Analysis of Critical Technical Issues in Aviation Forest Protection Operations

Minheng QIN

China Flying Dragon Special Aviation Company, Zhengzhou 450000, China

Abstract This paper puts forward essential technical issues pertinent to frontline personnel, including terminal managers, air traffic controllers, aerial observers, and operational aircrews engaged in aviation forest protection operations. Critical topics discussed include the calculation of coordinates, the establishment of a database for significant operational points, and the systems about communication and navigation and surveillance of aircraft. Ultimately, the paper provides recommendations designed to improve the safety and efficiency of aviation forest protection operations, thereby aligning with the objectives of the low-altitude economy policy.

Key words Aviation forest protection; Critical; Technical issues

1 Introduction

Aviation forest protection, a critical component of forestry engineering, is one of the most significant methods for forest fire prevention employed by developed countries globally[1]. Since the 1950s, aerial firefighting has been vigorously developed in Russia, Canada, and the United States, where aviation plays a pivotal role in combating forest fires[2]. Since 2009, aviation forest protection has gained prominence in China's efforts to prevent forest fires, significantly contributing to the safeguarding of forest resources and the protection of human lives and property[3].

However, in contrast to CCAR-121 airline transport flights, contemporary aviation forest protection operations at terminals in China present numerous technical challenges for terminal managers, aerial observers, air traffic controllers, operational aircrews, and other frontline personnel. These challenges not only hinder the efficiency of aviation forest protection operations but also pose significant risks to flight safety, being a "hidden killer" that warrants serious attention. In light of this, pertinent literatures alongside years of experience in the working in civil aviation field are synthesized to systematically and thoroughly examine these critical technical issues. This analysis serves to provide assurance and guidance for the safe and efficient execution of aviation forest protection operations. Furthermore, addressing these technical issues is an essential prerequisite for the successful implementation of China's low-altitude economic policy.

2 Coordinate calculation issues and related recommendations

2.1 Production of coordinate calculation issues In aviation forest protection operations, when a fire occurs, it is essential for the terminal to ascertain the approximate coordinates of the fire based on the bearing/bearing observed from various lookout towers. The literature[4] presents a coordinate calculation method developed on the Visual Basic Platform. However, this method is primarily derived from plane geometry and does not effectively calculate latitude and longitude based on the bearing of two points, resulting in a calculation error.

In addition, once the coordinates of the operational points, such as the fire point, water point, and air landing point, have been established, it is essential for air traffic controllers, aerial observers, and pilots to first verify the distance and bearing of these operational points in relation to the air landing and take-off points. This verification is crucial for determining the flight navigation data and elements. In contemporary aviation forest protection operations, frontline personnel typically employ a combination of traditional map navigation and GPS technology. Although this approach generally fulfills operational requirements, discrepancies in coordinate systems across various software and equipment may create significant inconveniences during actual flights, potentially resulting in positional inaccuracies.

2.2 Impact of different coordinate systems In geodetic theory[5], various ellipsoidal parameters are employed to establish distinct geodetic coordinate systems. The geodetic coordinate systems predominantly employed in China's surveying and mapping industry include the Beijing 54, Xi'an 80, and CGCS2000 systems. In contrast, the geodetic coordinate system utilized in civil aviation, as stipulated by the International Civil Aviation Organization (ICAO), is the WGS-84 coordinate system. Additionally, certain mapping software, such as Baidu Maps and Ovitalmap, typically utilize independent coordinate systems that are encrypted by CGCS2000. This discrepancy results in practical challenges, wherein the same geographical point may possess different coordinates across various coordinate systems, or conversely, the same set of coordinates may correspond to different locations in distinct coordinate systems.

To unify the position, regardless of the methods, equipment, and personnel used to obtain the coordinates of operational points, it is essential to convert these coordinates to the WGS-84 coordinate system in accordance with civil aviation requirements. Subsequently, this information can be made accessible to relevant stake-

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E-mail: xk1805@126.com

holders for the purpose of calculating flight navigation data and elements, as well as for visualization through various GIS software applications.

2.3 Bessel geodesic theme algorithm for coordinate calculation and software implementation The literature[6] discusses the application of the Bessel geodesic theme algorithm for the calculation of latitude and longitude. Specifically, when the latitude and longitude of two points are known, it is possible to compute their distance and bearing. Conversely, if the latitude and longitude of one point, along with its distance and bearing to another point, are known, the latitude and longitude of the second point can be determined. Furthermore, there exist additional forms, including distance-distance, bearing-bearing, *etc*. The approach that utilizes the bearing from two or more lookout towers to ascertain the coordinates of a fire exemplifies the bearing-bearing form. COMPSYS21 software has received approval for use from the Federal Aviation Administration (FAA) and is designed to perform geodetic calculations. This software encompasses eight distinct geodetic calculations: FORWARD, INVERSE, SEGMENT/SEGMENT, BEARING/BEARING, SEGMENT DISTANCE, CIRCLE BEARING, CIRCLE/CIRCLE, and SEGMENT BEARING. The results generated by these calculations can be directed to a user-specified printer or saved to a file[7]. Specific details regarding the calculations and their results are provided in the software manual and associated references, and will not be reiterated in this paper. The primary interface of the COMPSYS21 software is illustrated in Fig. 1.

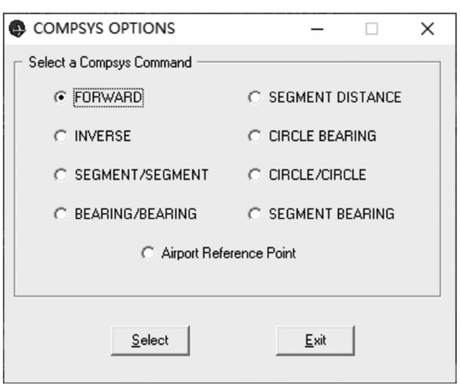

Fig. 1 Primary interface of COMPSYS21 software

2.4 Relevant recommendations All latitude and longitude data obtained during aviation forest protection operations must be uniformly converted to the WGS-84 coordinate system. This conversion is essential for the accurate calculation of flight navigation data and elements, as well as for effective visualization in various GIS software applications. Furthermore, the terminal should utilize COMPSYS21 software to conduct the coordinate calculations for each form when a computer is accessible. The results obtained by aerial observers and pilots utilizing GPS and other equipment should be compared with the results generated by the COMPSYS21 software. In the event of a significant discrepancy, a cross-check should be conducted to ensure the accuracy of the input parameters. Ultimately, the calculation results produced by the COMPSYS21 software should be considered authoritative.

3 Issues related to important operational point database and relevant recommendations

3.1 Significance of important operational point database

In aviation forest protection operations, it is frequently essential to obtain geographic location data, which may include information on fire sites, terminals, helicopter landing and take-off locations, aircraft landing zones, water points, obstacles, and significant landmarks. The utilization of latitude and longitude positioning is straightforward, intuitive, and convenient, serving as the primary method employed by frontline workers in contemporary practice. However, these points are frequently available on-site in various formats, including handwritten notes and screenshots. Their utilization has become more widespread across the organizational hierarchy, involving a greater number of individuals. Consequently, the transmission process is susceptible to errors, which can diminish work efficiency and potentially introduce security risks.

In the context of helicopters conducting searches for water points, it has become standard practice at terminals for helicopters engaged in patrol or training flights to document the coordinates of any identified water points. This information is subsequently communicated to other personnel. In contrast, the implementation of the center of gravity model, which employs the dynamic generation of weighted Voronoi diagrams via cellular automata, in conjunction with the local optimization of water source location planning for forest fire fighting through the alternating positioning allocation algorithm, markedly decreases the number of iterations necessary to identify the location for water sources. This approach enhances the rationality of the water source locations, thereby improving the overall efficiency of forest fire-fighting efforts[8]. However, this approach is contingent upon the use of ground-based computers and specialized personnel, and it can not be implemented during actual flights. In such situations, it is imperative for observers and pilots to ascertain the latitude and longitude of the nearest water point in proximity to the fire. Consequently, it is essential to create a comprehensive database of significant operational points at the terminal level. This database should be regularly updated and maintained to incorporate various types of operational points acquired through diverse methodologies during standard operational periods, ensuring rapid, accurate, and consistent access. For instance, a .csv format can be utilized for the database, as illustrated in Fig. 2.

3.2 Visualization of GIS platform for the critical operational point database Data can be exported to GIS platform data formats, including KML, KMZ, and GPX, through programming languages such as VBA, C#, and Python, as well as software applications like ArcGIS and TGO. Subsequently, this data can be imported into computers, mobile devices, and other GIS platforms, enabling the visualization of various types of operational points on maps. The GPX and KML data format files containing coordinates in the WGS-84 coordinate system, generated from the database, obviate the necessity for conversion from a local coordinate system to the WGS-84 coordinate system. This approach not only saves time but also mitigates the inconveniences associated

	A	B	C	D	E	F	G	H	I
1	Type	Name	Latitude/°	Longitude/°	Magnetic difference	Elevation	Tower frequency/MHz	Nav aids identifier	Nav aids frequency/MHz
2	Airport terminal	HUZHONG	52.019722	123.598889	-13	544	130.00		
3	Airport terminal	JIAGEDAQI	50.371111	124.1175	-13	370	130.00		
4	Airport terminal	QINGLIN	51.104722	125.328611	-13	422			
5	Airport terminal	TUQIANG	52.945811	122.767906	-13	485			
6	Airport terminal	YIZIQUAN	51.588333	126.314167	-13	400			
7	Landing point	AMUER	52.842224	123.1775	-13	526			
8	Landing point	DAZIYANGSHAN	50.672139	125.250278	-13	384			
9	Landing point	MANGUI	52.108334	122.0625	-13	617			
10	Landing point	QINGLIN	51.105556	125.327774	-13	431			
11	Landing point	SONGLINGQUXIAOYANGQIZHEN	50.789722	124.327444	-13	412			
12	Landing point	SONGLINGTINGJIPING	50.795555	124.295	-13	412			
13	Landing point	XINLIN	51.65167	124.38861	-13	500			
14	Landing point	YIZIQUAN	51.593887	126.30278	-13	347			
15	Landmark	DABAISHANLIAOWANGTA	51.296665	123.12666	-13	1511			
16	nav aids(NDB)	JIAGEDAQI	50.390528	124.112361	-13	370		JQ	0.434
17	nav aids(VOR)	JIAGEDAQI	50.371667	124.121389	-13	376		JGD	114.5
18	nav aids(VOR)	MOHE	52.915556	122.42	-13	563		MHN	112.1
19	Obstacle	DIANGAN378.4	50.384538	124.115408	-13	378			
20	Obstacle	DIANGAN379.5	50.38419	124.112137	-13	380			
21	Obstacle	DIANSHITA570.8	50.429403	124.122778	-13	571			
22	Obstacle	LEWANGTA745	50.541292	124.08144	-13	745			
23	Obstacle	LOU420	50.409289	124.112599	-13	420			
24	Obstacle	LOUFANG436.5	50.418649	124.123108	-13	437			
25	Obstacle	LOUFANG436.5	50.418463	124.124388	-13	437			
26	Obstacle	LOUFANG460.9	50.419483	124.123206	-13	461			
27	Obstacle	XINGZHENGFUWUFANGDING424.5	50.410111	124.107079	-13	425			
28	Patrol point	504-1YOUZHONGGONGLU	50.566666	125.316666	-13	335			
29	Patrol point	504-2GULONGGANHEDACHAZI	51.433334	126.016667	-13	464			
30	Patrol point	504-3DUOBUKUERHESHANGYOU	51.266666	123.85	-13	604			
31	Patrol point	505-1DAZIYANGSHAN	50.7	125.266667	-13	475			
32	Patrol point	505-2NANYANGHEKOU	51.216667	125.35	-13	402			
33	Patrol point	505-3TIAOANITASHAN	51.25	124.416667	-13	824			
34	Patrol point	506-1JINGOULINCHANGNAN	53.2575	122.143056	-13	658			
35	Patrol point	506-2KEBOHEKOU	52.616667	121.9	-13	617			
36	Patrol point	506-3EMUERHE	52.493333	123.118889	-13	607			
37	Patrol point	506-4QIHAOLINCHANGXICE	53.2525	123.588611	-13	353			
38	Patrol point	507-1XIAGALAIAOYIHE	52.295	122.927222	-13	1154			
39	Patrol point	507-2DABAISHAN	51.301111	123.126111	-13	1414			
40	Patrol point	507-3QIANJINLINCHANG	51.620556	124.133611	-13	581			
41	Patrol point	507-4HUMAHEZHILIU	52.337778	124.000556	-13	468			
42	Water point	HUZHONGQUQUSHUIDIAN	52.062222	123.566111	-13	505			
43	Water point	NADOULIHEDAZIYANGSHANQUSHUIDIAN	50.604389	125.243306	-13	342			
44	Water point	PANGUZHENQUSHUIDIAN	52.690278	123.8475	-13	415			
45	Water point	YALIHEFENCHANGQUSHUIDIAN	51.382778	123.385	-13	762			
46	Water point	YALIHEHUBINQUSHUIDIAN	51.545278	123.399444	-13	678			

Fig. 2 Excel-based database in .csv format

with coordinate conversion[9]. Commonly utilized GIS platforms encompass OvitalMap, the 2bulu App, and various domestic and international aviation-specific GIS platforms. These tools ultimately offer a convenient, rapid, and cost-effective solution for the precise positioning of small groups[10] (specific data formats pertain to the references, which will not be reiterated in this paper).

3.3 Relevant recommendations It is essential to establish, enhance, and maintain a comprehensive operational point database at both the master terminal level and the terminal level. This database should enable terminal managers, air traffic controllers, aerial observers, operational aircrews, and other frontline personnel to promptly access critical data during various situations, including emergencies such as fires and drills. The objective is to achieve an integrated data system encompassing command, dispatch, observation, and flight operations. Furthermore, this integration is crucial for ensuring data consistency and timeliness, thereby mitigating safety risks associated with delays or discrepancies in data transmission.

4 Issues and relevant recommendations about communication and navigation and surveillance of aircraft

4.1 Communication of aircraft During aviation forest protection operations, it is imperative that communication is maintained at all times between aircraft and between aircraft and ground terminals. This continuous contact is essential for preventing aerial collisions and for the effective transfer of critical information, including fire conditions and commands. This necessitates a mature, reliable, and stable communication system as the fundamental support for both the aircraft and the terminal. Currently, VHF station on the ground and airborne VHF radio constitute the standard equipment for air traffic control protection. These systems are characterized by advanced technology, enhanced signal clarity, and reduced interference from external sources. However, the existing VHF stations on the ground primarily cover airline routes and middle to high altitude airspace. Consequently, there is a pressing need to establish new VHF stations on the ground that adequately cover low altitude airspace[11].

In the Daxinganling region, the Genhe and Jiagedaqi terminals utilize the VHF frequency of 130.0 MHz. However, the low-altitude operations of helicopters, which are hindered by the surrounding mountainous terrain, frequently result in intermittent radio signals from these terminals. Consequently, it is necessary for other aircraft in the vicinity to act as relays to transmit the required information. Once there are no other aircraft present in the operational area and the aircraft is situated within a radio signal blind zone, communication between the aircraft and ground control is disrupted. Consequently, the pilot is unable to establish contact with ground personnel via the airborne VHF radio, and ground personnel can not communicate with the pilot through the VHF station on the ground. This interruption results in the failure to transmit critical information in a timely manner, which directly impacts flight safety and the execution of operational instructions. Furthermore, aerial observers rely primarily on mobile phones and Apps to transmit photographs and videos of fire incidents to ground personnel. However, the operational areas are frequently characterized by dense forests, which often lead to the loss of mobile phone signals. This disruption hinders the timely communication of fire conditions to ground teams, consequently delaying the response and management of the situation.

In light of this, all terminals should consistently advocate for the establishment of VHF stations on the ground within the operational area, with the aim of minimizing or entirely eliminating blind spots in VHF signal coverage. Concurrently, it is essential to utilize advanced and reliable communication technologies, such as satellites and the Beidou system, to equip terminals and observers with the most current and specialized communication equipment. This approach will ensure that communication between aerial observers and the terminal remains seamless and stable at all times.

4.2 Navigation and surveillance of aircraft Aircraft navigation and surveillance primarily concern the determination of an aircraft's location and altitude. From the perspective of the pilot, effective navigation is essential for ensuring the safe and accurate arrival of the aircraft at its intended destination. From the perspective of the terminal, the function of surveillance involves verifying the location and altitude of each aircraft via ground equipment displays, as well as executing command protocols to prevent potential collisions. Currently, with the exception of the Russian helicopter (model Mi-26TC), for which the flight navigator is tasked with aircraft navigation, pilots are responsible for aircraft navigation in all other aircrafts of Chinese civil aviation. In general, the navigation equipment utilized in airline transport aircraft is highly advanced and reliable, with minimal issues that could compromise flight safety. Conversely, the navigation aircrafts employed in aviation forest protection operations vary significantly among different manufacturers and models. This disparity in airborne navigation equipment leads to inconsistencies in navigation capability.

Contemporary aviation forest protection operations typically employ airborne GPS equipment or hand-held GPS equipment to ascertain the aircraft's location and flight navigation data and elements. Observers commonly utilize an aviation forest protection mapping system, which consists of tablet computer hardware integrated with software that combines GPS and GIS[12]. The determination of position coordinates, whether utilizing airborne GPS equipment, hand-held GPS devices, or aviation forest protection mapping systems, relies on satellite signals. However, these signals may be subject to interference or complete loss due to a variety of factors.

The most reliable method of navigation is the traditional NDB and VOR radio navigation system on the ground. These systems enable various types of aircraft airborne equipment employed by Chinese forest protection to receive signals and display bearings. However, their effectiveness is contingent upon the cooperation of ground equipment and is also influenced by the altitude of the flight. Using the Daxinganling area as a case study, it is observed that, with the exception of Jiagedaqi and Mohe, which are equipped with well-established NDB and VOR radio navigation system on the ground, the remaining take-off and landing points, as well as terminals, lack the radio navigation system on the ground. Consequently, the operational range for low-altitude flights is typically limited to approximately 150 km, a distance determined through empirical assessment, beyond which reception of radio signals from navigation stations is compromised. Once the satellite signal is lost during flight and the aircraft is at a low altitude, away from the navigation station area, it will enter a visual flight state without satellite or radio communication. This situation significantly increases the risk of losing navigation, with potentially severe consequences (numerous flight accidents attributed to navigation loss have occurred in various countries worldwide, and a detailed discussion of these incidents is beyond the scope of this paper). In the analysis of global flight accidents in 2006, it was observed that the predominant cause was loss of control, accounting for a total of 17 accidents and resulting in 800 fatalities. Among these incidents, six occurred during the take-off and landing phases. Flight accidents characterized by loss of control in the air are primarily attributed to hazardous approaches or mid-air collisions, loss of positional awareness, adverse weather conditions, and mechanical failures[13].

Automatic Dependent Surveillance-broadcast (ADS-B) is a next-generation navigation technology endorsed by the ICAO. This technology integrates communication, satellite navigation, and surveillance capabilities. The primary functions of ADS-B can be categorized into two components: ADS-B OUT and ADS-B IN. ADS-B OUT is utilized to transmit the aircraft's positional information externally, while ADS-B IN is employed to receive data from other aircraft and ground stations, thereby enhancing pilots' situational awareness of the surrounding environment[14]. The Zhangjiakou Low Altitude Flight Service System collaboratively developed by Zhongqi Hua'an (Beijing) Technology Co., Ltd. and Yuxiang Shengtai (Beijing) Aeronautical Science and Technology Co., Ltd. has received pilot approval from the Civil Aviation Administration of China (CAAC). This system's primary interface facilitates the real-time display of aircraft positions utilizing ADS-B technology, as illustrated in Fig. 3.

In actual visual flight operations, flight crews typically communicate their positions using airborne VHF radio. Concurrently, each crew member actively scans the surrounding airspace for other aircraft to prevent airborne collisions. This practice, however, can result in distractions and increased energy expenditure among crew members. The implementation of ADS-B IN technology enables the reception of signals transmitted by other aircraft, allowing for the direct display of their positions on the screen. This method is both precise and efficient in terms of time management. Longhao General Aviation Group Co., Ltd. is the first enterprise in China to successfully complete the retrofitting of ADS-B IN technology. The retrofitted equipment enables the direct display of the positions of neighboring aircraft and their actual track, significantly enhancing pilot's situational awareness, improving navigational accuracy, and promoting energy efficiency. An illustrative diagram of the airborne equipment provided with ADS-B IN is presented in Fig. 4.

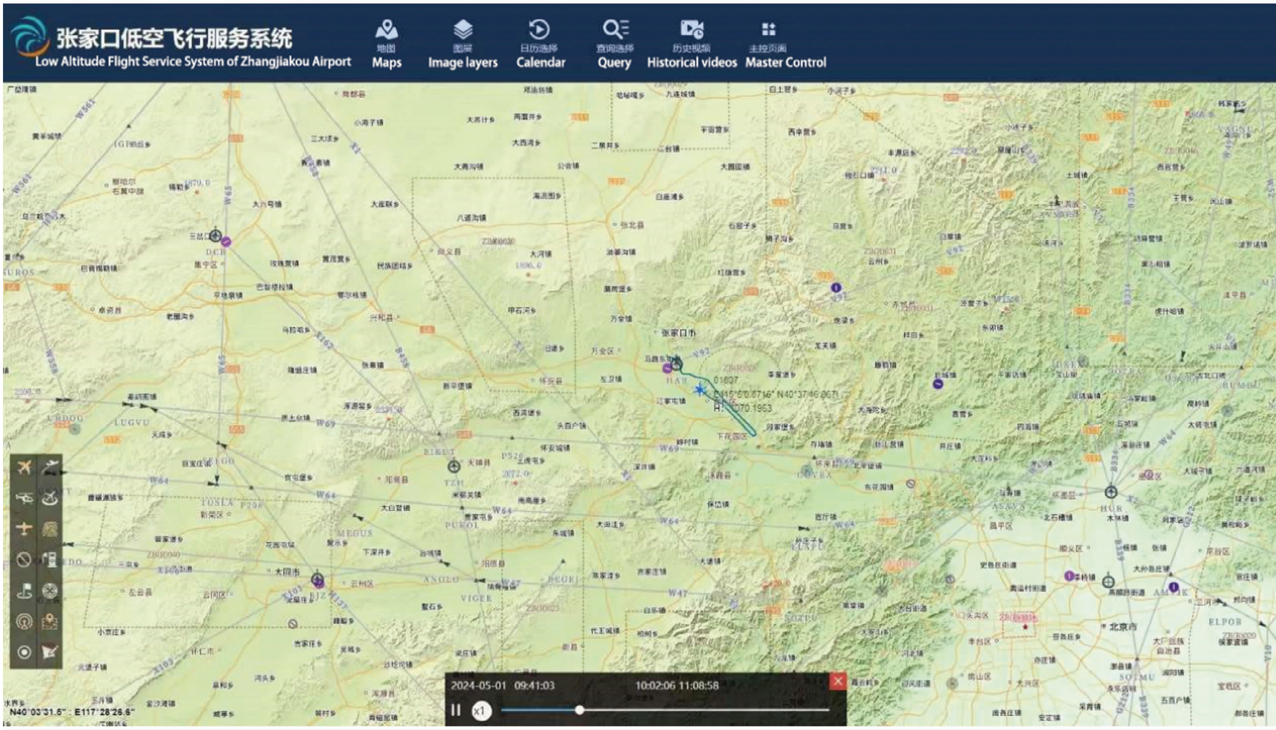

Fig. 3 Effect drawing of the ADS-B surveillance system at Zhangjiakou airport

Fig. 4 Effect drawing of airborne equipment fitted with ADS-B IN

In conclusion, all terminals should enhance the infrastructure of the NDB and VOR radio navigation system on the ground. Efforts should be made to ensure comprehensive coverage of all operational areas, alongside the integration of ADS-B surveillance systems. Airlines involved in these operations must prioritize the installation of ADS-B transmitters on aircraft that currently lack this technology. Concurrently, it is essential to fit aircraft with ADS-B IN airborne display equipment to enable pilots to accurately ascertain the positions of other aircraft via the onboard display equipment.

5 Conclusions

The operation of aviation forest protection necessitates extensive collaboration among various departments and job functions. In the context of firefighting, both leadership and ground personnel must adopt a strategic perspective akin to that of a chessboard, considering the overall situation. This approach emphasizes the importance of close cooperation, unity, and collaboration, as well as adherence to orders and directives[15]. Any negligence in any aspect of the fire-fighting process may compromise its overall effectiveness and, in severe instances, pose a threat to flight safety.

In 2024, China introduced the low-altitude economy policy, emphasizing that safety is the foundation of all operations. Ensuring safety while maximizing operational efficiency presents an additional challenge that must be addressed. In this paper, the experience in the working in civil aviation field is integrated to systematically and thoroughly identify and analyze the critical technical challenges encountered by frontline personnel engaged in aviation forest protection operations. The issues at hand not only compromise the efficiency of aviation forest protection operations but also pose significant threats to flight safety, functioning as "hidden killers" that warrant serious attention.

This paper aims to serve as a valuable reference for enhancing flight safety and operational efficiency, while also contributing to the advancement of management and operational units within the aviation forest protection industry. Furthermore, addressing these technical issues is a necessary prerequisite for the successful implementation of China's low-altitude economy policy.

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Based on these findings, a speculative discussion regarding the fire retardant mechanism is presented.

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