The Research Status and Development of Military Aircraft Ground Support Equipment

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Abstract. With the rapid development of aviation weapon equipment and the introduction of advanced technologies, new aviation support system concepts and support modes are emerging in recent years. Military aircraft support equipment is not only the material basis of an integrated support system for aviation weapon equipment, but also a significant factor affecting the combat effectiveness and the support cost. The improvement of support equipment performance and utilization rate contributes to the performance and the safety of weapon equipment. Ground support equipment carries a lot of basic support work and plays an increasingly important role in the ground support system. Combined with the research status of military aircraft ground support equipment, the configuration optimization of domestic military aircraft support resources and the status of ground support equipment standard system, this paper points out the main problems existing in military aircraft ground support equipment in China, and briefly describes the development trend of future aircraft support equipment, providing help and enlightenment for aviation support research.

Keywords: Ground support equipment · Research status · Configuration optimization · Standard system · Development trend

1 Introduction

According to standard GJB3872 [1], aircraft support equipment refers to the special support equipment that provides the environment and the corresponding conditions for use, detection and maintenance of aircraft systems and airborne equipment in the specified environment, including ground support equipment (GSE), air support equipment and shipboard support equipment. Among them, GSE carries a large number of basic support work [2, 3], including the implementation of gas, liquid, electricity, etc. GSE can be divided into power equipment (power supply vehicle, hydraulic pump vehicle), filling equipment (refueling vehicle, oxygen vehicle), thermal processing equipment (air conditioning vehicle, heating vehicle) and lifting installation equipment (tractor, crane). According to the structure form, GSE can also be divided into three types, vehicle type, fixed type and traction type [4].

Aircraft ground support equipment is not only the material basis of aviation weapon equipment ground support system (GSS), but also an important factor restricting the

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development of weapon equipment and affecting the life cycle cost. Different from the engine support mode of the air flight test mission, the ground static test of the whole aircraft is to continuously provide ground energy for the debugging and functional inspection of the aircraft hydraulic, flight control, avionics and other systems relying on GSE when the engine is not working, to verify whether the aircraft systems and airborne products can meet the flight standards. Therefore, the development of support equipment and the configuration optimization of resources have become the key to the effective development of aircraft support capability, which is of great significance to the product delivery and the rapid formation, continuous maintenance and boom of military combat effectiveness.

2 Development Process of Ground Support Equipment for Military Aircraft

Since the 1990s, aviation weapon equipment has entered a stage of rapid development. Countries are not only committed to the technical development of aviation equipment, but also pay attention to the construction of GSS. In terms of military GSS, foreign countries attached great importance to the control of GSE as early as 20 years ago. In order to achieve the operational ideas of rapid deployment, expeditionary warfare and the scale reduction of support equipment at that time, the US Air Force's headquarters established the "Air Force Support Equipment Working Group" and the "Support Equipment Vehicle Management Office", which were responsible for the development policy, development planning, strategic issues and the management of support equipment, respectively, to achieve the comprehensive management of air force logistics support equipment [5].

The early GSS is composed of a variety of single-function GSE. Different types of aircraft require different quality power supply, different flow and pressure of oxygen, nitrogen and hydraulic power energy to provide the support of equipment. Therefore, strict resource allocation and scheduling are required according to the actual functional requirements. To improve the support efficiency, the reliability of aircraft ground equipment and reduce the life cycle cost of equipment, in 1996, the United States Air Force proposed the concept of Modular Aircraft Support System (MASS) for a variety of single-function ground equipment and conducted a lot of research work. The resource allocation cost and the life cycle cost of equipment were reduced by 40% and 20%, respectively, and the reliability of the support system was improved by 15% [6]. The development and production of different models have changed the configuration requirements of GSS from single-function support equipment to multi-function support equipment, and the concept of support has also converted relying on increasing the scale of support to pursuing the modularization of support equipment. However, military non-standard equipment needs to be serialized and modularized to achieve the generalization of support equipment components. Such generalization components can be exchanged among similar support equipment, so as to reduce the scale of support equipment, improve the transfer capability and provide support for a variety of aircrafts. For example, the A/M27T hydraulic vehicle commonly used by the U.S. military can support different types of aircraft such as B2, C17 and F-22. The power supply vehicle can supply power to all transport aircraft and fighter aircraft, and the maintenance of troops and bases is applicable [7]. In the

1990s, BAE developed a new type of multi-functional ground support system (MAGSS). The system integrated lighting, environmental control, nitrogen supply and air compression functions on a portable device, and the fuel used was consistent with the fuel of the aircraft, which met the daily support requirements of multi-aircraft [1].

In 1997, Mashey first proposed the concept of "big data" [8], and the whole military aircraft system was gradually combined with big data. Since then, the development of GSS has begun to lag behind that of airborne system. The United States Department of Defense issued the "Product Assurance Guide for the 21st Century" guide in 2003, and proposed the concept of Performance Based Logistics (PBL), which took the support as a comprehensive and affordable performance package to purchase. Driven by the integrity and continuous mission capability of wartime equipment, it emphasized user-centered, constantly adapted to the requirements of new combat environment and combat style for equipment support [9]. In 2008, the F-22 project carried out supportability and self-support capacity design using PBL technology, focusing on reducing life-cycle support costs. The F-22 has a 50% reduction in the transport time required to deploy a squadron compared with the F15 [7].

With the continuous development of support equipment, the support mode and the support system are changing. The traditional ground support mode follows the passive reactive support process of "Failure occurrence - Detection isolation - Failure location - Resource scheduling - Equipment Maintenance", and the passive equipment support system cannot effectively support the rapid response ability required for future wars [10]. At the beginning of the development of the fourth-generation aircraft, the U.S. military put forward the concept of autonomic logistics support. This kind support technology is a logistics support system based on knowledge, which can identify and integrate a series of related information such as logistics support demand, supply chain management, reliability and safety of components to support and strengthen the implementation of tasks. The core of the autonomic logistics support system is the prognostic and health management (PHM) system and the joint distribution information system (JDIS). The PHM system applies advanced sensors and algorithm models to manage the health status of equipment and form decisions. The JDIS system informationizes equipment, personnel and other technical data to form real-time interoperability between systems [11–13]. The operation of autonomic logistics support system changes the traditional maintenance support strategy from post-maintenance and prevention to maintenance and a small amount of preventive maintenance based on real-time status, forming a two-level maintenance system, as shown in Fig. 1 [14].

In 2014, Lockheed Martin developed Autonomic Logistics Information System (ALIS) for the F-35 project, used for pre-maintenance and supply chain issues, as shown Fig. 2 [15, 16]. More than 400 F-35 aircrafts have been equipped with ALIS, which realizes the autonomy and decision support of logistics support procedures and reduces the cost of life cycle support [17].

In 2020, the U.S. Department of Defense launched a new support system - Operation Data Integration Network (ODIN) system for the problems of occasional database conflicts, outdated operating systems and cumbersome system hardware in ALIS [18]. ODIN system planned to host part of the original ALIS system to the cloud, saving hardware costs, enhancing data sharing between different departments, and reducing data

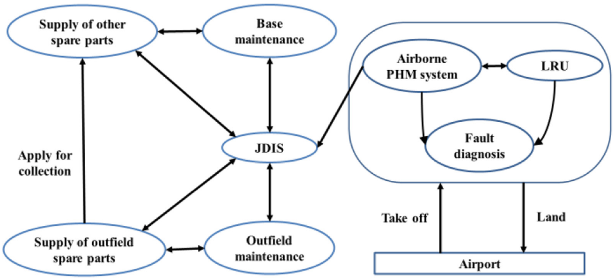

Fig. 1. Aircraft autonomic logistics support system [14]

Fig. 2. The F-35 concept map of autonomic support [16]

communication costs. In essence, ODIN system adopts a new organizational model and development model, which is a major change for ALIS. Compared with ALIS, the hardware cost and the volume are reduced by 30% and 75%, respectively, and the enhanced computing ability shortens the processing time by 50%.

Advanced foreign military aircraft support mode promotes the development of GSS towards digitalization and automation. However, China starts late in the control of GSE. At first, some support technologies are introduced in accordance with the characteristics and needs of Chinese aviation industry. In 1981, Aviation Industry Group and Air Force introduced reliability centered maintenance (RCM) technology [19], which was applied in the ground support of J6 aircraft and extended the maintenance period under the premise of ensuring combat performance. Since 2003, RCM technology has been widely used in the field of support and maintenance of major weapon equipment [20, 21]. In the face of the large-scale and rapid development of domestic aviation weapon equipment, the traditional ground support mode causes more life cycle costs, which increases the possibility of false alarms and false alarms. The investment of a large amount of manpower and material resources may also not improve the aircraft's mission rate.

In the past, military aircraft ground equipment had the problems of single support function, backward support mode and low resource utilization rate. These factors seriously restricted the development of GSE and could not satisfy the needs of modern air force operations. In 2007, a certain station of the domestic air force completed the construction task of the first batch of multi-aircraft comprehensive support bases. The smooth construction of the base marked a historic leap in the flight support mode of the air force air force station, from supporting fewer aircrafts to multiple aircrafts in a single airport, greatly improving the support efficiency [22].

With the continuous development of Chinese aviation technology, the PHM concept was introduced during the "Tenth Five-Year Plan" period. The basic research on PHM of airborne system for aviation equipment was started, and the experimental research was carried out combined with model technology in the "Twelfth Five-Year Plan" period. At present, the fault diagnosis and fault isolation of line replaceable unit (LRU) for flight control, hydraulic energy, avionics, life insurance [23] and other systems are mainly focused on the model research technology, which makes the airborne system support farewell to the backward maintenance era. However, the development of GSS is slow and lagged behind the current support demand. There is still a certain gap with the construction goal [24] required by the comprehensive support of domestic weapon equipment, and it is not adapted to the development of the new generation of fighter support towards the direction of life-cycle and system management.

3 Configuration Optimization of Ground Support Equipment for Military Aircraft

Scientific optimization of resource allocation can effectively solve the problem of insufficient and excess resource allocation, greatly improving the efficiency of military aircraft support and reducing the cost. Existing optimal allocation methods mainly take the average satisfaction rate of equipment as the optimization objective, and take the equipment utilization rate, equipment operation cost and equipment scale as the constraint conditions [25]. The Petri net [26], the queuing theory [27] and other theories are used to model, and the intelligent algorithms such as genetic algorithm, particle swarm optimization algorithm [28] and related combinations are used to solve the problem, so as to obtain the optimal allocation scheme of support equipment.

Zhu established the resource optimization allocation model of maintenance support equipment based on variable precision rough set, and realized the resource optimization allocation of multi-resource points and multi-demand points under different precisions combined with the particle swarm optimization algorithm [29]. Han analyzed the constraints of aircraft support process and resources under integrated support mode, and established a multi-aircraft integrated aircraft support scheduling model [30]. Su studied the support resource constraints and the process constraints of carrier-based aircraft surface under different man-machine matching modes, and compared the advantages and disadvantages of various matching modes through simulation tests [31].

Bu established a Monte Carlo queuing model with the utilization rate and the cost of support equipment as the main constraint conditions and the aircraft departure rate as the objective function. Genetic optimization algorithm was used to optimize the configuration scheme of support equipment [32]. Zhang proposed the optimal allocation model of grassroots-level test equipment based on the types, methods and characteristics of grassroots-level equipment maintenance support tasks and the shortest average maintenance time of equipment [33]. Through genetic algorithm, Cui systematically analyzed the constraints such as operation process, process execution mode, resource transfer and allocation, and incorporated mobile support vehicles into the scope of support resources [34]. To optimize the configuration of integrated support vehicles, Cui analyzed the demand and parameter index system of mobile combat support, and constructed the evaluation model of mobile combat support capability by multi-level fuzzy comprehensive evaluation method [35]. In recent years, with the continuous development of information network and the wide application of big data and artificial intelligence, the role of information resource management in the configuration optimization of military aircraft support equipment has gradually become prominent [36].

4 Standard System of Ground Support Equipment for Military Aircraft

In the early years, the United Kingdom, the United States and Australia signed the "Defense Military Standardization Cooperation Agreement", and jointly carried out standardization construction. Subsequently, China established a relatively perfect standard system of safeguard equipment, including basic, management and technical standards [37]. The basic standards are the supporting materials for management standards and technical standards. Technical standards are in the form of hierarchical classes, including top-level standards, generic standards and dedicated standards. As shown in Fig. 3, the top-level standard is GJB5967《Support equipment planning and development requirements》. The general class standard includes 16 items, such as GJB1132《General specification for aircraft ground support equipment》 and the special class standard includes 50 items, such as GJB1125《General specification for aircraft cloth cover》 [38]. The establishment of military aircraft ground support equipment standard system has greatly standardized the development and maintenance of support equipment.

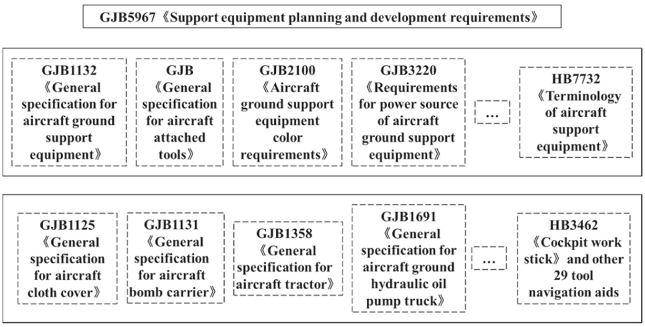

Fig. 3. Military aircraft support equipment standard system diagram [38]

5 Main Problems Existing in Ground Support Equipment

With the progress of technology and the improvement of user requirements, the design and development of military aircraft support equipment have made progress in functional modularization and integration, volume miniaturization and operation convenience. However, the comprehensive development and optimal configuration of support equipment are still lagging, and some problems need to be solved urgently.

5.1 Insufficient Generalization of Support Equipment

Although some support equipment integrates multiple functions, reducing the number of support equipment and facilitating the aircraft support work in the outfield, the support equipment after function integration has worse usability and lower efficiency than before. For example, a certain type of air tightness tester integrates many inspection functions such as cabin air tightness inspection, air tightness inspection of air tightness belt and air tightness inspection of radar pressurization system. However, when checking the air tightness of radar pressurization system, the pressurization process is too slow [38]. In addition, some function integration is only the integration of hardware, and the software has not been really realized, which is lack of universality.

5.2 Poor Environmental Adaptability

Since the newly developed support equipment has been gradually applied, some equipment has not carried out environmental identification tests or insufficient environmental identification tests, leading to more faults in the outfield, especially in some harsh environments. For example, a certain type of charging and discharging test system exits the faults of no output current and black screen of the monitor in the coastal high temperature and humidity environment [38].

5.3 Difficult Transportation

The transportability of support equipment is a comprehensive performance of the adaptability of railway, highway, waterway and air transport modes. The mobile combat mode puts forward higher requirements for the transfer of GSE. Due to the large volume and weight of common support equipment, the equipment transition is difficult. Some support equipment is designed without considering the needs of transfer transportation, without setting hanging points or special packing boxes, and without considering the impact of vibration, temperature and pressure changes on the bearing capacity of the equipment under various transportation conditions, all of which bring great inconvenience to transfer transportation [39].

5.4 Lack of Effective Information Management in Resource Allocation

Although a large number of domestic support equipment resource allocation optimization work has been carried out [40], the level of informatization and intelligence of support equipment needs to be improved, and the instant communication and information management of support resources with support needs have not been realized. The visual support system based on the Internet of Things, satellite positioning, radio frequency identification technology can shorten the response time. In the future, the configuration optimization system can be combined to output the required support resource allocation scheme, and provide decision makers with a choice.

6 Development Trend of Ground Support Equipment for Military Aircraft

With the continuous development of aviation weapon equipment, the support equipment has experienced a qualitative change process of "Completely relying on imports - Imitation research and development - Independent research and development". Although the research and development production capacity of domestic weapon equipment can meet the needs of the army, the leapfrog development of weapon equipment puts forward higher requirements for the support capacity of GSE. The ground support mode of the second and third generation aircraft belongs to the point-to-point energy output structure, and there is a decentralized control between the support equipment and the debugging resources such as the aircraft position. However, in the new international situation, the demand for GSS of the new aircrafts is no longer limited to the improvement of the quality and quantity of support equipment, but it is necessary to improve the cognition and attention of the demand for the economic, comprehensive and intelligent ability of the support system, and centralize the control and multi-degree allocation of various ground resources. It is committed to improving the interactive sharing, resource allocation rate and information management and control ability of the support equipment.

The development trend of military aircraft ground support equipment is not only the improvement of support equipment performance and system standards, but also the transformation of support mode and the optimization of support resource allocation. With the continuous improvement of the level of weapon equipment, the prediction of equipment data and resource demand will be more accurate, and the efficiency of resource allocation will be higher. The development direction of support resources is also moving closer to the demand for scientific management, the continuous maintenance of equipment combat effectiveness and the reduction of equipment life cycle cost.

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