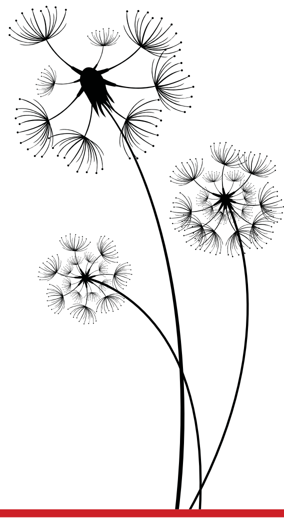
White Paper

www.rfsworld.com

Base Station Antennas: Pushing the Limits of Wind Loading on Macro Sites



Author:

Julien Touchet, Mechanical Engineer

Co-Authors:

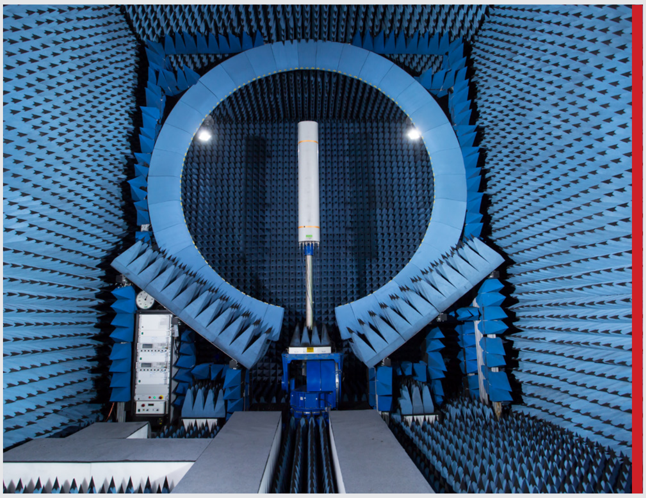
Giampiero Capraro, Global Product Manager

Asaad Elsaadani, Mechanical Engineer

Jean Pierre Harel, R&D Manager

Damon Sun, Mechanical Engineer

Table of Contents



EXECUTIVE SUMMARY

Macro Sites: Pushing the limits of wind loading

As the appetite for data continues to grow, wireless providers need to deploy more and more base station antennas to keep pace and deliver the required capacity. With 5G roll outs gathering momentum, we are seeing existing cell sites pushed to their load-bearing limit, but more is still needed. Due to the cost and logistical challenges, acquiring new sites is often not a practical option, meaning equipment designers need to push to extend the wind loading limits to ease the problem.

The advancements needed from a design perspective must tackle the problem from several angles. First in the design itself, to ensure service providers can use existing sites as efficiently as possible. Secondly, in the testing and measurement of wind loading capabilities to minimize incidental redundancy and move as close as is safely possible to physical wind loading limits.

RFS is committed to both aspects, however, this paper explores the latter, looking at calculation and testing methods with the aim of addressing elements of the macro site headache facing service providers.

BUILDING ON CURRENT STANDARDS

To date, one of the biggest limitations for equipment designers has been that the standards used by civil engineers to design towers and supporting structures (EN1991-1-4 / TIA222) do not easily translate for Base Station Antennas.

The shapes covered by the above standards are symmetrical and the calculated wind load force is typically equivalent to drag force only, and does not account for the lift force. This has limits when applied to antenna design. Of course antennas still need to adhere to these standards from a legal perspective, but more is needed to be able to give customers a clear view of the wind loading capabilities.

This led to the development of the P-BASTA12 recommendations. These have been developed with antenna vendors to "standardize" the measurement processes between the different antenna vendors and give meaningful information to customers looking to maximize the potential of cell tower sites. It recommends changes to wind tunnel testing which in turn allows calculations to take into consideration lift force factors and better inform the decision making process.

Rather than looking at the drag force in three positions (front/side/rear) using the European Standard EN1991-1-4 method or TIA-222 methodology which uses Effective Projected Area and a shielding coefficient to calculate the drag force of the wind at any direction, the P-BASTA12 recommendations look at the resultant force which is the vector sum of the drag force and the lift force.

The drag force is parallel to the direction of flow, while the lift force is perpendicular to the direction of the flow and results from an asymmetry in the flow around the antenna. The total force is the combination of the two vectors (drag and lift) which gives the resultant force. This is tested in a wind tunnel environment and provides calculations of force distribution, drag and lift components in all directions. By adding this into the equation, we are provided with more accurate wind load values, giving a clearer picture of wind load capabilities and full transparency to operators as they make decisions on how to approach tower loading.

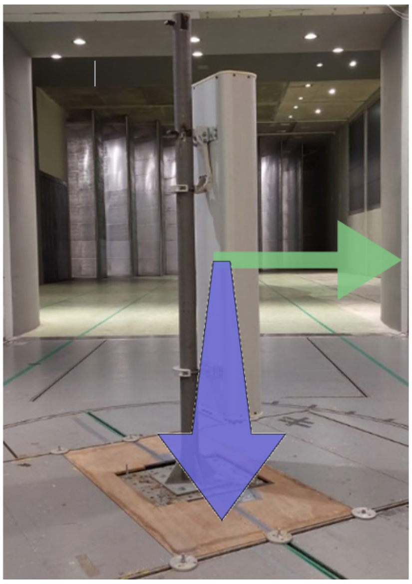


Figure 1: Antenna in test configuration

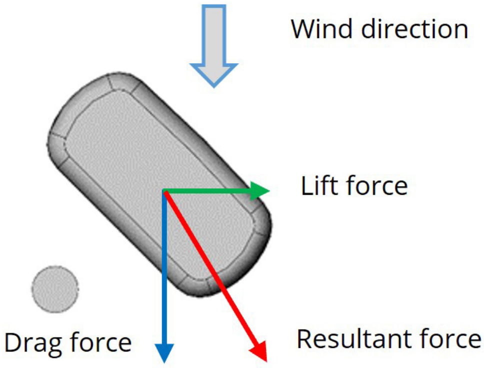


Figure 2: Drag, Lift and Resultant force

NOTE: P-BASTA is not a substitution for existing standards, the associated requirements still need to be met from a legal perspective. P-BASTA is instead a recommendation for Base Station Antenna Standards which complements existing regulations.

The wind tunnel experiment provides more accurate results, as the test accounts for the unequal round corners and unsymmetrical shapes. This is demonstrated below with a comparison of the drag coefficient between wind tunnel and the standard EN1991-1-4 for different antennas. The drag coefficient Cd is calculated using the following formula:

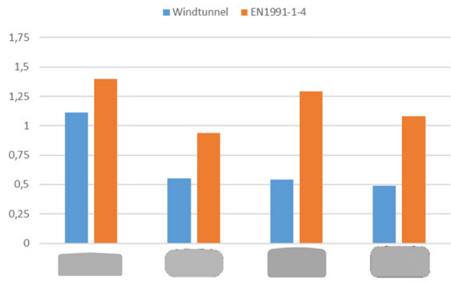
$$Cd = \frac{Drag\ force}{Q0 \ .\ S}$$

Where	Q0	Dynamic pressure	1063	[Pa]
	S	Projected area		[m²]

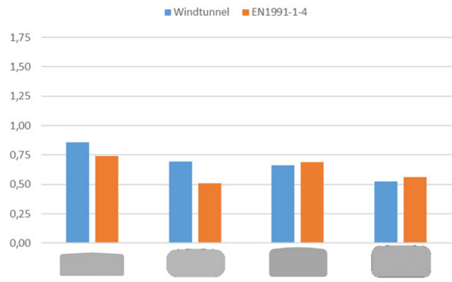
$$Q0 = \frac{1}{2}\ x\ \rho\ x\ V^2$$

Where	ρ	Air density	1.225	[kg/m3]
	V	Windspeed	41.6	[m/s]

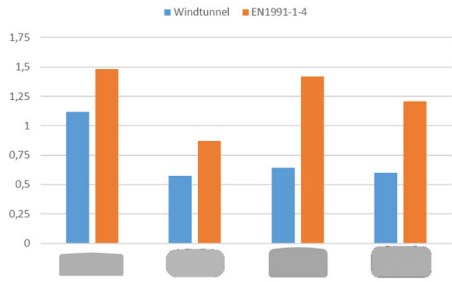
FRONTAL POSITION



LATERAL POSITION



REAR POSITION



We observed that for both frontal and rear position the measured drag coefficient can be more than two times lower than the standard. The reason for this discrepancy is that the standard does not consider the critical Reynolds number* characterized by a drop in the drag. This phenomenon is visible when you perform a windspeed sweep on the antenna. Depending on the antenna shape, a decrease of the drag coefficient should be observed followed by a convergence. This convergence is important to accurately conduct windspeed interpolation.

By taking the time to refine measurement techniques to ensure the most accurate possible test results, we are now able to look at pushing the wind loading efficiency of base station antennas.

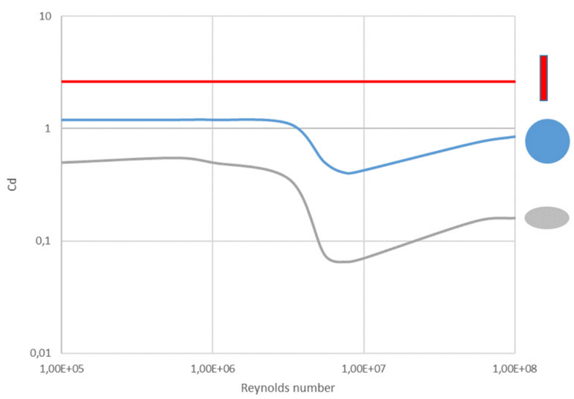


Figure 3: Drag coefficient vs Reynolds number

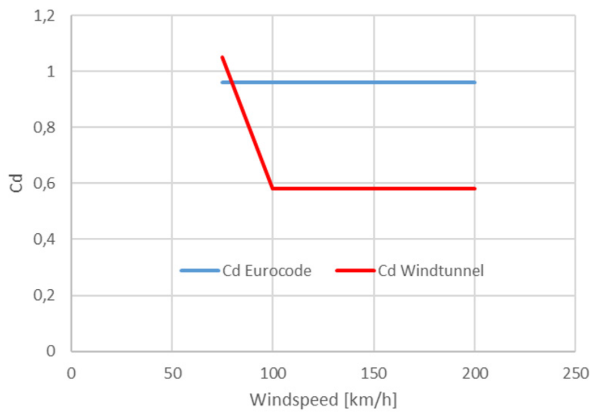


Figure 4: Comparison drag coefficient vs windspeed

* $Re = \frac{V\ .\ L}{\nu}$

Where	L	Characteristic dimension	[m]
	ν	Kinematic viscosity	[m²/s]

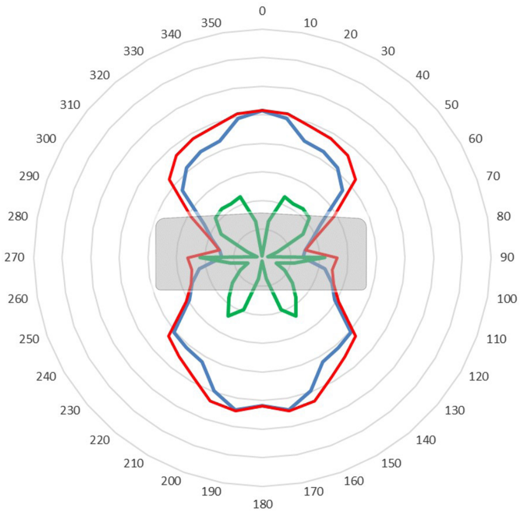
WIND LOAD ON A BASE STATION ANTENNA

Now that we have established a way to enhance the accuracy of wind load testing, let's look at how the takeaways can be used to enhance antenna design.

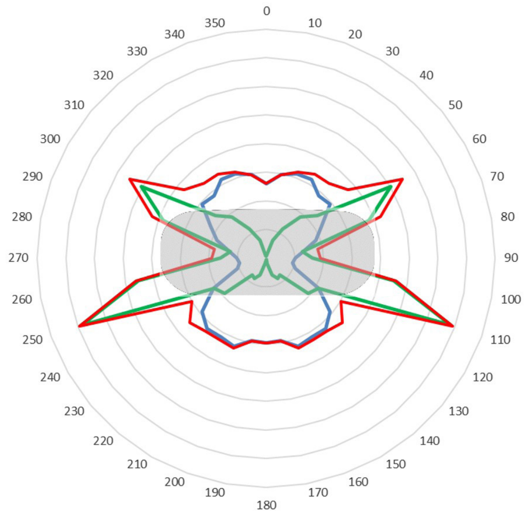
The geometry of the radome will give an accurate indication of the wind load. A "square" form factor will experience predominantly a drag force while a "rounded" shape will mainly see a lift component. As an example, consider a rectangular radome with differently shaped corners:

- A rectangular shape with sharp corners will see a high drag and a low lift. Flow detachment occurs early when wind hits the antenna creating a high wake without any lifting effect.
- A rectangular shape with rounded corners will result in a low drag and a high lift. Flow detachment occurs later until it faces an adverse pressure gradient. Depending on the angle the wind hits the antenna, the lifting effect becomes important because the antenna acts as an airfoil.

This is illustrated below, showing the distribution of forces (**drag** / lift / **resultant**) on two rectangular shapes with different corners:



High Drag / Low Lift



Low Drag / High Lift

A rounded antenna offers a better drag force than a squarer antenna, but it can be subjected to a strong force gradient with a higher lift force depending on the attack angle of the wind. For 20 years, the dynamic wind load test has been part of the RFS antenna qualification process and our antennas designed to ensure maximum efficiency.

TESTING TO ENSURE MAXIMUM EFFICIENCY

Taking into consideration the challenges involved with calculating wind load, a standard method has been published in NGMN P-BASTA v12.0. RFS uses this as a basis to carry out wind load testing, with an emphasis on ensuring the most accurate calculations to allow wireless providers to make informed decisions. The tests are carried out at the CSTB (Centre Scientifique et Technique du Bâtiment), this is operated by a French national organization providing research and innovation, consultancy, testing, training, and certification services in the construction industry. There are multiple wind tunnels across the site, but for Base Station Antenna applications, RFS uses the Jules Verne climatic wind tunnel. This has an aerodynamic cross-section of 30 m², minimizing the impact of the wind tunnel on the measurement.

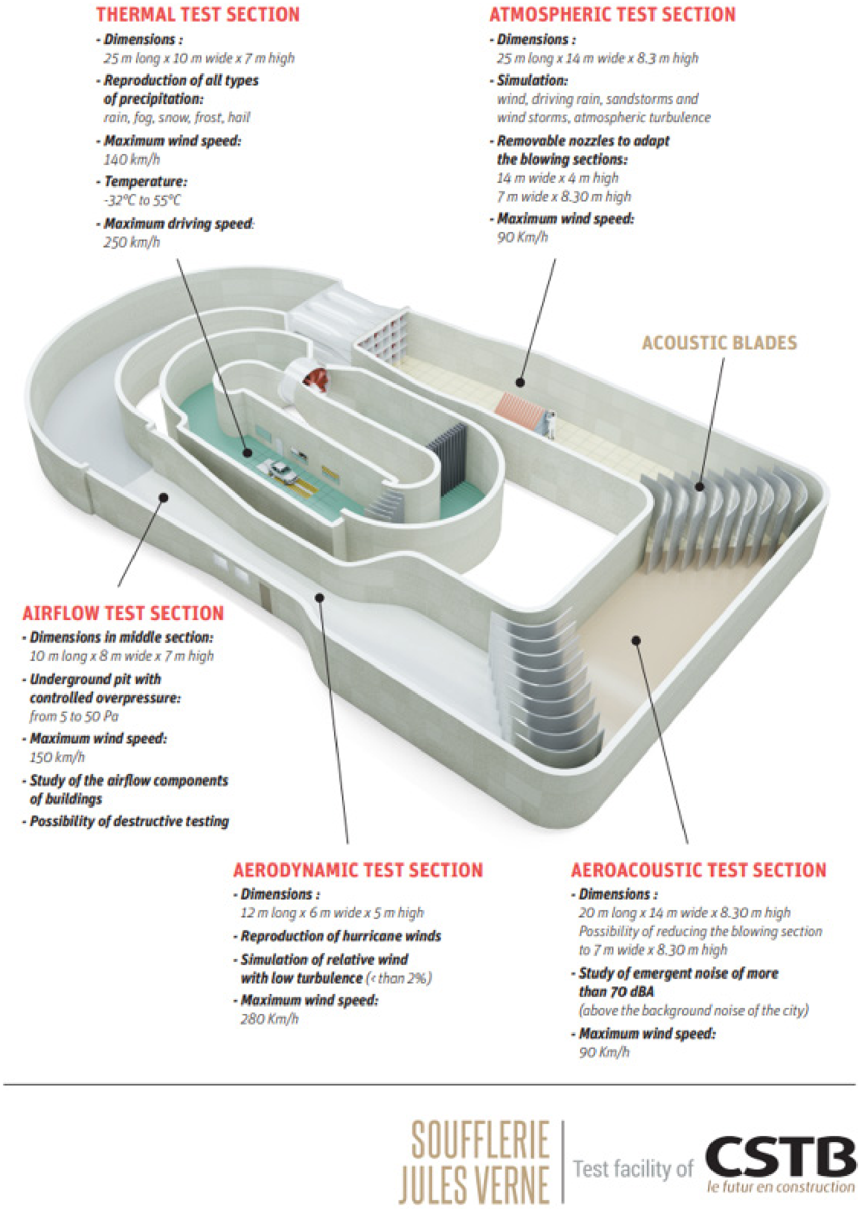


Figure 5

The focus at the testing site is to maximize accuracy, only in this way we can focus on pushing the limits of wind loading to ensure maximum site efficiency. The next section looks in detail at how we approach testing and the gains it allows us to deliver for our customers.

Antenna test sequence providing the 360° polar plot

In the testing set up, the pole is set on the dynamometric balance of the turntable which is equipped with force sensors. The pole is tested alone with different wind attack angles to give the drag force which will be used for the pole deduction. Afterward, the antenna is installed at the minimum mechanical down tilt. The pole must fully cover the antenna while respecting the minimum distance from the ground of 300mm to avoid any turbulence generated by the floor.

Before starting the test, a Reynolds sweep is performed to characterize the antenna profile. Depending on the geometry, the aerodynamic coefficient might not converge making windspeed interpolation impossible, which is critical to ensure that all final values are correct.

Tests are then run to generate a 360° polar plot. The wind speed is set at 150km/h with data acquisition every 10°. For a symmetrical antenna the scanning is performed from 0 to 180°. For asymmetrical antenna, the scanning is performed from 0 to 360°. Data acquisitions are carried out for one minute, at 20 Hz, filtered at 10 Hz. The collected data is then used to calculate and mean values of each force. The means values of the forces are in the reference frame of the antenna (Fx, Fy). If needed, a change of reference frame is calculated to have the drag and the lift force expressed in reference frame of the wind tunnel (F_{Drag} F_{Lift}). At this step, the force measured the force of the antenna + pole ($F_{antenna}+_{pole}$).

Drag	$F_{Drag} = F_x.\ \cos\alpha + F_y.\sin\alpha$
Lift	$F_{Lift} = -F_x.\sin\alpha + F_y.\cos\alpha$
Resultant	$F_{Resultant} = \sqrt{F_x^2 + F_y^2} = \sqrt{F_{Drag}^2 + F_{Lift}^2}$

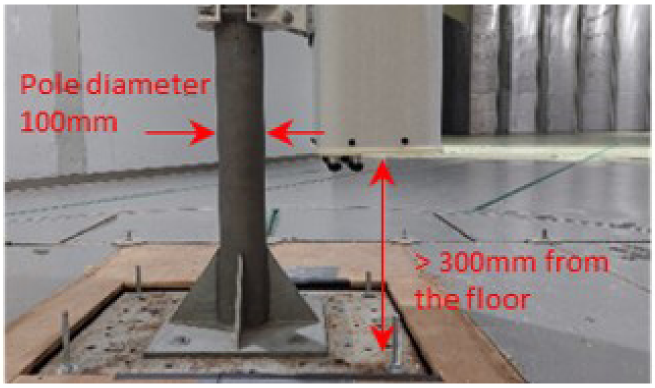


Figure 6: Installation requirement

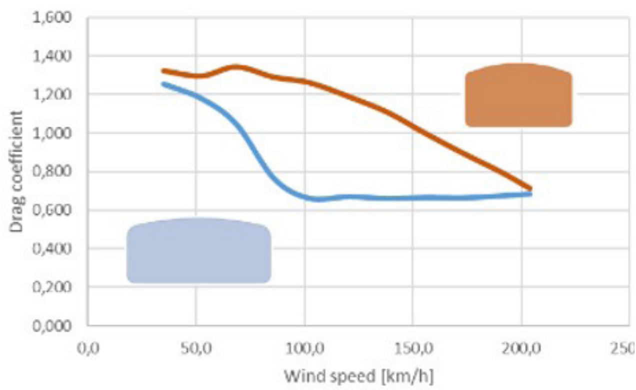


Figure 7: Reynolds sweep convergence check

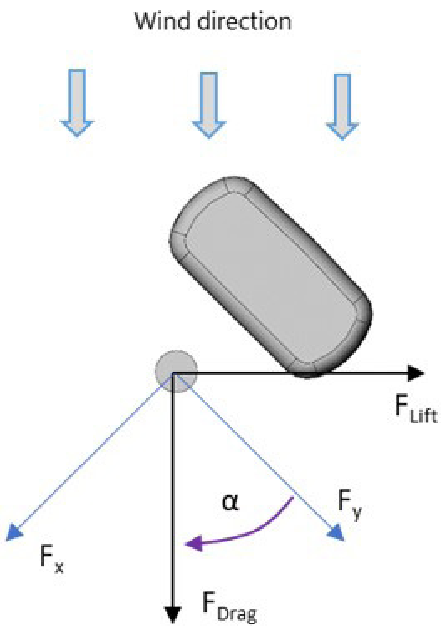


Figure 8: Reference frames (antenna vs wind tunnel)

Before sharing, the wind load force of the antenna alone ($F_{antenna}$), the drag of the pole (F_{pole}) must be deducted from the measurement. The drag force is deducted when the pole is exposed depending on the angle of attack of the wind. To better define the angle range for pole deduction, RFS uses Computer Aid Design software, again to ensure maximum accuracy in the results.

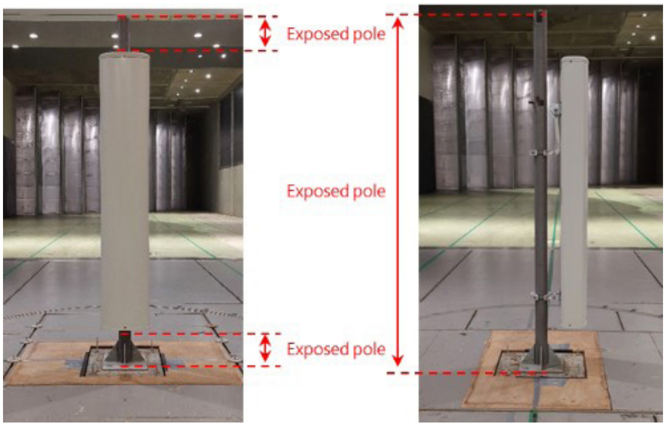


Figure 9: Subtraction when the pole is exposed

In action

As demonstrated in figure 10, RFS used this method to test a 2.0m antenna with a pole of 2.8m. Assuming the drag force of the pole is measured at ~185N. It means that the pole contribution to the total force is either 55N or 185N depending on the angle of attack of the wind.

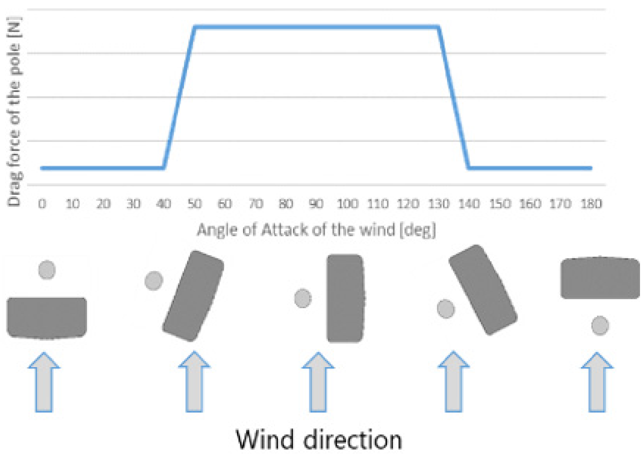


Figure 10: Drag of the pole depending on the angle

For P-BASTA11, RFS provided the resultant force of the antenna alone according to the formula below:

$$F_{Resultant\ (antenna\ alone)} = \sqrt{F_{Drag}{}^{2}_{(antenna+pole)} + F_{Lift}{}^{2}_{(antenna\ alone)}}$$

With:

$$F_{Drag\ (antenna\ alone)} = F_{Drag\ (antenna+pole)} - F_{Drag\ (pole)}$$

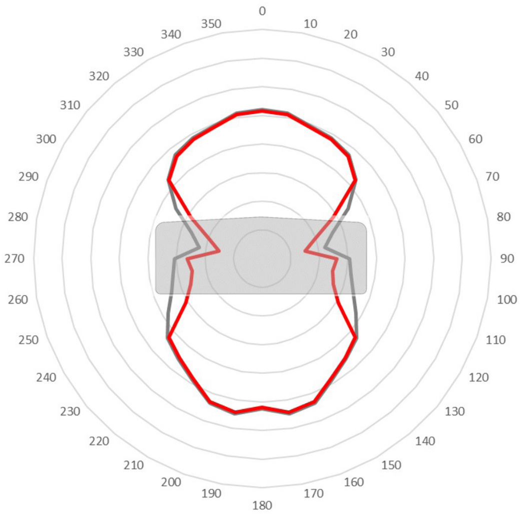
$$F_{Lift\ (antenna\ alone)} = F_{Lift\ (antenna+pole)}$$

Following P-BASTA12 method, the resultant force of the antenna alone is:

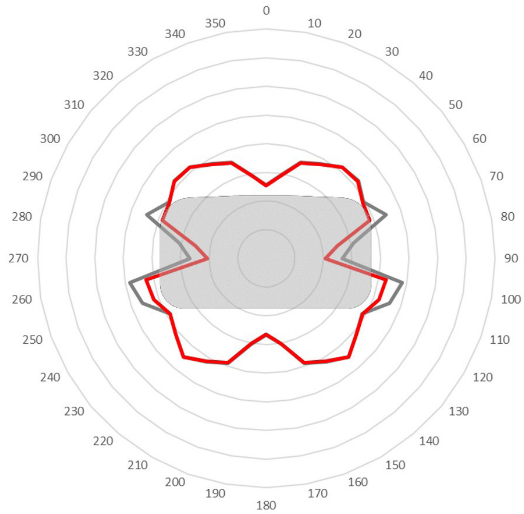
$$F_{Resultant\ (antenna\ alone)} = F_{Resultant\ (antenna+pole)} - F_{Drag\ (pole)}$$

Impact of the pole deduction on the maximum wind load

The pole deduction occurs in lateral position and depending on the shape of the radome, the maximum wind load is impacted. Below we can see the force distribution between resultant force antenna+pole and resultant force antenna alone.



Squared shape
The pole deduction does not impact the maximum force.

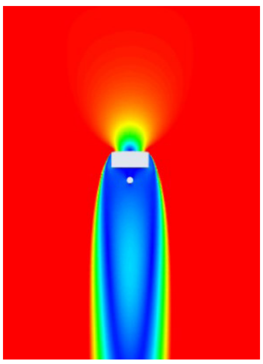


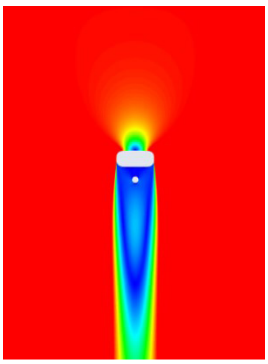
Rounded shape
The pole deduction impacts the maximum force.

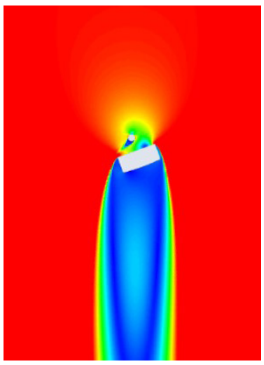
Between P-BASTA11 and P-BASTA12 there is no impact on the RFS antennas equipped with a squared shape. However, for the RFS antenna equipped with a rounded shape, P-BASTA12 can provide a benefit of ~5% on the maximum wind load, demonstrating that more accurate testing standards make a significant difference when it comes to wireless providers being able to reap the benefits of improved antenna design.

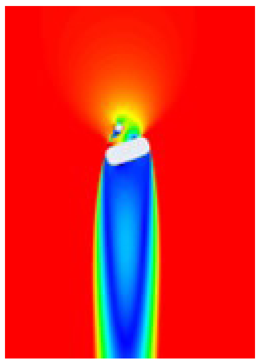
Computational Fluid Dynamic simulation (CFD)

Wind loading strategies are a key differentiator for operators, and it is crucial as a partner we employ rigorous testing to ensure the solutions provided meet their expectations and deliver on our promises. Therefore, the next step is to optimize the radome profile with Computational Fluid Dynamics (CFD). Drag and lift force reduction is a priority and using computer simulation allows us to identify the best approach to achieve this.


Standard shape
AoA 0°


Enhanced shape
AoA 0°


Standard shape
AoA 160°


Enhanced shape
AoA 160°

The computer simulation provides a solid foundation, but before starting the test on the final product, a mockup is tested with pressure monitoring testing.

Pressures monitoring testing

This is a vital step in the process for two reasons. Firstly, this allows cross checking and confirms the accuracy of the numerical simulation. Secondly, it allows us to fine tune the enhanced shape in dynamic conditions to ensure optimal design. Each mockup from CFD development is 3D printed. They are equipped with one crown of ~120 pressure taps. The testbed has also a pole equipped with one crown of 30 pressure taps. Pressure is then measured with multi-channel piezoresistive differential sensors. The aerodynamic forces are calculated using the profiles of the measured pressures.

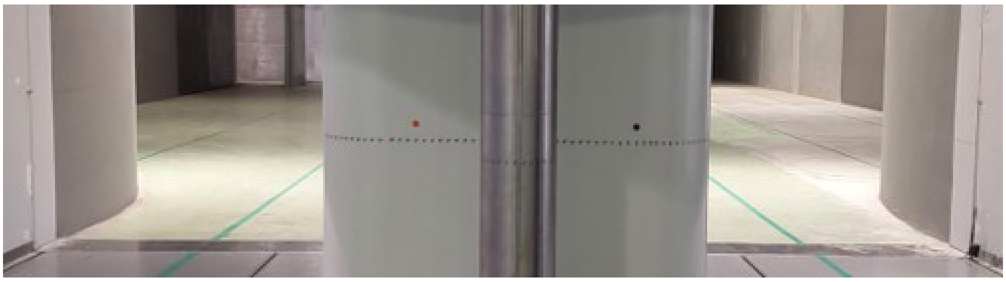


Figure 11: Pressures monitoring

In addition, this process allows us to understand the impact of the pole on each antenna and calculate the real force coming from the antenna separately, to give a better understanding of the relationship between the pole and the antenna, which is a key point for discussion for the Next Generation Mobile Networks (NGMN) as it seeks to identify opportunities for improvements that will benefit future networks.

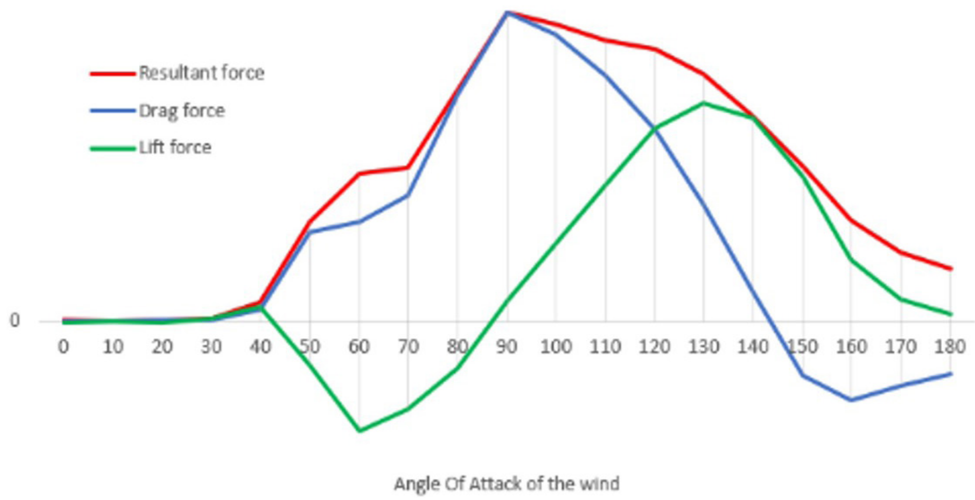


Figure 12: Drag, Lift and Resultant of the pole

CONCLUSION

Wind loading is a topic of conversation that will continue to dominate the telecommunication space as the pressure to increase capacity only builds. For us at RFS we have over our 120-year history focused on making technological advancements that will benefit both the industry and our customers and remain committed to enhancing antenna design to deliver that. However, this is just one piece of the puzzle, the second aspect is being able to measure those gains. By focusing on this we can ensure wireless providers can squeeze every ounce of capacity out of their tower sites, with confidence in the robust testing that allows efficiency gains to be made.

If you would like to hear more about our commitment to enhanced testing to improve wind loading, please get in touch paula.mennone@rfsworld.com

APPENDIX: WIND TUNNEL CALIBRATION

The aerodynamic balance is regularly calibrated to provide the most accurate forces. Standard masses are used to pull on the pole and control the response of the force sensors. Similarly, dynamic pressure applied by wind on the front face of the antenna is characterized by the measurement from a Pitot tube located above, which is correlated with the dynamic pressure measured at the location of the antenna with another Pitot tube before commencing the tests.

Figure 13: Calibration of the aerodynamic balance

APPENDIX: REFERENCES

1. NGMN-P-BASTA Recommendation on Base Station Antenna Standards v12.0, January-2022
2. NGMN-P-BASTA Recommendation on Base Station Antenna Standards V11.1, March-2019
3. NGMN-P-BASTA Recommendation on Base Station Antenna Standards V9.6, January-2013
4. EN1991-1-4:2005 Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. April 2005
5. NF EN 1991-1-4 National annexe, March-2008
6. TIA-222-H Structural Standard for Antenna Supporting Structures and Antennas, October-2017
7. TIA-222-G Structural Standard for Antenna Supporting Structures and Antennas, August-2005

RADIO FREQUENCY SYSTEMS

ABOUT RFS

Radio Frequency Systems (RFS) delivers the end-to-end RF solutions and expert services needed to evolve wireless and broadcast networks today and tomorrow. Our cables, connectors, antenna systems and RF conditioning products are based on more than 120 years of experience delivering cutting-edge RF solutions and industry firsts. As a result, our solutions are recognized globally for their innovation, superior performance and unmatched quality.

As an ISO-compliant company with global operations, we bring our customers world-class engineering and manufacturing skills backed with comprehensive local support services. Our customers know they can rely on our expertise and commitment to excellence from initial design to final delivery and beyond — whether they're looking to support 5G, deploy small cells, empower smart cities or improve indoor coverage in the most challenging locations.

For more information, visit www.rfsworld.com

Follow us on Twitter: www.twitter.com/RFSworld

TRADEMARKS OF RFS

RFS® is a registered trademark of Radio Frequency Systems. All other trademarks are the property of their respective owners.