Study on the Ballistic-Resistant Airworthiness Standards for Commercial Aircraft Cockpit Door

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Abstract

In response to the requirements for ballistic-resistant airworthiness standards of cockpit doors for Chinese commercial aircraft, this study selected six potential gun cartridges and six potential cockpit door material combinations from both domestic and international sources for live-fire shooting tests based on a comparative analysis of relevant industrial standards on bullet penetration capabilities. By comparing and analyzing the test results, the order of penetration power of various gun cartridges on various door materials was obtained. Further, considering the current situation of civil aviation security in China, suggestions on suitable airworthiness standards and compliance methods for anti-hijacking cockpit doors of commercial aircraft in China were proposed, providing a reference for clarifying the technical requirements of CCAR 25.795 a(2) for airworthiness standards.

Keywords: Cockpit door, Ballistic-resistant, CCAR 25.795a(2), Live-fire shooting test

After the "911" incident in the United States in 2001, the FAA recognized the importance of ensuring the safety of the cockpit and preventing the hijacking of aircraft, and subsequently revised the airworthiness regulations for transport category aircraft (14 CFR 25[1]), adding section 25.795 "Security Matters", which requires the design of aircraft cockpit doors to resist violent intrusion and the penetration of light weapons ammunition, with ballistic-resistant capability meeting the III A protection level of NIJ 0101.04. The airworthiness regulations for transport category aircraft in China (CCAR-25-R4[2]) also introduced section 25.795, requiring the cockpit door to resist the penetration of light weapon firepower and explosive devices, meeting the requirements of the authority, but did not specify the specific standard value required.

Based on a comparative analysis of relevant domestic and international industrial standards on bullet protection, this study selected six combinations of gun cartridges and six potential anti-hijacking cockpit door materials from both domestic and international sources for live-fire shooting tests, thereby obtaining the order of penetration power of various gun cartridges on various materials through comparative analysis. On this basis, further combining the current situation and potential security risks of civil aviation security in China, suggestions on suitable airworthiness standards and compliance methods for anti-hijacking cockpit doors of commercial aircraft in China were proposed, providing an important reference for clarifying the technical requirements of CCAR 25.795a(2) for airworthiness standards.

1. Analysis of Ballistic-resistant Airworthiness Requirements for Cockpit Doors

After the "911" incident in the United States, the FAA fully recognized the importance of aircraft security and successively issued three amendments (Amdt.25-106, 25-127, 25-138) for transport category aircraft, adding and continuously revising and improving section 25.795 "Security Matters", of which the first two amendments involve requirements for cockpit intrusion prevention. The currently effective requirement for bullet protection is section 25.795a(3), requiring that the cockpit partition, door, and any other division separating the passenger area and cockpit must be designed to resist the penetration of light weapon firepower and explosive devices, achieving a protection level equivalent to NIJ 0101.04 III A.

China's "Transport Category Aircraft Airworthiness Standards" (CCAR-25-R4) issued in 2011 also introduced 25.795 Security Matters (equivalent to Amdt.25-106). Among them, section 25.795a(2) is a requirement for ballistic-resistant cockpit doors, requiring that the cockpit door must be designed and installed to resist the penetration of light weapon firepower and explosive devices, and meet the requirements of the authority.

To meet the above requirements for cockpit doors to resist the penetration of light weapons and explosive devices, Methods of Compliance (MoC) such as descriptive documents(MoC1), analysis/calculations(MoC2), and laboratory tests(MoC4) are usually used for verification. Among them, the most important is the MoC4 laboratory demonstration tests. The FAA proposed in AC 25.795-2A[3] a compliance verification test method to meet the requirements for cockpit anti-light weapon penetration, including the selection of test plate materials, gun cartridges, test firing angles and times, evidence sheets, test facilities (see Figure 1), and detailed test procedures, as well as judgment criteria.

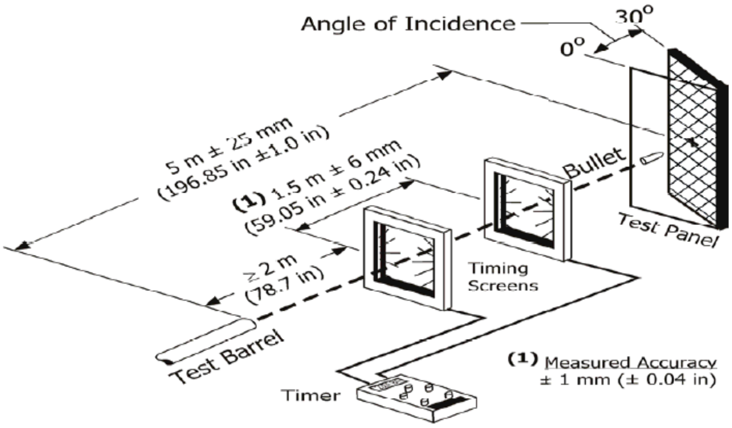


Figure 1 – Test arrangement for ballistic test panels.

2. Analysis of Bulletproof Industrial Standards for Cockpit Doors

2.1 2.1 FAA-Required Bulletproof Industrial Standards for Cockpit Doors

The FAA in the United States has directly defined the bulletproof standard for cockpit doors in its regulations as the NIJ 0101.04[4] IIIA protection level. This level requires the ability to defend against 9mm full metal jacket round nose (FMJ RN) bullets, with a bullet weight of 8.0g and a minimum impact velocity not exceeding 427m/s; it can also defend against .44 Magnum semi-jacketed hollow-point bullets, with a bullet weight of 15.6g and a minimum impact velocity not exceeding 427m/s. The bulletproof testing method outlined in this standard is largely consistent with that in AC 25.795-2A.

2.2 Overview of Bulletproof Industrial Standards in China

Currently, China's bulletproof equipment industrial standards are mainly divided into two categories: military standards and police standards. From the perspective of equipment types, the bulletproof standards for personal protective equipment mainly include helmets and bulletproof vests. Bulletproof vest standards include GA 141-2010 Police Bulletproof Vest [5], GJB 4300A-2012 Military Bulletproof Vest Safety Technical Performance Requirements [6], and bulletproof helmet standards include GA293-2012 Police Bulletproof Helmet and Face Shield [7], GJB 5115-2004 Military Bulletproof Helmet Safety Technical Performance Requirements [8], etc.

Considering the bulletproof requirements of cockpit doors, which require the ability to prevent the penetration of light weapons (pistols), the research should focus on the protection standards for pistol bullets. Among them, GA 141-2010 and GJB 4300A-2012, as China's most basic bulletproof rating standards, cover all types of pistols and corresponding bullets mentioned in the above standards. Therefore, this article focuses on studying the bulletproof requirements and testing methods of the above two standards, thereby comparing them with the NIJ 0101.04 standard IIIA bulletproof level referenced in 25.795.

GA141-2010 classifies bullet protection levels into 6 grades, with grades above 6 classified as special grades. Among them, grades 1 to 2 correspond to pistol bullets, and grades 3 and above correspond to submachine gun and rifle bullets. Appendix A recommends grades 4 and below for pistol bullets, which are characterized by a bullet speed below 480m/s. In the GJB 4300A-2012 standard, comprehensive consideration is given to the protection capabilities of fragments and bullets, with bullet protection levels included in protection levels II and III. Among them, level II corresponds to pistol bullets, and level III corresponds to rifle bullets. According to the comparison principle of the same type of bullets, the same or similar initial bullet speed, the protective level defined by the two standards corresponds to Figure 2 below. In terms of pistol bullets, the protective level of GA141-2010 can cover GJB 4300A-2012.

Protection Level in GA 141-2010	
Type-51, 7.62mm gun bullets (lead core) Initial velocity: 445±10m/s	2
Type-53 7.62mm armor-piercing incendiary bullet Initial velocity: 810±10m/s	Special (Recommendation)

Protection Level in GJB 4300-2012	
II	Type-51, 7.62mm gun bullets (lead core) Initial velocity: 445±10m/s
III	Type-53 7.62mm armor-piercing incendiary bullet Initial velocity: 808m/s

Figure 2 – Comparison of protective levels of Chinese police and military bulletproof vests

2.3 Comparison of Bulletproof Capabilities Between Domestic and International Standards

Through a comparative analysis of NIJ 0101.04, GA 141-2010, and GJB 4300-2012, it was found that bullet structure (including bullet shape, bullet diameter, bullet core material, etc.), bullet weight, and bullet speed are common grading factors in bulletproof level classification. Among them, bullet weight and bullet speed directly affect impact energy. The penetration power of bullets is not only related to impact energy but also to bullet structure. Taking the two pistol bullets specified in the NIJ 0101.04 IIIA protection level as the benchmark, the corresponding protection levels in the GA 141-2010 standard are mainly GA2 level and GA recommended level 4. After comprehensive analysis, the final combination of alternative bullets selected for the following domestic bulletproof capability comparison test verification of anti-hijacking cockpit doors is shown in Table 1.

Table 1 – Combination of Bulletproof Capability Verification for Domestic Cockpit Doors

No.	Bullets	Nominal masses (g)	Structures of bullet warheads	Initial velocity (m/s)	Corresponding level of protection
①	Type-51, 7.62mm gun bullets (lead core)	5.6	Round nose, lead core, steel and copper Jacketed	445±10	level 2, GA141-2010
②	Type-51, 7.62mm gun bullets (steel core)	5.68	Round nose, steel core, copper Jacketed	445±10	GA141-2010
③	DAP92A2, 9mm gun bullets (steel core)	8.0	Round nose, steel core, copper Jacketed	360±10	Recommendation level 4, Appendix A, GA141-2010
④	9 mm Full Metal Jacketed Round Nose (FMJ RN) bullets	8.1	Round nose, lead core, Full Metal Jacketed	427±9.1	IIIA, NIJ 0101.04
⑤	DAP92, 5.8mm gun bullets (steel core)	3.0	Point, steel core, steel and copper Jacketed	480±10	Recommendation level 4, Appendix A, GA141-2010
⑥	.44 Magnum Jacketed Hollow Point (JHP) bullets	15.6 g	Hollow Point, Magnum Jacketed, lead core	427±9.1	IIIA, NIJ 0101.04

A total of 6 different bullet combinations were selected, of which bullets No.4 and No.6 represent the test conditions specified in the NIJ 0101.04 IIIA level, while bullets No.1, 2, 3, and 5 represent domestic gun cartridges. Among them, bullets No. 2, which is suitable for the Type-79 light submachine gun in GA 141, was modified to be fired by the Type-54 pistol due to the consideration that the bulletproofing of the cockpit door is a handgun threat. The initial velocity was reduced, and the threat impact was lower than the original Level-4 protection level. Bullets No.1, 3, and 5 correspond to the Level-2 and recommended Level-4 protection specified in GA 141, respectively.

3. Ballistic Test of Cockpit Door Materials

3.1 Selected Materials for Testing

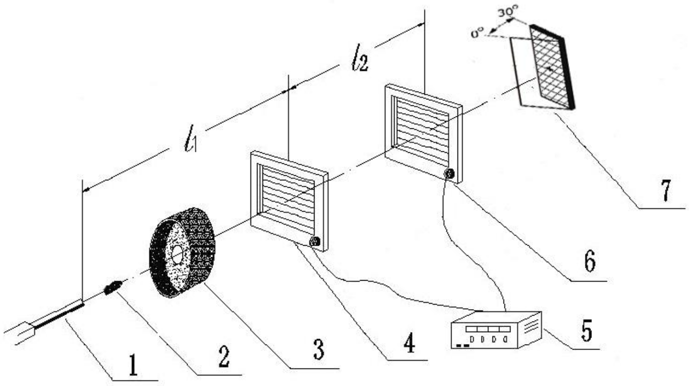
Six types of material targets (see Table 2) potentially suitable for cockpit door ballistic protection were selected for live-fire testing with the six types of ammunition listed in Table 1 to determine the penetration power of the six typical ammunition types against the six materials.

Table 2 - Target Sample Parameters

Target sample Type	Material standard / brand	Size (mm×mm)	Thickness (mm)	Area density (kg/m^2)
Bulletproof steel plates (ductile steel)	——	333×325	3.3	24.5
Titanium alloy (Ti-6Al-4V) plates	AMS4911	300×300	5.5	24.1
Polybenzoxazole（PBO）Composite material plates	Zylon HM	400×400	5.3	6.9
Aramid fiber 3 Composite material plates	Aramid fiber 3	400×400	5.0	6.3
High strength polyethylene (PE) fiber composite plates	Spectrashield	350×350	5.0	4.9
High strength polyethylene (PE) fiber composite plates	Dyneema	400×400	5.2	5.0

3.2 Test Method

The test site was selected at a gunfire test range. The test method was conducted in accordance with the requirements of AC 25.795-2A (see Figure 3 for test setup). Each ammunition type was fired six times on each target plate, with the impact positions illustrated in Figure 4. The impact angles of #1, #2, #3, and #6 shots were 0°, while the #4 and #5 shots had an impact angle of 30°.



Explanation:
1 - Test firearm 2 - Fragment simulation ammunition 3 - Cartridge catcher 4 - Initial velocity target trigger screen
5 - Chronograph 6 - Final velocity target trigger screen 7 - Test sample
l_1 - Distance from gun muzzle to initial velocity target trigger screen l_2 - Distance between velocity target screens

Figure 3 - Schematic diagram of ballistic test system setup

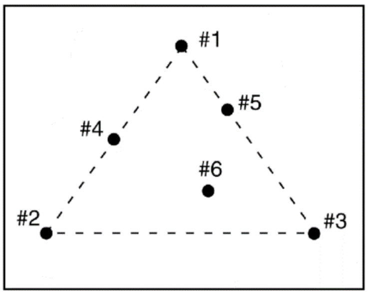


Figure 4 - Test impact positions

To eliminate random factors, the above-mentioned firing test was repeated three times on three target plates of the same material for each gun cartridge. The test results were classified as penetration and non-penetration. In cases of non-penetration, the deformation of the target plate sample was used to evaluate the penetration power of the projectile. For metallic materials, permanent deformation would occur after impact, with the deformation amount being the maximum height after deformation. For composite material plates, deformation would occur with rebound, and the deformation amount was measured by the maximum indentation depth of the backing material.

3.3 Test Results

Taking the titanium alloy plate (Ti-6Al-4V) as an example, the conditions after testing with the six gun cartridges in Table 1 are shown in Figure 5, and the test results are summarized in Table 3.

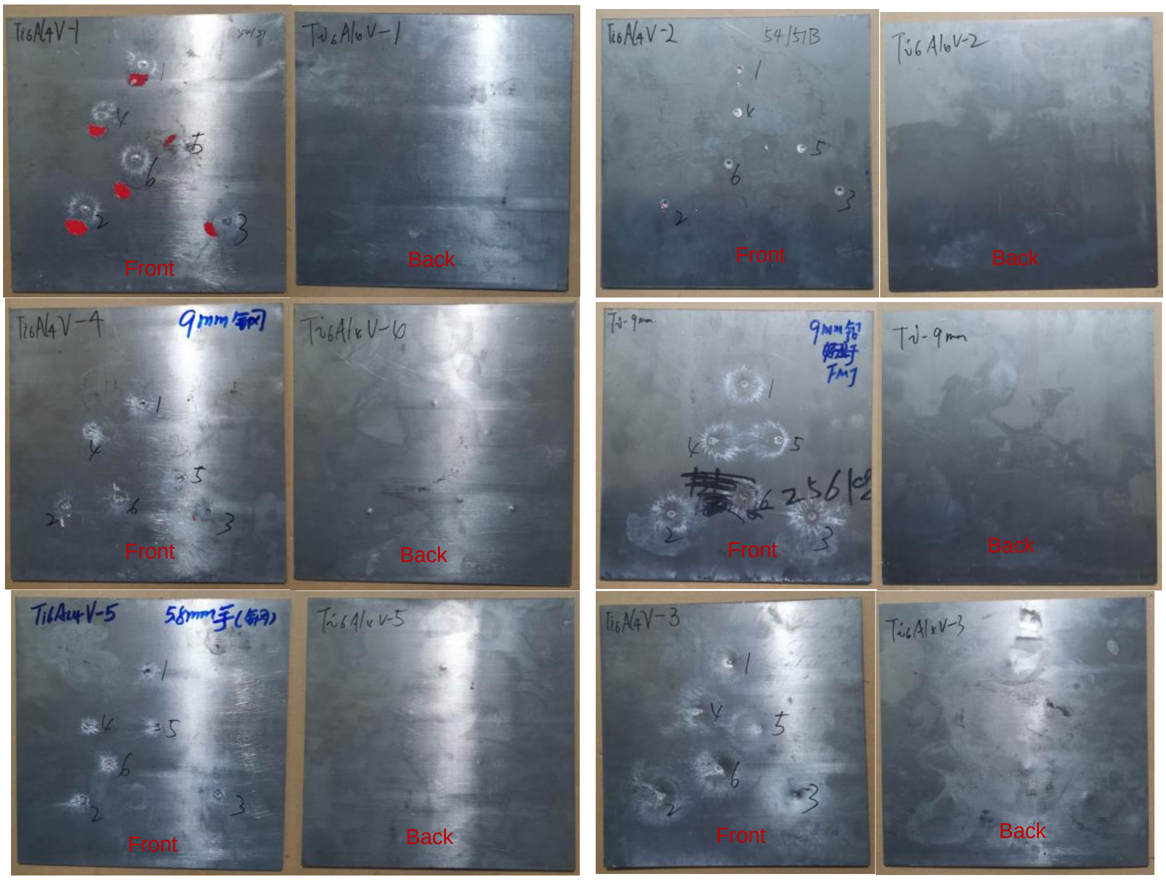


Figure 5 - Conditions of titanium alloy plate (Ti-6Al-4V) after testing

Table 3 - Test results of titanium alloy plate (Ti-6Al-4V)

Bullets	Penetration Status	Average Vertical Impact Deformation (mm)	Average Angled Impact Deformation (mm)
Type 51, 7.62mm gun bullets (lead core)	0 penetration	0	0
Type 51, 7.62mm gun bullets (steel core)	0 penetration	0.07	0.03
DAP92A2, 9mm gun bullets (steel core)	0 penetration, with 2 bullets causing cracks on the back	0.43	0
9 mm Full Metal Jacketed Round Nose (FMJ RN) bullets	0 penetration	0	0
DAP92, 5.8mm gun bullets (steel core)	0 penetration	0.10	0
.44 Magnum Jacketed Hollow Point (JHP) bullets	0 penetration, with no cracks on the back	0.74	0

From the test results, for the titanium alloy plate (Ti-6Al-4V), the DAP92A2 9mm pistol bullet (steel core) exhibited the greatest penetration power, with two shots causing cracks on the back of the sample. Secondly, the .44 semi-jacketed hollow-point (SJHP) bullet had a relatively high penetration power, though it did not cause cracks on the back of the sample, it caused significant deformation with the largest mean vertical deformation. The penetration power of the remaining four ammunition types, ranked by the deformation of the target plate, was DAP92 5.8mm pistol bullet (steel core) > Type-51 7.62mm pistol bullet (steel core) > FMJ RN 9mm (lead core) > Type-51 7.62mm pistol bullet (lead core).

Therefore, for the titanium alloy plate (Ti-6Al-4V), the top four ammunition types with the highest penetration power were, in order, the DAP92A2 9mm pistol bullet (steel core), .44 semi-jacketed hollow-point (SJHP) bullet, DAP92 5.8mm pistol bullet (steel core), and Type-51 7.62mm pistol bullet (steel core).

Taking the high-strength polyethylene fiber composite plate (Spectra) as an example, the conditions after testing with the six gun cartridges in Table 1 are shown in Figure 6, and the test results are summarized in Table 4.

Based on the test results, for the high-strength polyethylene fiber composite plate (Spectra), the

DAP92 5.8mm pistol round (steel core), Type-51 7.62mm pistol round (steel core), and DAP92A2 9mm pistol round (steel core) showed the greatest penetration power, all resulting in six complete penetrations of the sample. The penetration power of the remaining three rounds, ranked according to the deformation of the target plate, is .44 semi-jacketed hollow-point (SJHP) round > FMJ RN 9mm (lead core) > Type-51 7.62mm pistol round (lead core).

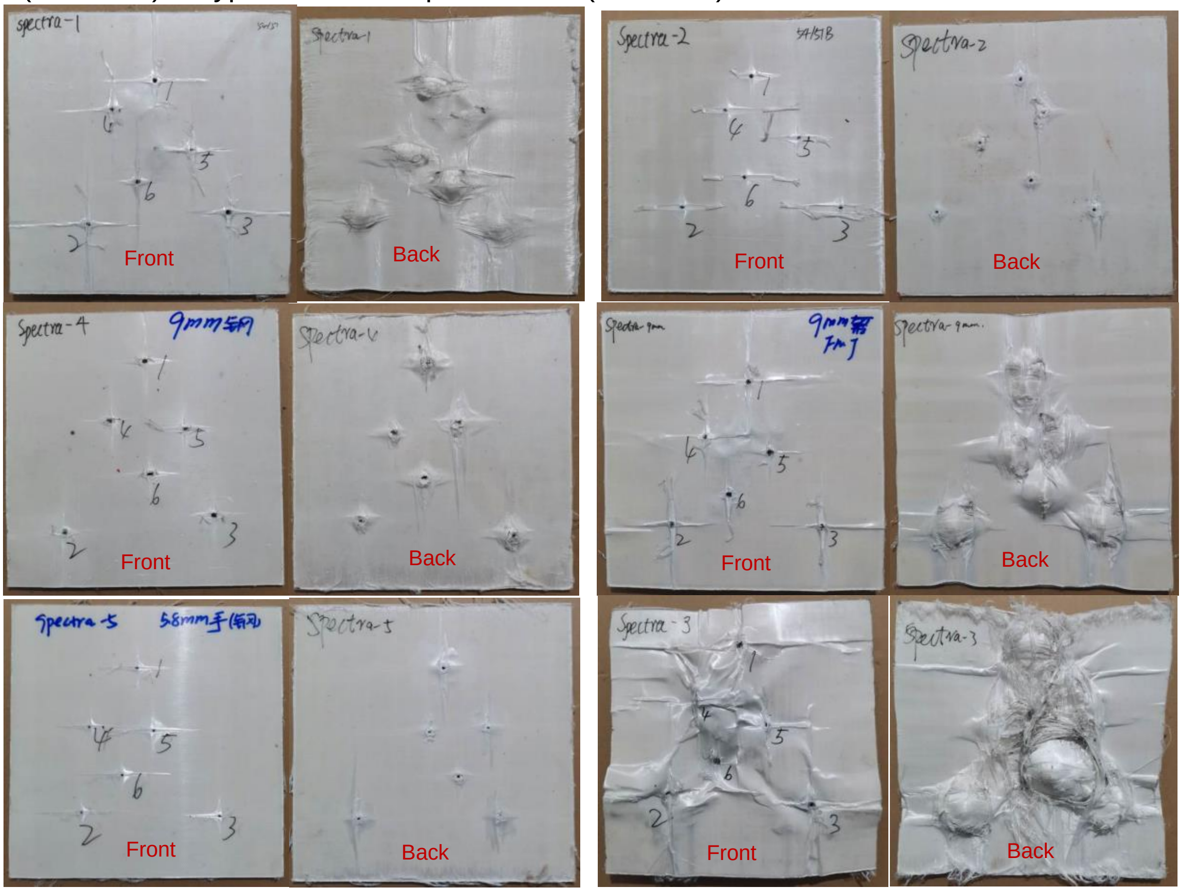


Figure 6 - Condition of high-strength polyethylene fiber composite plate (spectra) after testing

Table 4 - Test results of high-strength polyethylene fiber composite plate (Spectra)

Bullets	Penetration Status	Average Vertical Impact Deformation (mm)	Average Angled Impact Deformation (mm)
Type 51, 7.62mm gun bullets (lead core)	0 penetration	20.1	22.6
Type 51, 7.62mm gun bullets (steel core)	6 penetrations	/	/
DAP92A2, 9mm gun bullets (steel core)	6 penetrations	/	/
9 mm Full Metal Jacketed Round Nose (FMJ RN) bullets	0 penetration	24.7	23.9
DAP92, 5.8mm gun bullets (steel core)	6 penetrations	/	/
.44 Magnum Jacketed Hollow Point (JHP) bullets	0 penetration	34.2	31.5

Table 5 - Test results of six material plates

Rank	Zylon HM, PBO	Dyneema	Spectrashield	Aramid fiber 3	Titanium alloy	Bulletproof steel
1	⑤	⑤	⑤	⑤	③	⑤
2	②	②	②	②	⑥	⑥
3	③	③	③	③	⑤	④
4	⑥	⑥	⑥	⑥	②	②
5	④	④	④	④	④	①
6	①	①	①	①	①	③

Therefore, for the high-strength polyethylene fiber composite plate (Spectra), the top four rounds in terms of penetration power are DAP92 5.8mm pistol round (steel core), Type-51 7.62mm pistol round (steel core), DAP92A2 9mm pistol round (steel core), and .44 semi-jacketed hollow-point (SJHP) round.

Based on the analysis mentioned above, the penetration power of the six types of ammunition against six different materials is ranked from high to low in Table 5.

From the test results in the table, we can draw the following conclusions:

(1) Different projectiles exhibit different penetration power against different types of bulletproof materials. Under the same conditions, steel-core rounds have stronger perforation and penetration capabilities compared to lead-core rounds, while lead-core rounds exhibit stronger overall destructive power; especially for composite material plates, steel-core rounds can basically achieve full perforation and penetration, but for metal materials, steel-core rounds are more difficult to penetrate.

(2) Among the aforementioned six typical rounds, on the whole, the DAP92 5.8mm pistol round (steel core) exhibits the greatest power and the strongest penetration capability; while the Type-51 7.62mm pistol round (lead core) has the smallest power and the weakest penetration capability.

(3) For fiber-reinforced composite plates such as polybenzoxazole(PBO), high-strength polyethylene fiber, and aramid, the top four rounds in terms of penetration power are DAP92 5.8mm pistol round (steel core), Type-51 7.62mm pistol round (steel core), DAP92A2 9mm pistol round (steel core), and .44 semi-jacketed hollow-point (SJHP) round.

(4) The Type-51 7.62mm pistol bullet (steel core) exhibits strong penetration ability against high-strength polyethylene fiber and aramid bulletproof plates; however, its penetrating ability against bulletproof steel plates is slightly weaker than the .44 semi-jacketed hollow point (SJHP) bullet and the FMJ RN 9mm (lead core) bullet.

4. Analysis of Airworthiness Standards and Compliance Methods for Anti-Hijacking Cockpit Doors

4.1 Recommendation on Selection of Bullets for NIJ 0101.04 IIIA Protection Level

In response to the NIJ 0101.04 IIIA protection level requirements, based on the test results, all six materials can effectively defend against the .44 semi-jacketed hollow point (SJHP) bullets and the 9mm full metal jacket round nose (FMJ RN) lead-core bullets. Furthermore, the penetration power of the .44 bullets is greater than that of the 9mm bullets. Therefore, it can be concluded that for commonly used materials such as steel plates, titanium alloy plates, polyethylene composite plates (PE plates), and aramid composite plates for civilian aviation cockpit doors, the penetration power of the .44 semi-jacketed hollow point (SJHP) bullets is greater than that of the 9mm FMJ RN (lead-core) bullets.

Consequently, applying this conclusion to the airworthiness compliance verification and review process, when using the NIJ 0101.04 IIIA protection level as the requirement for preventing light weapon intrusion into the cockpit door, only the .44 semi-jacketed hollow point (SJHP) bullets need to be used for testing. If the protection against this bullet is met, it can be considered to meet the NIJ 0101.04 IIIA protection level requirements.

4.2 Analysis of Substituting of Foreign Bullets with Domestic Bullets

According to the NIJ 0101.04 IIIA protection level requirements, when conducting ballistic testing, it is necessary to use the .44 semi-jacketed hollow point (SJHP) and the 9mm FMJ RN (lead-core) bullets. However, these two types of bullets are relatively rare and costly in China. Therefore, it is necessary to analyze the feasibility of using domestic bullets to replace these two bullets for airworthiness compliance verification testing based on the test results.

From the test results, for composite material plates, the penetration power of the DAP92A2 9mm pistol bullet (steel core) is slightly greater than that of the .44 bullet. For steel plates, the penetration power and damage effect of the DAP92 5.8mm pistol bullet (steel core) are both significant, with bullet capture observed. However, the DAP92 bullet penetrated 5 times while the .44 bullet did not penetrate. The penetration power of the DAP92 bullet is significantly higher than that of the .44 bullet. For titanium alloy plates, none of the six bullets tested penetrated, but the DAP92A2 9mm pistol bullet (steel core) caused cracks on the back of 2 bullets, while the .44 bullet did not have cracks but had a mean vertical impact deformation of 0.74mm, which is larger than that of the DAP92 bullet (0.43mm), both being less than 1mm. It can be considered that the penetration power of the two bullets against titanium alloy plates is roughly equivalent.

In summary, based on the existing test data, for composite material plates, it is feasible to use the

DAP92A2 9mm pistol bullet (steel core) instead of the .44 bullet for testing, but it will be slightly stricter and more conservative. For steel plates, it is feasible to use the DAP92 5.8mm pistol bullet (steel core) instead of the .44 bullet, but it will also be slightly stricter and more conservative. For titanium alloy plates, using the DAP92A2 9mm pistol bullet (steel core) for testing is relatively feasible.

5. Conclusions and Recommendations

Based on a comparative analysis of domestic and international industrial standards related to bulletproof materials, this paper selected six types of ammunition and six possible combinations of materials for anti-hijacking cockpit doors, conducting live-fire tests. Through comparative analysis of the test results, the penetration power of six types of ammunition against six types of materials was ranked, and the following conclusions and recommendations were further derived.

(1) Recommendations for bulletproof airworthiness standards for anti-hijacking cockpit doors in china

Through the aforementioned comparative analysis and experimental research, it has been found that the penetration power of Chinese handgun ammunition is higher than that of NIJ 0101.04 IIIA level handgun ammunition. Therefore, if considering no other factors, the protective level of commercial aircraft cockpit doors against the intrusion of Chinese handgun ammunition should not be lower than the recommended level 4 of GA141-2010 Appendix A. The specific protective level requirements are as follows:

GA141-2010 Appendix A Recommended Level 4:

This level defends against the threat of DAP92 type 5.8mm handgun ammunition (pointed steel core, lead column, copper-clad steel jacket), with a bullet weight of 3.0g and a muzzle velocity of 480±10m/s (fired using the QSZ92 type 5.8mm handgun).

(2) Recommendations for two gun cartridges testing for NIJ 0101.04 Ⅲa protective level

Through comparative research, it has been found that for commonly used materials in civil aviation cockpit doors, such as steel plates, titanium alloy plates, polyethylene composite plates, and aramid composite plates, the penetration power of .44 semi-jacketed hollow-point (SJHP) ammunition exceeds that of FMJ RN 9mm (lead core) ammunition.

Therefore, when conducting live-fire tests using the NIJ 0101.04 ⅢA protective level, only .44 semi-jacketed hollow-point (SJHP) ammunition can be used for testing. If the protection against this ammunition is met, it can be considered to meet the NIJ 0101.04 ⅢA protective level requirements.

(3) Recommendations for using Chinese ammunition as a substitute for foreign ammunition in testing

If adopting the NIJ 0101.04 IIIA level requirements and seeking domestic ammunition to replace the corresponding ammunition of the NIJ 0101.04 IIIA level during testing, the following substitution schemes are feasible:

For titanium alloy plates, using DAP92A2 type 9mm handgun ammunition (steel core) as a substitute for NIJ 0101.04 IIIA level ammunition is relatively feasible.

For steel plates, using DAP92 type 5.8mm handgun ammunition (steel core) as a substitute for NIJ 0101.04 IIIA level ammunition is feasible, but it will be stricter and more conservative.

For composite material plates, using DAP92A2 type 9mm handgun ammunition (steel core) as a substitute for NIJ 0101.04 IIIA level ammunition is feasible, but it will be stricter and more conservative.

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