RCS reduction and scattering analysis of screw array

Lin Zhang * and Hongqian Zhu

Air Force Engineering University, Xi'an, China;

* LZhang0319@163.com

Abstract. Screw or rivet arrays are widely distributed in aircrafts, which have become the main factors affecting the aircraft invisibility when achieves the suppression of strong scattering sources. The work analyzes the invisible characteristic of smooth circular and triangular screw array, it can be concluded that a screw array with a round smooth surface provides better invisibility than a triangular head screw array, except for certain angles that result in specular reflections. The maximum reduction in invisibility can reach up to 46.4dB. The comparison results demonstrate the effectiveness and feasibility of the proposed angle manipulation method for low RCS screw structures. This may promote the development of low-detection capabilities for weak sources such as screws, rivets, or gaps in aircraft.

Keywords: Radar Cross Section; Screw array; scattering analysis; RCS reduction.

1. Introduction

Stealth is not only important for improving aircraft survivability on the battlefield but also a key indicator of modern weapons and equipment [1] for modern information war. For the aircraft, stealth includes radar, infrared, radio, optics and acoustic invisibility et.al, and radar stealth capability has the largest proportion in medium or long-distance air combat. Although the RCS of strong scattering sources have been suppressed, but the scattering proportion of screws or rivets [3] in the overall RCS also increases significantly, especially at specific polarizations and incident angles [1-2]. It is indicated that the scattering of ten round head screws with a diameter of 10 mm can cover an area of 1 m2 [4-5], and the screws or rivets are distributed in an array in aircraft. Therefore, reducing the RCS of various electromagnetic discontinuities such as screws or rivets [6-11], is crucial for minimizing radar detection probability of stealth aircraft.

In this work, a low RCS screw head and the corresponding angle range of the strong scattering manipulation principle were proposed based on the theory of configuration stealth. The scattering distribution and RCS reduction properties of octagonal, hexagonal, triangular, and round head screws were analyzed. It can be seen that the triangular screw head has the maximum RCS reduction and the narrowest strong scattering angle range compared to the round head. Additionally, we proposed a round screw head with a smooth surface. We then researched the invisibility and strong scattering angle scope of the corresponding screw array and triangular head screw array. The comparison results indicate that the screw array with a round smooth surface has a lower RCS than the triangular head screw array, and the maximum reduction can reach up to 46.4 dB.

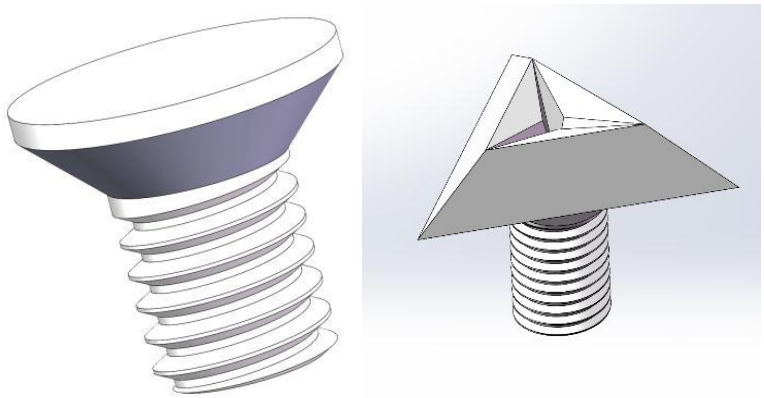
2. Angle regualtion of low RCS screw arrays

According to the RCS contribution of screw structure, screw head is the significant structure that affects the invisibility. With the scattering mechanism, we found that the triangular screw head has an excellent stealth performance compared with round slotted head and other regular polygon head screws. To enhance the stealth effect, a smooth round screw is introduced and investigated. Fig.1 shows the schematic diagram of the smooth circular screw and triangular screw. The radius and thickness of the smooth, round screw head are both 7.2 mm and 0.87 mm, and the body length is 10.52 mm. As well as the screws arranged in an array on the equipment, we investigated the stealth performance of screw arrays with smooth round heads, using the triangular screw head as a reference standard in this paper. Due to the absence of slots that match the screwdriver, a mechanical spring is utilized as the body of the screw, and magnetic tools are used to insert or

remove it. According to the horizontal incident wave shown in Fig.2, Fig.3 gives the RCS radar map for the triangular and smooth round screw arrays when the incident angle ranges from -45° to 45° . As seen in the figure, the smooth circular screw array exhibits excellent stealth performance at any angle.

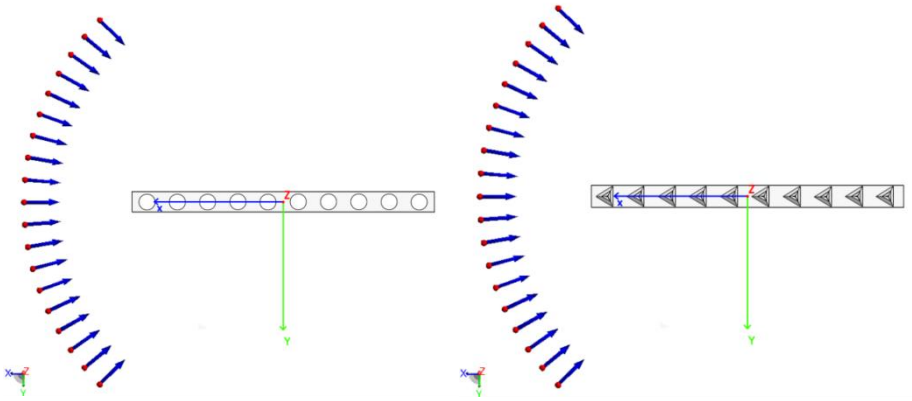
Underlying horizontal and vertical incidences, Fig.4 and Fig.5 illustrate the absolute RCS reduction (ΔRCS=σtriangular -σsmooth round) of the screw array with triangular and smooth round heads in HH and VV polarization respectively. The side lengths of the triangular screw head on the upper and lower surfaces are 9.32 mm and 18.79 mm, respectively. The angle between the side and bottom of the triangular frustum head is 51.8° . The spacing between screws in the x and y directions is 30 mm, whether it is on a smooth round surface or a triangular screw array. It is obvious that when an electromagnetic wave is horizontally incident, the RCS reduction of a round screw array with a smooth surface, which is comparable to that of a triangular head in VV polarization is significantly greater than that of HH. In VV polarization, there is a minimum 4.82 dB decrease at all angles and frequencies, and the maximum decrease can reach 46.4 dB. However, in the HH polarization, the round smooth surface screw array exhibited the best stealth effect with a reduction of 15.6 dB while the RCS values of the triangular screw array were smaller at specific angles. This is due to the mirror reflection created by the smooth screw array in horizontal polarization. Thus, the reduction in scattering in this scenario is slightly weaker compared to that in vertical conditions.

Besides, the reduction distribution under vertical incidence shown in Fig.5 is also different from the horizontal incidence shown in Fig.4. Similarly, the invisible effect in VV polarization was better than that in HH polarization. From the comparisons of results, we can see the angle that the stealth performance of the smooth screw array is weaker than that of the triangular screw array, focusing within ± 15 ° . The results indicated that the incident wave within this range approached the strong mirror scattering area for the smooth round screw array. Further analysis also revealed that the angle corresponding to the inferior invisibility under both polarizations is ± 30°. According to the geometry of triangular and smooth round screws, the angle between the side surface of the screw with a triangular head and the bottom is 51.8° . Therefore, the strong mirror scattering for each triangular head screw is similar to ± 30° , resulting in the corresponding relatively poor stealth performance for a smooth round screw array.



（a）circular head （b）triangular head

Figure 1: Geometry diagram of screw



(a) HH polarization (b) VV polarization

Figure 2: RCS comparison of triangular head and round head

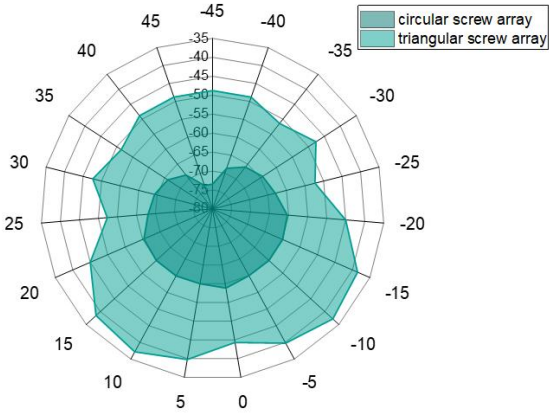
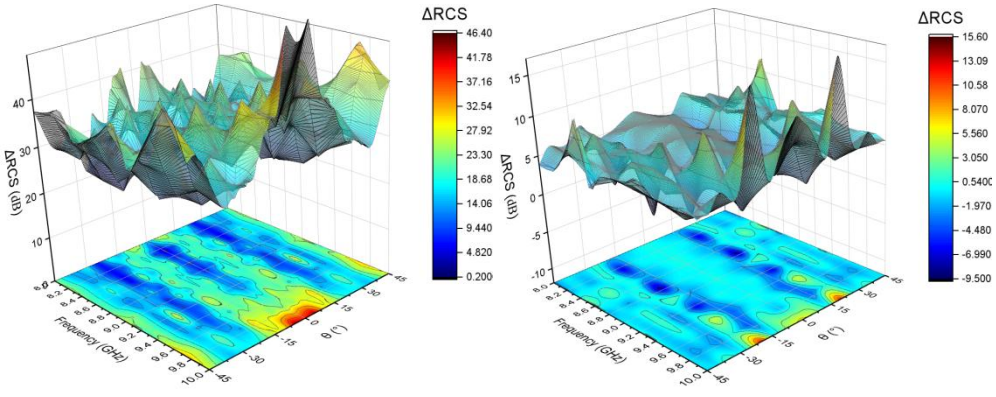
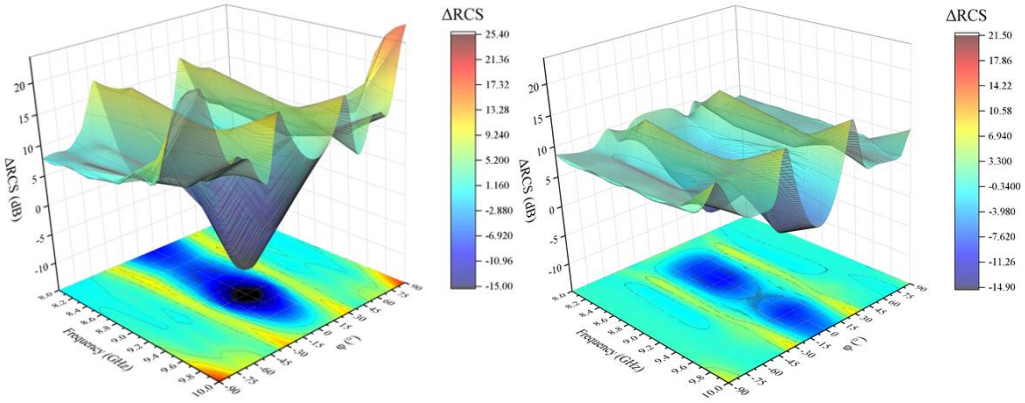


Figure 3: RCS of screw array at different incident angle



(a) VV polarization (b) HH polarization

Figure 4: RCS reduction of screw array under horizontal incidence



(a) VV polarization (b) HH polarization

Figure 5: RCS reduction of screw array under vertical incidence

3. Conclusion

Based on the geometry stealth theory, this study proposes an angle regulation method for low RCS screws that corresponds to peak scattering. The work revealed a systematic decrease in RCS and strong scattering angle range, indicating the accuracy and effectiveness of the angle control method for regular frustum screw heads. Furthermore, a round screw with a smooth surface and its corresponding array was introduced. The RCS shows a significant decrease compared to a triangular head screw array. While under vertical incidence, the stealth effect at certain angles is worse than that of horizontal conditions. This is caused by the mirror scattering on the tilted side of the triangular frustum screw head. The results illustrate the effectiveness and feasibility of the low-scattering screw design and angle manipulation method, which can provide theoretical support for reducing RCS of aircraft with the weak scattering sources.

Acknowledgment

Natural Science Foundation of Shaanxi Province (No. 2024-JC-QN-0690).
National Key Lab of Aerospace Power System and Plasma Technology (No.GJZD22021301).

References

[1] Sang JH. Low-observable technologies of aircraft [M]. Beijing: Aviation Industry Press, 2013.

[2] Ji JZ, Huang PL, Ma YP, et al. Invisibility principle [M]. Beijing: Beihang University Press, 2018.

[3] Sang JH, Zhang ZB, Wang S. Research on the radar cross section of weak scatters on stealth vehicle [J]. Advances in Aeronautical Science and Engineering, 2012, 3(3): 257-262.

[4] Huang PL, Liu ZH. Experimental research on the scattering characteristics of the bolt/rivet objects[J]. Acta Aeronautica, 2009, 30(5): 912-918.

[5] Liu ZH, Wang XL, Wang J, et al. Novel extraction approach of electromagnetic scattering for ideal discontinuities [J]. Advances in aeronautical science and engineering, 2017, 8(2): 236-243.

[6] Huang PL, Liu ZH. Scattering mechanism of electromagnetic discontinuities regularly distributed on aircraft surface [J]. Systems engineering and electronics, 2017, 39(11): 675-680.

[7] Liu ZH, Ji JZ, Wang J, et al. scattering mechanism of electromagnetic discontinuities regularly distributed on aircraft [J]. Systems Engineering and Electronics, 2017, 39 (11): 2428-2433.

[8] Yang HL, Wen DE and Wang HY. Analysis of EM Scattering from rivets on conducting Plate[J]. Journal of microwaves, 2005, 21(5): 14-21.

[9] Yang He-lin, Liu ZL, Wen DE, et al. Study on the EM scattering of rivets on the plate[J]. Wuhan University Journal of Natural Sciences, 2005, 10: 559-561.

[10] Guo JL, Ji YC and Liu QZ. Analysis of the scattering of rivet on aircraft[J]. Journal of electronics, 2002, 19: 434-437.

[11] Liu, Zhanhe, Peilin Huang, and Xu Gao. A novel numerical method for computing RCS of discontinuous characters[C]. In 2009 3rd European Conference on Antennas and Propagation, pp. 3714-3717. IEEE, 2009.