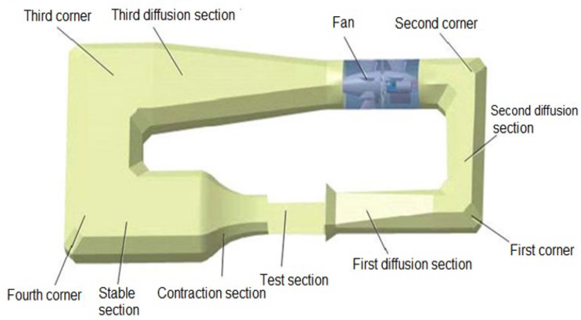


Figure 22 Structural sketch of wind tunnel of Jilin university

2. Wind tunnel blocking effect

Wind tunnel testing is an important means to study the wind load of the antenna. When the antenna is tested in the wind tunnel, an antenna with a certain length is installed in the wind tunnel. The actual antenna length is usually long, as the antenna tested in the wind tunnel should not be too short. Therefore, when conducting the wind tunnel test, the antenna length to be measured should be as long as possible (in the allowable range) to obtain the real antenna resistance coefficient. But this is often limited by the blockage ratio. For the wind tunnel with a small cross-sectional area of the test section, the blockage effect may be a common problem.

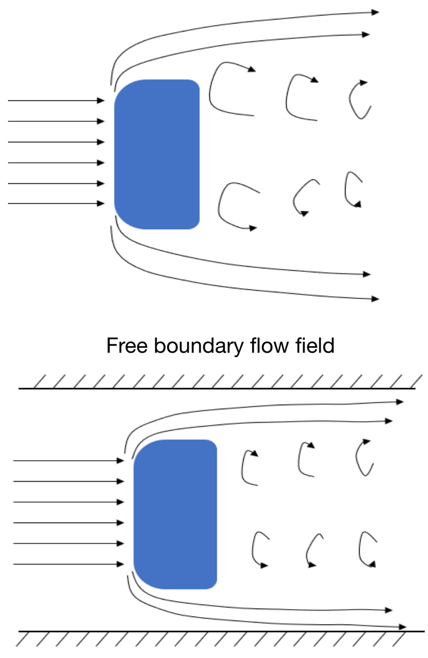


Figure 23 2D block flow field diagram

The blockage effect mainly depends on the size of the model and the section size of the working section of the wind tunnel. The ratio of the projected area of the model in the flow direction to the cross-sectional area of the wind tunnel, i.e. the blocking ratio, is the characterization. Some studies have shown that the error of the blocking effect on the pressure coefficient of the plate perpendicular to the incoming flow may be several times that of the true value. It can be seen that the blockage effect is important to obtain accurate test results. The main influence of the blockage effect on the test is that the airflow will produce flow around and wake when it flows past the antenna. The wall constraint of a closed wind tunnel will prevent the lateral streamline and wake from expanding freely, but there is no restriction in the actual nature.

Generally speaking, the blockage effect can be ignored when the blockage ratio is controlled within 5%. However, if the actual antenna product is used for the 1:1 wind tunnel test, the requirement of this blockage ratio is almost not met by the closed wind tunnel. Therefore, the blockage ratio correction method is usually considered to solve this problem, that is, multiplying the drag coefficient measured by the experiment by a scaling factor. In the field of aviation and automobile, the theoretical correction of the blockage effect in wind tunnel test is relatively mature, but this correction method is not suitable for antenna blockage effect correction. Because the antenna is mostly blunt-body structure, the wake is wide, while the shape of an aircraft or car is streamlined and the wake is narrow. A more refined correction method is needed for the blunt-body structure of the antenna. However, the blockage effect has little effect on the open wind tunnel, and the more accurate drag coefficient can be obtained without modifying the blockage ratio. Therefore, in this case, it is a better choice to choose the open wind tunnel for the experiment.

References

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