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Study on some issues about safety assurance and maintenance of China's maritime search and rescue helicopter

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STUDY ON SOME ISSUES ABOUT SAFETY ASSURANCE AND MAINTENANCE OF CHINA'S MARITIME SEARCH AND RESCUE HELICOPTER

By

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A research paper submitted to the World Maritime University in partial Fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

(Maritime Safety and Environmental Management)

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DECLARATION

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: **Study on some issues about safety assurance and maintenance of China's maritime search and rescue helicopter**

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Since so many ships travel in the vast ocean, some accidents occur. Ships collided in the sea are usually alone. It takes several hours for the nearest ships or professional search and rescue forces to come to help. Because of unique advantages, helicopter plays a great important role in search and rescue as a new-type and fast force.

The first part of this essay introduces the background of accidents in the ocean. Then the characters and development of MSRHs were presented. As well as Chinese MSRH force and comparison of MSRH force between China and other developed countries like America and Japan. The third part is the most important part which highlights how to improve safety assurance of MSRHs. This part first discusses some measures to improve training of maintenance personnel. Then focuses on design of a framework for managing human factors special for reducing and preventing human errors made by aircraft maintenance personnel. Last discusses airworthiness compliance approach of fatigue assessment for important design of helicopter. The fourth part focuses on some maintenance support problems on aging MSRHs. And puts forward some countermeasures for maintaining aging MSRHs.

KEY WORDS: MSRH, safety assurance, HF, maintenance personnel, management framework, airworthiness compliance, modification, aging helicopters

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LIST OF ABBREVIATIONS

ACC	United States Air Combat Command
ADAMS	Aircraft dispatch and maintenance safety
ATA	Air Transportation Association of America
CAAC	Civil Aviation Administration of China
CCAR	China Civil Aviation Regulations
EU	European Union
FAR	Federal Aviation Regulations
HE	Human Error
HFACS	Human Factors Analysis and Classification System
HFG	Human Factor Engineering
IMO	International Maritime Organization
MSRH	Maritime Search and Rescue Helicopter
STC	Supplement Type Certification
TC	Type Certificate
USCG	United States Coast Guard
VTC	Validation Type Certificate

CHAPTER 1:

Introduction

As everyone knows, maritime transportation has many advantages of large capacity, low cost, strong continuity, smaller pollution damage compared to highway, railway and other means of transportation. These advantages make maritime transportation play a more and more important role in the development of the national economy. According to statistics, about ninety percent of the world's goods is carried by shipping. Shipping safety is a problem we must consider while shipping industry developed so fast. Transport by sea is a high-risk industry, there are a variety of risks, most of which belong to non-traditional unsafe factors, such as lightning, hurricanes, tsunamis and other force majeure of natural disasters, as well as accidents like stranding, collision, fire, oil spill, explosion, sinking and missing, or pirates and maritime terrorism threat to the safety of maritime transport. These risks lead to significant property damage and human casualties.

Helicopters are wildly used in search and rescue of shipwrecked as a kind of search and rescue force. There are many problems encountered during maintenance and support. For example, maintenance personnel are keys to guarantee the safety of helicopters, the problem of how to improve their quality is of significance. Although many companies have carried out many kinds of training programs and plans, there still are not enough eligible maintenance personnel. In consideration of the increasing need for maintenance personnel due to the boom of helicopter industry, this article introduces some methods to improve the level of training. Human factor has been studied almost in all fields. Several research models were proposed to solve the failure problems such as SHEL model, REASON model, HFACS model and MEDA and ADAMS model. But these models are proved to be completely inapplicable to analysis of human errors made by maintenance personnel. Thus, this dissertation puts forward an analysis framework based on MEDA and ADAMS which is special for human errors of maintenance personnel. In the third part of main body, airworthiness assessment after important modification is discussed. Many modifications can be directly used in helicopters after acquiring the certificate of manufacturer. But in some cases, it is not enough, so take China for example, there are some other progresses for airworthiness assessment of significant modifications. This part takes camera system modification as an example to explain the procedure. In Chapter 4, in face of aging helicopters, it is not proper to perform maintenance and support in accordance with previous standards. In order to make the best of the aging helicopters, some other countermeasures are proposed.

CHAPTER 2:

Chinese MSRH force

2.1 The development of MSRH

The earliest references for vertical flight came from China. Since around 400 BC, Chinese children have played with bamboo flying toys . This bamboo-copter is spun by rolling a stick attached to a rotor. The spinning creates lift, and the toy flies when released (Richard P., H., 2003, pp.22-23). Helicopter is aircraft which is provided lift and propulsion by one or more rotary rotors. Lift of fixed-wing aircraft comes from fixed wings on the fuselage. When fixed-wing aircrafts fly forward, relative motion come up between the wing and air, thus create lift. The principle of Helicopter's generating lift is similar to fixed-wing aircrafts, the only difference is that the former comes from rotor wings which rotate around a fixed axis. Unlike fixed-wing aircraft generating relative motion by flying forward of whole body, helicopter generates relative motion by wings' rotating. However, reactive torque which is equal to rotating torque but opposite direction will also generate at the same time. For single-rotor helicopter, common practice to balance the reactive torque is to add another small rotor at the end of the fuselage called tail rotor which will generate reverse moment of force. For multi-rotor helicopter, adopt the method of reverse rotation between rotor wings to offset the effect of reactive torque.

As a result of the way of generating lift, helicopter needs no high speed during flying.

It is able to take off and land vertically, and to hover for extended periods of time, as well as the aircraft's handling properties under low airspeed conditions. Due to the operating characteristics, helicopter has been chosen to conduct tasks that were previously not possible with other aircraft. Today, helicopter uses include transportation of people and cargo, military uses, construction, firefighting, search and rescue, tourism, medical transport, law enforcement, agriculture, news and media, and aerial observation.

2.2 The characteristics of MSRH

Maritime search and rescue is an important use of helicopter. Its advantages are as follows compared with search and rescue ships:

Fast

General cruising speed of MSRH is 150 knots, while speed of ships is about 15 knots. For emergency rescue, faster is better absolutely. On one hand, the cooling speed of human body in seawater is 25 times faster than that in air. Under normal circumstances, a healthy adult will be in coma after being in the 15 ℃ water for 3.5 hours. He will not survive after 3.5 hours in 10 ℃ water. And dead just 1 hour and 40 minutes later in 0℃ seawater (W. J., 2015, p.123). So, time is life. On the other hand, the earlier helicopter arrived at the scene, the more accurately datum to find and more precise estimates of rescue scope, thus reduced the difficulty of search and rescue. In the South China Sea, there often have ships, crew or fishermen who need bailout. It will take 10 hours to get to Yongxing Island Sansha city from Sanya city by ship which is about 180 nautical miles away. But it takes only 1.5 hours by helicopter. The efficiency and success rate of rescue are greatly improved.

Wide field of vision

The working height of Helicopter generally remain in 60 ~ 150 meters which is far higher than ships. It is more visual sensitive for vessels and rafts targets on the surface of sea. In addition, the search radius of helicopter is bigger than that of ships. When equipped with electronic guidance equipment and infrared search instrument equipment, helicopter can quickly search for targets and do accurate positioning, thus to improve the searching efficiency and reduce the cost.

Less affected by the wind and waves

On September 29, 2011, affected by the typhoon "NESAT", there was violent storm and roaring waves and heavy rain fall in Zhujiang estuary. About 33 nautical miles southwest in Zhuhai province, a steel ship hull flood water seriously. There are 12 people on board. Rescue crew take off immediately after receiving information. Arrived at the scene, the visibility is very low in the rain and the wind power was nine-class. Half of the ship hull has sunk. The weather was very bad, ships were at the port to avoid typhoon, heavy winds and waves made it hard for rescue ship get close to the ship in distress. Regular rescue method did not work. But the influence of rescue helicopter by wind and waves is relatively smaller than rescue ship. Flight is not restricted by wind. It can be stably hovering in strong wind, and get close to accident ships from air. Once fund risk on its own, it can fly away immediately.

2.3 Present Chinese MSRH force

On March 5, 2001, to meet the need of three-dimensional rescue work of China, rescue and salvage bureau of the Ministry of Transport set up *Shanghai rescue and salvage bureau helicopter fleet of Ministry of Transport* in Shanghai, which now is *Ministry of Transport first flying service of East China Sea*. Then, another three flying services were set respectively.

They bear several missions of emergency response to maritime accidents, human rescue and provide security for maritime transport and Marine resources development in the China Sea. At present, four rescue flying services possess 14 search and rescue helicopters, including newly introduced 2 S-76 D type helicopter in 2015. Among them, EC225 is the biggest type of Airbus Helicopter and the world's most advanced commercial helicopter which enable to carry 24 passengers with all-weather flight ability. It is equipped with ditching float and airborne life raft and the world's most advanced automatic drive and instrument display equipment.

Figure 2.1: EC225 search and rescue helicopter
Source: EC225, 2011.

The EC225 is based on the Eurocopter AS332L2 Super Puma, improving upon the design with a five-blade main rotor incorporating a new airfoil shape to reduce vibration and noise levels. The blades of the rotors feature a composite spar and parabolic blade tips; they can also be equipped with an anti-icing system to enable the aircraft to operate within very cold climates. The helicopter is powered by two Turbomeca Makila 2A1 turboshaft engines mounted over the cabin; these engines are capable of providing 14 per cent more engine power and feature an extra dual-channel full authority digital engine control (FADEC) system for high reliability, a further backup system is present in the event of both FADEC systems failing. The FADEC system ensures that engine power is always kept within the limits of thegearbox. Many of the mechanical components, particularly of the engines, were designed to be modular to ease maintenance, and composite materials were used where possible to reduce the aircraft's weight.

Basic performance:

Maximum take-off weight: 11 200 kg

Empty weight: 5256 kg

Maximum range: 980 km

Equipment on board: 1) 4-axis autopilot makes it possible to hovering over the search and rescue region even in the worst weather. 2) A LUCAS 42325 electric hoist can lift two people or a stretcher. 3) Weather radar. 4) GPS or Doppler navigation system. 5) Launching device of emergency locator can directly connect with satellite. 6) Lifesaving stretcher. 7) Lifesaving basket.

Figure 2.2: S-76 series helicopters

Source: S-76 C+/ S-76 C++/ S-76D, 2011

The S-76 is of conventional configuration, with a four-bladed fully articulated main rotor and a four-bladed anti-torque rotor on the port side of the tail boom. Two turbo shaft engines are located above the passenger cabin. In the prototypes and initial production aircraft, these engines were Allison 250-C30s, a new version of the popular Allison 250 engine developed specially for the S-76, with a single-stage centrifugal compressor instead of the multi-stage axial centrifugal compressor of earlier models of the engine, rated at 650 SHP (480 kW) for take-off. These engines are connected to the main rotor by the main gearbox, a three-stage unit with a bull gear as its final stage rather than the planetary gear used by previous generations of Sikorsky helicopters. This arrangement gave 30% fewer parts and lower costs than a more conventional design.

Basic performance of S-76 C+:

Maximum take-off weight: 5307 kg

Empty weight: 3012 kg

Maximum range: 780 km

Equipment on board: 1) 4-axis autopilot can realize automatic positioning hovering. 2) LUCAS42325 electric hoist, maximum safe bearing 600 lb (270 kg). 3) The PLY-3 infrared imager can detect the raft and man overboard within 360 ° direction in the distance of 3000 meters. 4) SX-16 searching floodlights. 5) PRIMUS701 radar. 6) Flight management system is a highly integrated navigation management system which can provide 6 kinds of automatic mode for search and rescue. 7) Lifesaving stretcher. 8) Lifesaving basket.

2.4 Comparison with developed countries

There are two examples of MSRH force of America and Japan. The USCG has 68 fixed wing aircraft for cruise and rescue and 136 search and rescue helicopters. The configuration principle of air base is harbor district, fishing area, recreation areas, densely populated areas and other accident-prone areas. The distance of each air base is between 200 nautical miles and 500 nautical miles. Each base is allocated different helicopters and fixed-wing aircrafts based on different tasks while the minimum configuration is three helicopters: one is for search and rescue duty, one takes training mission and search and rescue backup, the other one is for maintenance to ensure high rate of search and rescue. Helicopter is the first choice for life searching and rescue at sea in the United States, the equipped helicopter standard of United States is that less than 2 hours to the scene. Japanese coast guard has 75 aircrafts, including 29 fixed-wing aircrafts and 46 helicopters. Fixed-wing aircraft consists of 8 large aircrafts, 21 medium-sized aircrafts.

Compared with the developed countries, there is still a big gap. Firstly, the length of coastline in China is more than 32,000 kilometers, is one of the world's longest coastline countries. China has four flying services which possess only 12 helicopters and 8 bases, the scope of search and rescue is about 110 miles. The number of helicopters, base construction and scope of search and rescue of China is still far from enough with respect to the coastline of China. Secondly, China failed to make full use of the civil aviation organizations and social flight forces for maritime rescue, air rescue network is relatively single. Thirdly, China is currently training for rescue at night, temporarily unable to achieve 24 hours of search and rescue at sea.

CHAPTER 3:

Improvement of safety assurance of MSRH

MSRH flight is to safeguard people who are in danger at sea, timely and accurately search and rescue personnel in danger. This chapter mainly discusses some management methods and measures in improving the safety guarantee, for example how weather influences flight, how to improve the maintenance personnel training level, how to perform important modification for helicopter, research on human factors of helicopter maintenance personnel and optimization of ship-helicopter three dimension cooperation.

3.1 Raise the level of maintenance personnel training

Enhancing the maintenance personnel training can improve the maintenance quality of helicopters and equipment, reduce the occurrence rate of accidents and rework and improve the airworthiness of MSRH. In the current rapid development of civil aviation, strengthening maintenance personnel training work has become an important basic work. But, some deficiencies in maintenance personnel training lead to few eligible maintenance personnel to make it hard to meet the need. The following are some measures to raise the level of maintenance personnel training.

Establish thorough training system

In order to accomplish maintenance personnel training, thorough training system should be established to guarantee the training goal can truly be achieved. The maintenance department should establish a set of training management system and determine the training mission, objectives and requirements. Establish a corresponding punishment and incentive system at the same time to arouse the enthusiasm of staff. Enterprise shall establish a specific training administrative department under the guidance of training system and make the training schedule. Administrative department should be in accordance with the requirements of the training system, strengthen supervision and check of the training work to improve the training efficiency.

Adopt scientific training methods

Training management department shall choose scientific training methods according to the quality of training personnel and training requirements. Practical training process is divided into classroom training and operational training. Maintenance department can select the corresponding training methods combining their resources. When maintenance department needs the assistance from external training resources, the relevant departments shall select the training institutions and faculties according to the requirement of the training curriculum. In the process of external classroom training, maintenance personnel need related training institutions to improve during the training of relevant certification and skills. Management departments shall do a good job in personnel training arrangement when employees can't attend training in the external training. When enterprise internal resources are relatively perfect, internal classroom training could be considered. Maintenance training process shall be in accordance with the requirements of the training curriculum, formulate relevant training materials, and standardize the training. Internal classroom training process should establish the corresponding teaching log to record training personnel training process and strengthen the management of personnel training. For the maintenance personnel with certain foundation, on-the-job training could be arranged, in particular to implement related practice.

Complete training outline

Complete training outline is to determine the training objectives and training of personnel, and to test training effects, improve the technical skill of maintenance personnel, to make the training more targeted and more efficient. In order to improve the quality of training, meet the needs of the market, especially in order to improve the efficiency of the training, the training outline elaboration work should be strengthened. In the process of the traditional training, long training time and few qualified training personnel is not conducive to improve the training schedule. Changing the mode of training authorization can improve the efficiency of the training, reduce the authorization period in the training process. Completing the training outline can effectively reduce the influence of the helicopter type in the process of training, so as to improve the efficiency of the training.

3.2 Application of HFE

Despite the significant achievements in aviation safety, there are also some problems in the field of aviation flight, especially the slow progress in solving the problem of human error. At present, the proportion of flight accidents due to the equipment declines, but the proportion of various types of accidents caused by the maintenance is increasing. The United States Air Combat Command (ACC) accident survey data show that human error in maintenance human error is the main cause of aircraft accidents and incidents in both civil aviation and military aviation. According to the world’s aviation accident statistics, aviation maintenance error accounts for 80.5

percent, in addition, 20% to 30% of flameout in flight is also related to the aviation maintenance error (Wang J. X., 2009, pp.3-4). Therefore, it is of great significance to take positive measures to prevent and control aircraft maintenance support error and to reduce accidents and accident symptom, ensure flight safety ultimately.

3.2.1 Analysis models

Since the 1940 s, research work on human errors in the field of aviation has been carried out. Some experts and scholars put forward various models to explain the causes of human errors. During the research of human factor theory, commonly used are SHEL model, Reason model and Human Factors Analysis and Classification System—HFACS, and Maintenance Error Decision Aid (MEDA) developed by Boeing company and aircraft dispatch and maintenance safety (ADAMS) developed by Scientific Research of EU.

3.2.1.1 SHEL model

SHEL model (Frank H., 2007, pp.46-47) was first proposed by Elwyn Edwards in 1972, and developed to describe as a graphical interface by Frank H. Hawkins in 1975, see Figure 3.1. This figure is an auxiliary tool for understanding human factors which indicates errors easily occur on the contact between the center position of *Liveware* and *Hardware*, *Software* and *Environment*. This Model emphasizes the matching problem of the interface elements, each box is zigzag which requires system elements match carefully to avoid causing intra-system stress and even split.

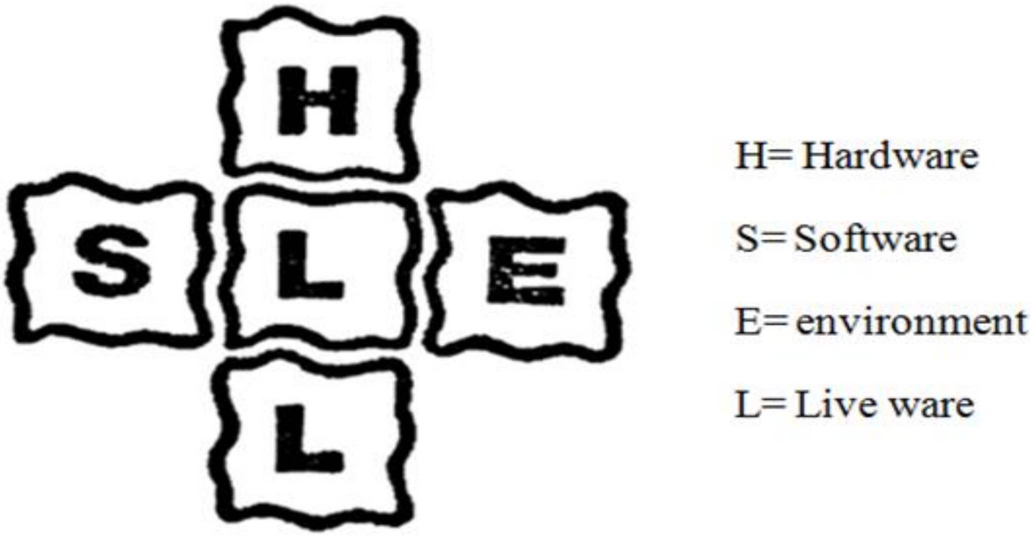


Figure 3.1: SHEL model

Live ware is the center of the system and also the most important elements of the system. But individual performance exists some differences in reality, and has a lot of restrictions, so that the other parts must adapt to it, and match with it.

Live ware – Hardware: the interface between the structural body and human in a system. If the interface failed it can cause potential harm or accidents. The user is not very clear, because human's subjective ability to adapt will hide the effects of this kind of failure.

Live ware – Software: the interface between human and non-physical aspects (such as operating procedure, check the card and computer program, etc). The existing problems is not as clear as interface between liveware and hardware so that it is difficult to check out and resolve (such as a wrong understanding to check card).

Live ware – Environment: the interface between human and non-natural environment and natural environment. The relationship is affected by the current politics, economics, management culture and other mechanism.

Live ware – Live ware: the interface between human, such as the crew members, group collaboration, etc. The interpersonal relationship of the group and its invisible pressure has great influence on the performance of people

As a tool of human factor investigation, SHEL model mainly is confirmation of unsafe events caused by the mismatch of the interface. This model only makes a generalized demarcation of that error prone to occur in the mismatching interface between liveware and hardware, software, environment. It is the model guide of human factors investigating, but cannot be directly applied to the actual safety management.

3.2.1. 2 Reason model

Reason model (Reason J., 2005, pp. 56-60) was proposed by James Reason in his book Human Error in 1990. This model believes that the cause of the accident is not only the fault of the operator and the interference of the environment, the deeper reason is the organizational defect. The failure is divided into active failure and latent failure. Reason model is hierarchical, unsafe events take place after losing several barriers when multiple layers defects appears in an accident inducing factors simultaneously or sequentially. The specific model is shown as figure 3.2. As an accident analysis framework, Reason model emphasizes the potential factors or hidden dangers which influence the behavior of human, beyond the behavior analysis of unsafe behavior by the view of systematic perspective. But this model is just theoretical analysis, it does not clearly define the unsafe factors and does not solve the problems in the application of the field of aviation safety.

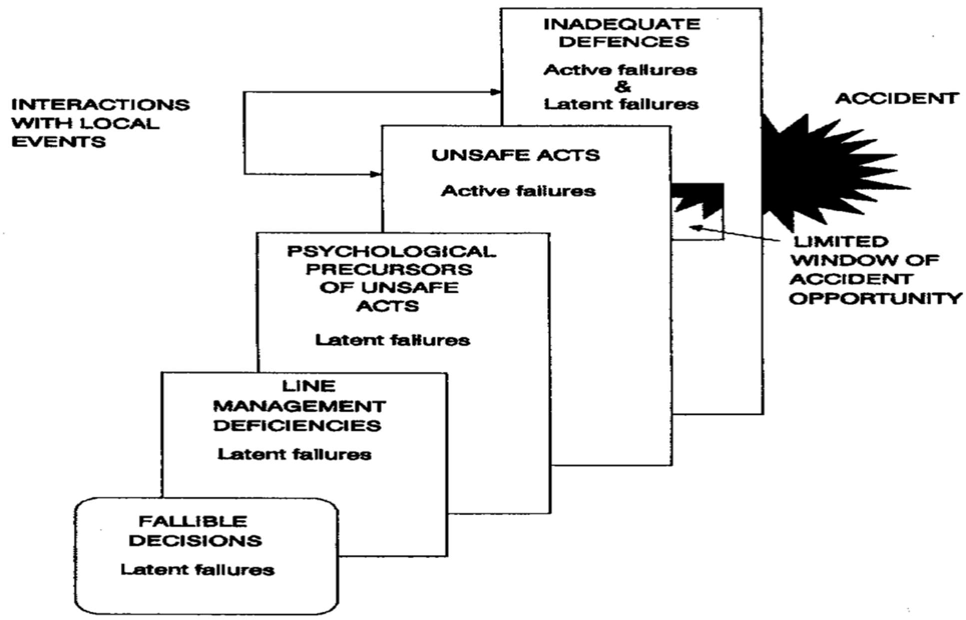


Figure 3.2: Reason model

Resource: Baumler. (2015).

3.2.1. 3 HFACS

The Human Factor Analysis and Classification System (HFACS) was proposed by American scholars Wiegmann and Shappell in 2000 which was developed based on Reason model. Active failure and latent failure in Reason model are divided into four layers, they are Unsafe Acts, Signs of Unsafe Acts, Unsafe Supervision and Administration and organizational factors. Figure 3.3 is the structure of HFACS. Maintenance is carried out under line management. The loophole of line management layer belongs to latent failure which has potential impact on the system. Many human errors can be found in management layer. But in practice, not all organizations have this line procedure. This model just classifies the simple errors and can't be used directly.

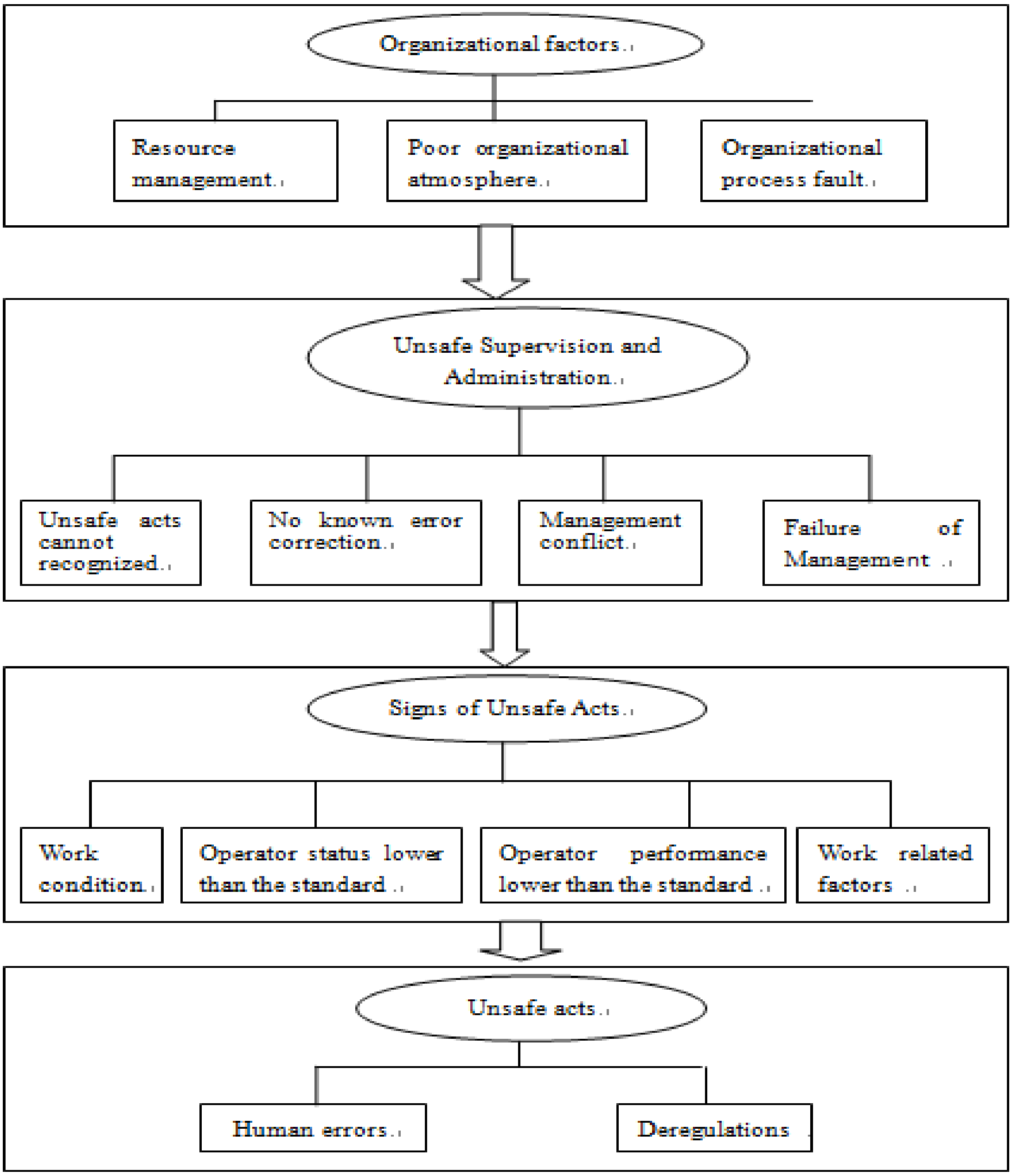


Figure 3.3: HFACS

3.2.1.4 MEDA

Maintenance Error Decision Aid, MEDA (Fan J., 2002,) was developed by Boeing Company in 1995, which is a human-centered system investigation tool for induced factors of human error, focusing on errors that have already existed based on aviation maintenance environment. It aims to find out the real inducement which leads to human errors through in-depth analysis of the root causes of events occurred, put forward corresponding solutions and take possible safety measures to prevent the recurrence of similar errors. MEDA advocates a non-punishment culture that is intended to help airlines to turn to investigate the causes of errors systematically rather than punishment of the individual. When an accident occurs, figure 3.4 is generally used to investigate the causes of errors.

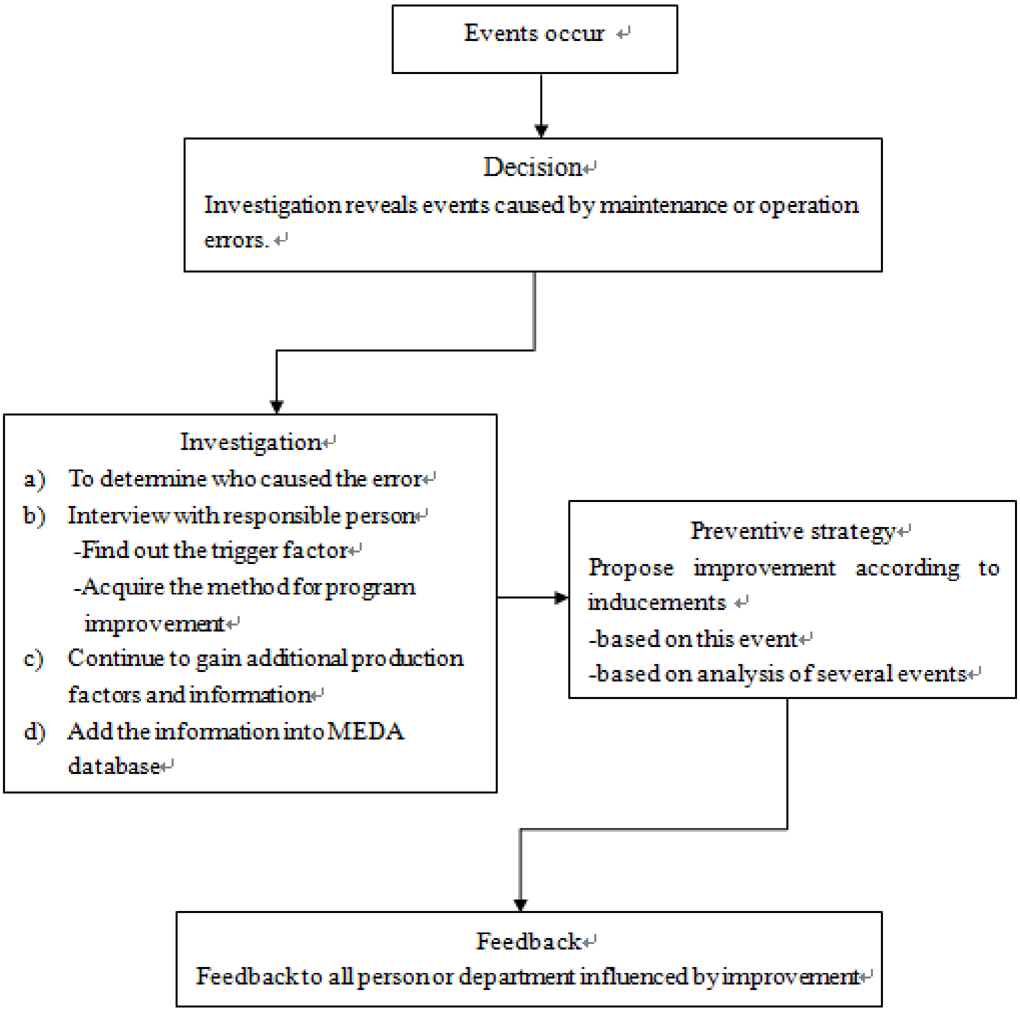


Figure 3.4: Process flow of MEDA

Events occur

When events occur, such as pilot finds the fuel gauge indicating failure and get ready to alternate, maintenance support personnel should immediately exclude the failure and make a record.

Decision

Maintenance department determines whether this event is related to the maintenance support. If the answer is yes, then the relevant personnel should be ordered to carry out a MEDA investigation.

Investigation

Investigators record the event information by MEDA survey sheet. The contents of survey include all information about helicopter: description of the event, errors of the event, reasons lead to errors and a preventive measures list. This information will be added to the maintenance and support fault database.

Preventive strategy

To try to avoid similar errors in the future, investigators conducted a practical check of preventive measures, implementation, and then track the results.

Feedback

The results of the investigation of the event and preventive measures should be provided to all persons or departments influenced by improvement

MED believes that human error belongs to the normal performance of maintenance support personnel, people always makes mistakes at work. Because human behavior is always subject to physical health, psychological stress, environmental and other factors, when people are affected by these factors, mistakes get out. To investigate human error is to find out the interferences of each incident, to take targeted preventive measures. MEDA divides human errors into two categories: one is errors caused by the interaction of system designs, manufacturing defects and faults. Another is related to people's cognitive level, subjective initiative, individual differences and mutual effect.

MEDA is widely used in its Boeing customers, there are currently about 70 Boeing customers like the United States Continental Airlines, United Airlines and British Airways, etc completely or partly use MEDA to manage human errors. According to the airline's statistics, after the use of MEDA, not only human errors in the maintenance support decline apparently, there are some other changes. Delay due to Mechanical reason reduced by 17% (Zhang B. Z., 1998, pp.36-38). Maintenance work procedure is improved and optimized. It improves the punishment culture of traditional maintenance work.

3.2.1.5 ADAMS

Aircraft Dispatch and Maintenance Safety, ADAMS (Xu D. Y. & He J., 2010, pp.32-37) was developed by the EU's scientific research and technology development fifth framework in 2004. Its work is to develop an analytic system of person's reliability and effectiveness and maintenance procedure of helicopter, research and design human factors to integrate safety system for aircraft dispatch and maintenance. In order to improve the design, quality management and learning of organization, and make the cost benefit analysis and evaluation in the maintenance work.

ADAMS researched and developed an information management system of maintenance errors for collection and collation of safety information of helicopter maintenance support process. It is used to diagnose and manage human error by the use of combination method of bottom-up post-event management and top-down active control. Figure 3.5 shows the main contents and method of ADAMS

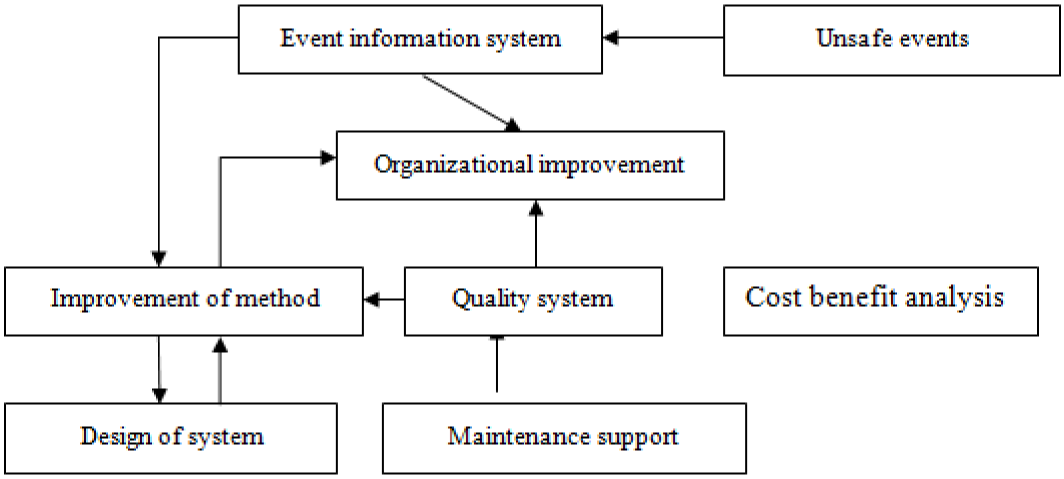


Figure 3.5: Framework of ADAMS

3.3 HFE analysis framework based on MEDA and ADAMS

3.3.1 Goals

Reducing human error in maintenance support should ensure that analysis must turn to system from the interface of human and machine. Therefore, the error analysis has two main steps: the first step in the analysis of the inducement which concerns why errors happened. The second step is strategic analysis which focuses on what improvement in organizational system can reduce the maintenance error.

The goals of error management can be generalized as follows:

(a) Reduce errors - To intervene directly in the error source, formulate preventive measures to reduce the occurrence of errors, such as improve accessibility of components, work lighting improvement and provide better training for maintenance personnel.

(b) Capture errors - Assume that errors have occurred, try to find errors before the helicopter flying, such as review and self-inspection after work and the accompanied review inspection.

(c) Tolerate errors – Provide capacity of no serious consequences after sustaining some errors. Errors still occur, take measures to limit the harmful effects. During the maintenance, error tolerance refers to the helicopter design and maintenance support system design. For example adopt various hydraulic or electrical systems and develop a structural inspection program.

3.3.2 Institutional framework

Based on actual maintenance support program of flying service, it is requirement of implementation of managing human error to establish a set of institutional framework of maintenance support human error management and build corresponding database. According to safety management status of XX Search and Rescue Flying Service, institutional framework is shown as Figure 3.6. Maintenance crew act as the implementation group, professional leaders act as work auditor, quality and safety supervision steering group acts as the core, flight safety committee acts as the highest safety decision-making body.

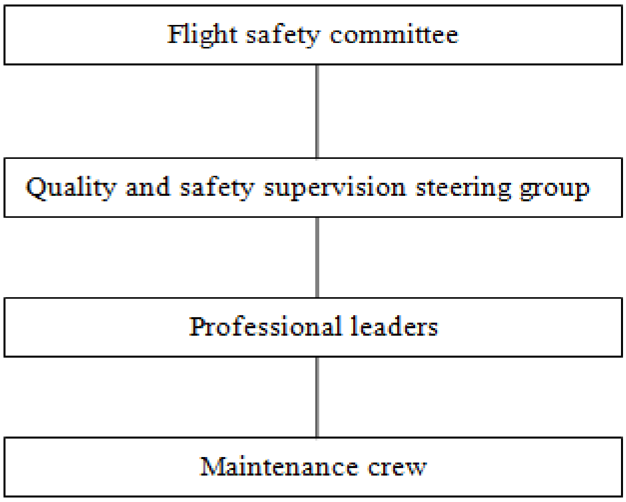
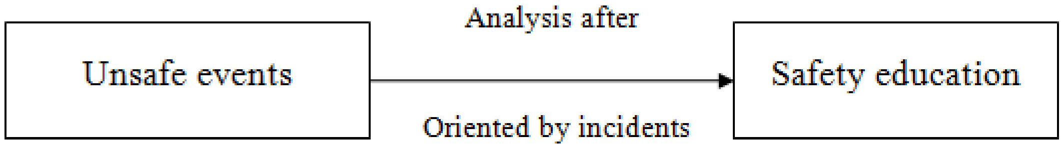


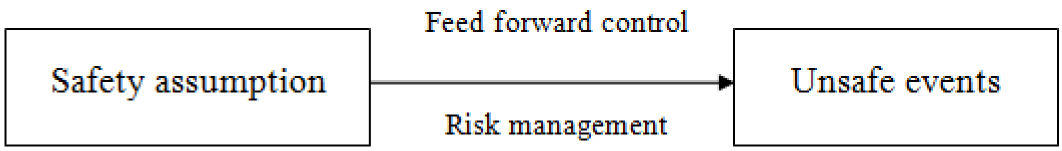
Figure 3.6: institutional framework of maintenance support human error management

3.3.3 Analytical procedure

At present, there is no organization carrying out thorough analysis on human factors of the incident occurred, and there is no shared unsafe events database of human factors in the field of maintenance support. Only adopting of MEDA method has little effect on collection and use the critical data. So it is necessary to combine MEDA with two methods of unsafe events and risk management of ADAMS. The two methods are bottom-up processing and top-down processing which complement for each other. The conceptual model is seen as figure 3.7.



Conceptual model of top-down processing



Conceptual model of bottom-up processing

Figure 3.7: Conceptual models

According to actual work of XX Flying service, we establish general framework of analytical procedure which is shown in figure 3.8.

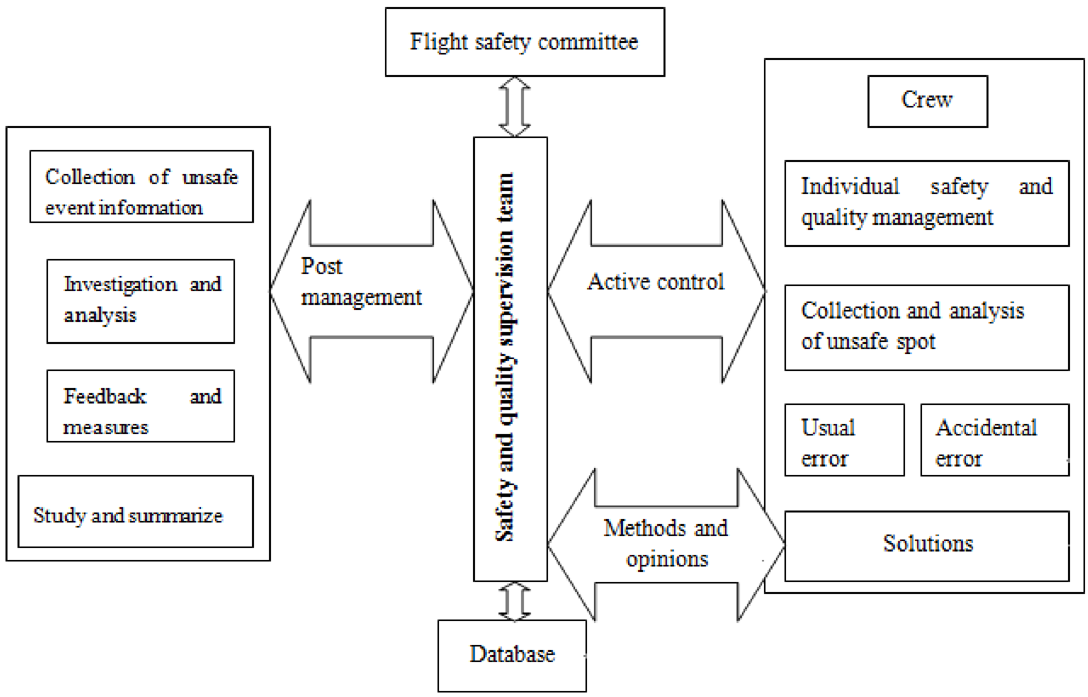


Figure 3.8: General framework of maintenance human error analytical procedure

3.3.4 Case analysis

3.3.4.1 Overview of event

On April 25 201 1, during the preparation of XX flying service helicopter maintenance before flight, maintenance personnel proceeded ground test. In the process of starting the engine, quality inspector found an unknown liquid leakage under the fuselage, and its cockpit engine lubricating oil pressure meter indicated low, so, quality inspector ordered immediately to shut down the engine. Helicopter and engine were safe without collateral damage. The direct cause of the incident is that the engine lubricating oil filler cap was not installed in place which lead to overflow from the cap after pressure.

3.3.4.2 Post-event management

Post-event management: Investigation of human factors. On April 24, the helicopter mechanic did not cover the lube oil filler cap in accordance with the regulations in adding lubricating oil. And the mechanic did not check the work, which resulted in the overflow of lubricating oil from covering gap after pressure during ground test on April 25. The engine almost seized as a result of poor lubrication for lubricating oil leakage.

On April 24, 2011, after duty cycle operation test of engine, helicopter was pulled to parking apron. Mechanic found engine lubrication oil mass was lower than stated value, he finished adding engine lubrication oil work. It is close to off-duty. He did not report to mechanic, nor ask mechanic to check. Analysis of safety factors: on the aspect of human factors, mechanic suffered bad mental state and fatigue after a day of work, as well as the individual blind self-confidence, did not ask the mechanic to review. On the aspect of organizational management, lack of check and mutual check between mechanics, time limit and bad information communication among crew. On the aspect of equipment, design deficiency of engine accessories.

On the morning of April 25, 2011, the mechanic did not prepare well test card reader operation work test before warming helicopter, and the leader of on-site mechanics knew this situation but did not ask the crew strictly implement card reading operation, nor did he check the helicopter before engine test. And he did not ask the mechanic whether the relevant work has done to the helicopter. He confidently organized the work of test, eventually leading to unsafe events. Analysis of safety factors: on the aspect of human factors, insufficient knowledge of mechanic and mechanic leader, blind self-confidence. On the aspect of organizational management, lack of check and mutual check, ineffective organization and deficiency of information communication.

Figure 3.9 shows the causing factors of this event. Investigation report was submitted to safety quality supervision steering group, and deliver to flight safety committee and the crew after check.

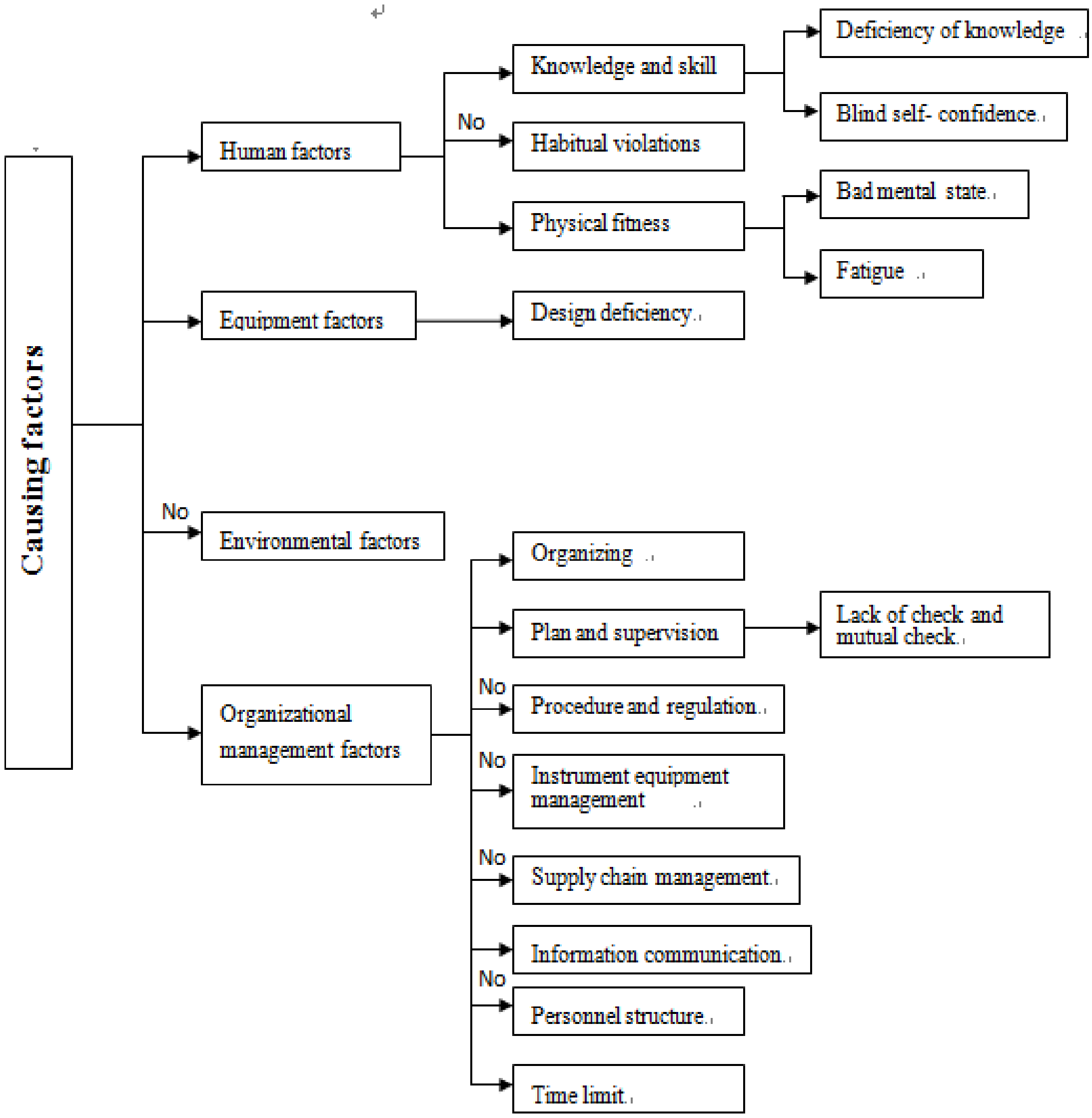


Figure 3.9: Causing factors of the event

Post-event management: Feedback of measures. Report needs feedbacks, the following are some measures to feedback: Firstly, when maintenance personnel work alone, they should remind each other, mutual supervision, one man operation and someone else review. Secondly, the leadership must organize the work of strict standards, communicate with the crew in time and do targeted inspection. Thirdly, all operating personnel should check in accordance with the provisions, enter the next work after signing

Except for the direct feedback, we can also consider to prevent human errors from the aspect of human factors engineering. For example, mental regulation which is to improve self-awareness, mental state and the psychological quality through the adjustment of their own needs, cognition, emotion and behavior, etc so that the crew have stronger ability to deal with complex tasks and challenges. Reduce work fatigue such as improving working conditions or providing suitable workbench and chairs. Improve the structure reasonably, like redesign of lubricating oil filler cap. If the mechanic does not recover the filler cap, it will upspring automatically.

These suggestions feedback to the mechanic leader, mechanic leader summons the personnel for learning, training and technical preparation. It is assisted and supervised by the quality and safety supervision steering group. Quality and safety supervision steering group type the information as investigation report into a database.

3.3.4.3 Active control

Active control: unsafe event source

Find out relevant information of such problems from a database and analyze and summarize, and then return to the maintenance crew to determine the root cause of lubricating oil leakage problem during the helicopter ground testing. Analyze deeper reasons from the direct reason.

(a) The mechanic recovered the engine lubricating oil cap wrong.

(b) Bad mental state of operator.

(c) Blind self-confidence. Mechanic did not report the work he did to mechanic leader.

(d) Insufficient information communication. Communication and coordination awareness is poor. The operator did his work completely by virtue of personal operating habits.

(e) Lack of check and mutual check. Mechanical leader was not strict for the requirements during engine test. The regime is useless. Mechanic did not read card. The mechanic leader did not check in accordance with the requirements before test.

(f) The organizing was not strict and was accustomed to the violation. In accordance with the requirements of the equipment department, all kinds of operations can be released only after the completion of the inspection and signature. Obviously, in this case these regulations were not strictly implemented.

Active control: Safety prevention guidelines

Establish good safety culture of maintenance support, operate strictly according to the rules and regulations.

Reasonably distribute maintenance work, never give the crew incompetent work.

Professional team leader correct the problem timely, implement supervision and inspection mechanisms.

Strengthen the check and mutual check

Enhance communication and coordination between the crew members.

Active control: Reproduce simulation of operation order

Feed these safety prevention guidelines back to maintenance support personnel. Make a standard based on these guidelines for operators to conduct maintenance support. Figure 3.10 shows the operational process of adding engine lubricating oil. Figure 3.11 shows the operational process of ground test before flight.

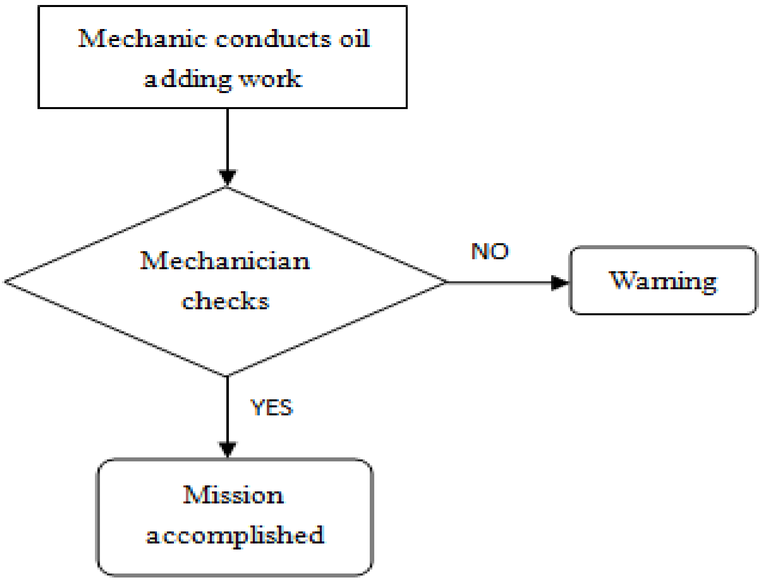


Figure 3.10: Operational process of adding engine lubricating oil

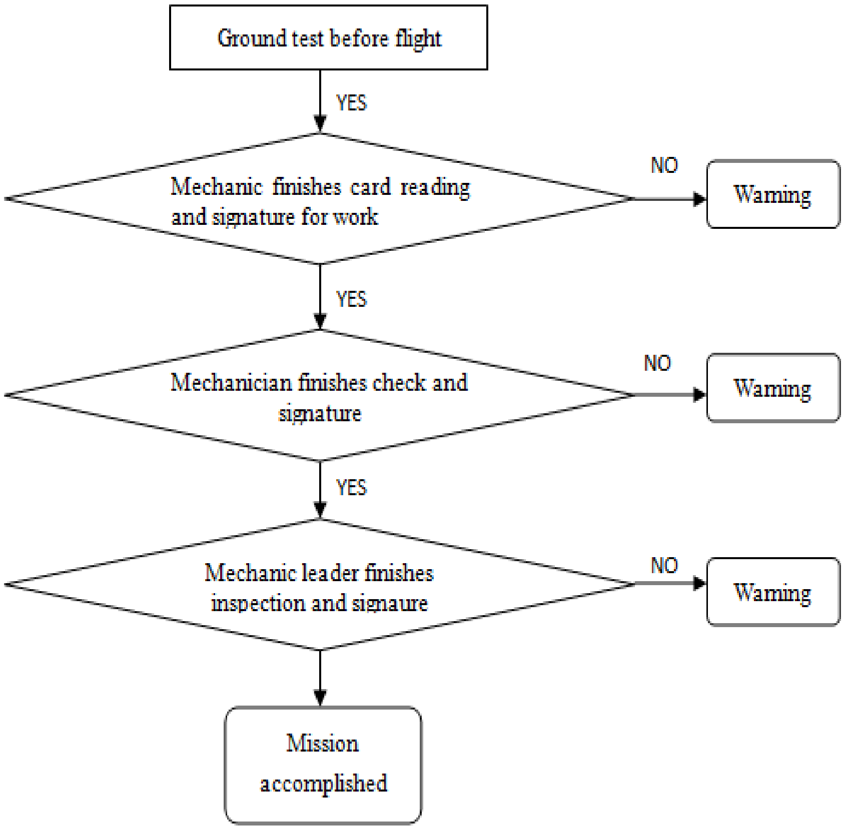


Figure 3.11: Operational process of ground test before flight

3.3.5 Conclusion

Prevention and control of maintenance support human errors should be based on error reduction, error capture and error tolerance. The goal is to effectively reduce the occurrence of errors and avoid severe air-ground accidents caused by human factors. To improve the flying safety of MSRH, analysis framework of maintenance human error is proposed based on MEDA model and ADAMS model which combines top-down active control and bottom-up post-event management.

3.4 Fatigue assessment for significant modification design of helicopter

Significant modification of design refers to those modifications which is not listed in the design specification of the helicopter or parts manufacturers, and possibly have obvious influence on the airworthiness factors such as weight, balance, structural strength, performance, dynamic characteristics and flight characteristics, or those modifications that cannot be accomplished in accordance with the method that has been accepted or by basic operation.

MSRHs are often encountered retrofitting and refitting of some equipment to meet the requirements of search and rescue tasks. Considering from the aspect of helicopter airworthiness, in order not to affect flight performance and the safety of helicopters, modification must comply with the corresponding requirements of the civil aviation airworthiness regulations. To ensure the validity and security of modification, airworthiness compliance verification of design modification must be conducted.

In the modification design of helicopters, it is often related to the determination of the duration of the inspection interval and compliance verification work. So, it is necessary and important to carry out compliance verification of fatigue assessment in the process of significant modification design of helicopters.

3.4.1 Airworthiness certification process of significant modifications

Most of the past aircraft modifications were certified by Supplement Type Certification (STC), providing modified drawings by the design company. As a result of long time to acquire STC and only certified by FAA can get STC, it influenced the development of airlines. Under the background, Civil Aviation Administration of China issued verification programs of significant modification instrument of ratification, which can accelerate the modification. And it also can enhance the ability of independent innovation to provide better operational support for the airlines.

The qualification approval of significant modification consists of Submit application for modification design, preliminary review of the Bureau (the formation of the preliminary report), acceptance, establish review group, determine the basis of modification, compliance review, summary form of a project review, submit significant modification review report, approval by the Bureau, certification and formulating monitoring program of the modification, maintain continuous airworthiness.

3.4.2 Regulations on airworthiness of helicopter's fatigue assessment

According to civil aviation regulations, helicopters can generally be divided into two types: Normal type rotor aircraft and Transport type rotor aircraft. Part 27 and Part 29 are corresponding aviation regulations respectively. FAR and CCAR make specific provision of fatigue assessment for normal type rotor aircraft.

(a) Every part of the flight structure (include rotor wing, rotor drive system between

the engine and the rotor hub, control mechanism, fuselage, undercarriage and the main connecting piece connected with each of the above parts) that may cause catastrophic accidents must be identified, and shall be assessed in accordance with the provisions of this section (b), (c), (d) or (e).

(b) In case of replacement time, inspection interval or other procedures out of accordance with section A27.4 of annex A of this regulation, fatigue tolerance assessment must be indicated to ensure the probability of catastrophic fatigue failure is minuteness.

(c) The replacement time assessment must show that the probability of catastrophic fatigue failure occurrence is minuteness within the replacement time provided in accordance with section A27.4 of annex A

(d) The following applies to the safety assessment of damage:

It shall be indicated that all local damage is easy to check in accordance with inspection procedures provided in article A27.4 of annex A of the regulations.

It must be determined the time interval from the time that any local failure become easy to inspect to the local damage extended to that the remaining structure strength can bear limit load or the maximum loads.

It must be indicated that time interval determined above is long enough for interval between inspections and relevant checking program provided in article A27.4 of annex A, to ensure the probability of catastrophic fatigue failure is minuteness

(e) The combination of replacement time and safety assessment of the damage can be assessed by the combination of this article (c) and (d). For this kind of combination, it must be indicated combination of approved replacement time, inspection interval and related program is provided in article A27.4 of annex A, and to ensure the probability of catastrophic fatigue failure is minuteness.

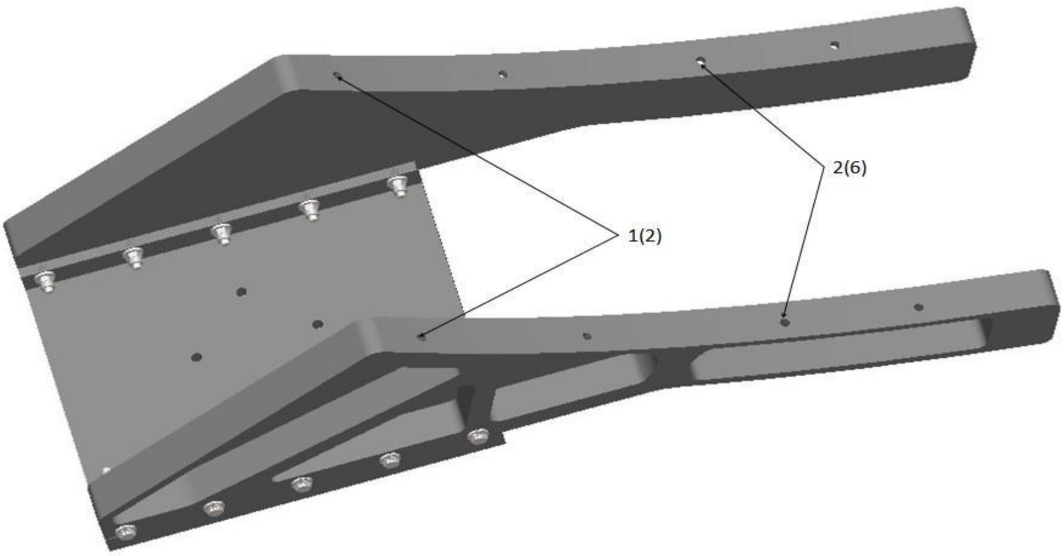
3.4.3 Application case of fatigue assessment

3.4.3.1 Overview

Helicopter camera system has great use in the maritime search and rescue. It provides valuable material for study and record, and it retains evidence for tasks. The certification of important modifications design of helicopter camera system mainly includes compliance check list (the basis of the airworthiness certification), conformity description, stress analysis, analysis of weight and balance, fatigue assessment, electromagnetic compatibility experimentation, etc. Because there are so many details relevant to helicopter camera system modification design, in this part we just discuss the compliance verification plan and compliance verification work of fatigue assessment in the modification design of helicopter camera system.

Figure 3.12 is the design sketch of helicopter camera system. The system and pylons weigh 34.7 Kg, which is fixed in the landing lampshade of helicopter through 8 mounting holes. The cable of the camera system is fixed on the helicopter's abdominal skin with strong adhesive tape. Mounting holes in pylons and landing lampshade are shown in figure 3.13 and figure 3.14 respectively.

Figure 3.12: Design sketch of helicopter camera system



1-Two mounting holes of bolt AN3-11A connecting pylon and helicopter
2- Six mounting holes of bolt AN3-5A connecting pylon and helicopter

Figure 3.13: Mounting holes in pylon

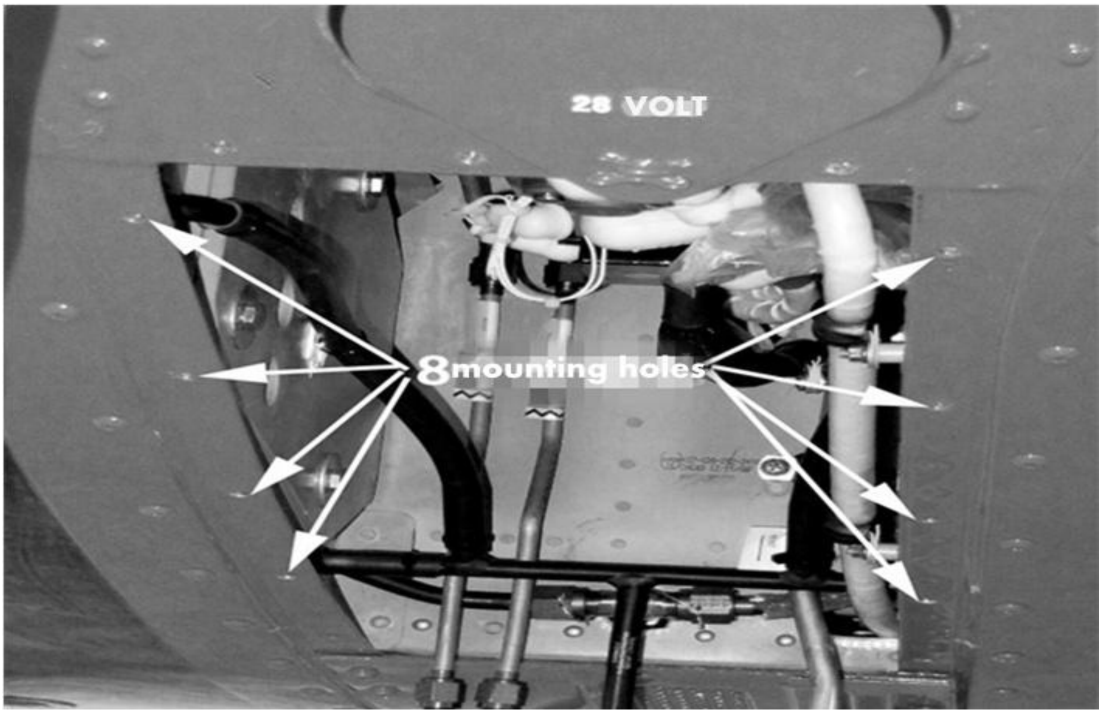


Figure 3.14: 8 mounting holes to pylon in landing light

3.4.3.2 Conformance verification plan

The basis of the airworthiness certification

CCAR-27-R1, the Airworthiness Regulations of Normal type rotor aircraft regulated in flight, strength, design and structure, power plant, equipment, use restrictions and materials. Therefore, the basis for airworthiness certification of important modifications should select applicative airworthiness provisions according to the influence modifications put on performance and safety of the helicopter. And the final confirmation of the basis needs to pass the approval of civil aviation administration. At the same time, requirements for the application of design of the helicopter important modifications shall not be less than the requirements of the relevant provisions of the Type Certificate (TC) and Validation Type Certificate (VTC).

Table 3.1 is selected approval basis of structural aspects according to the TC and VTC of the helicopter to aim at the probable influences of modification of camera system on the aviation safety and performance.

Applicable types: X helicopter Chapter in ATA: 25 Equipment or facilities	MC0: Sketch MC1: Description of design MC2: Analysis and calculation MC3:Safety assessment				MC4:Testroom test MC5:Ground test MC6:Air test MC7:Inspection				MC8:Simulator test MC9:Appraisal of equipment	
approval basis related to CCAR27	Approaches of Conformance									
	MC 0	MC 1	MC 2	MC 3	MC 4	MC 5	MC 6	MC 7	MC 8	MC 9
CCAR 27.25(a)(1)		1								
CCAR 27.27			2							
CCAR 27.29		1								
CCAR 27.251					4					
CCAR 27.301			2							
CCAR 27.303		1								
CCAR 27.305(a)			2							
CCAR 27.307(a)			2							
CCAR 27.309		1								
CCAR 27.321		1								
CCAR 27.561(b)(d)			2		4					
CCAR 27.571			2		4					
CCAR 27.601			2							
CCAR 27.603		1								
CCAR 27.605		1								
CCAR 27.607(a)		1								
CCAR 27.609		1			4					
CCAR 27.610		1			4					
CCAR 27.611		1								
CCAR 27.613		1								
CCAR 27.619(a)3		1								
CCAR 27.625(a)		1								
CCAR 27.865(a)(e)(f)		1								
CCAR 27.1501		1								
CCAR 27.1529		1								
CCAR 27.1581		1								
CCAR 27.1583(c)		1								

Table 3.1: Approval basis of structural aspects of camera system modification design

Conformance verification plan

According to the requirement of approval basis of structural aspects of camera system modification design, following work should be done during airworthiness approval: conformance check list (the basis of airworthiness approval), conformance description, stress analysis, weight and balance analysis, fatigue assessment, etc. Table 3.2 is conformance verification plan specially made for this program.

Number	Project name	Provisions of verification	Contents of verification	Remarks
1	Conformance description	Apply to all provisions	All applicable provisions must have conformance descriptions including referenced designed materials and test analysis	
2	Stress analysis	CCAR 27.301, 27.303, 27.305(a), 27.307(a), 27.561(b)(d)	Finite element analysis on the equipment, ensure the equipment structure under ultimate load will not encounter damage or failure	
3	Weight and balance analysis	CCAR 27.25(a)(1), 27.27, 27.29	Calculation analysis on helicopter center of gravity after installing camera system's influence, and balancing method to ensure the center of gravity meets flight manual requirements	
4	Fatigue assessment	CCAR 27.571	Confirm the fatigue assessment of key parts after the installation, and fatigue tolerance analysis and the fatigue test, verify that the structure fatigue life meet the requirements	
5	Vibration test	CCAR 27.251	Carry out vibration tests to validate it satisfies the requirement of vibration	
6	Impulse test	CCAR 27.301, 27.303, 27.305(a), 27.307(a), 27.561(b)(d)	Carry out impulse test and wind resistance test, verify equipment works well under all kinds of ultimate load	
7	Continuous airworthiness file	CCAR 27.6112(a), CCAR 27.1529	Compile continuous airworthiness files	
8	Engineering order	CCAR 27.1301	compile camera system installation and disassembly operation procedures and specifications	
9	Flight manual supplementary pages	CCAR 27.1581, 27.1583(c)	Compile Restriction to the helicopter flight of installation of camera system into the flight manual complementary pages	

Table 3.2: Conformance verification plan of modification design of helicopter camera system

3.4.3.3 Confirmation of fatigue assessment structure

CCAR 27. 571 regulates that accidents caused by fatigue are indicated to be evitable through assessment to strength of critical element, detail design and manufacturing. Parts need to be assessed including rotor wings, rotor drive system between engine and rotor hub, operating system, fuselage, fixed and movable control surface, support of engine and gearing, landing gear, and connector related to these parts. The confirmation of fatigue assessment should be built on the basis of classification of components including fatigue assessment confirmation of certain components and fatigue assessment confirmation of certain dangerous place.

3.4.3.4 Analysis and test of fatigue

Test and analysis should be taken on those parts which have been confirmed of certain components and certain dangerous place. Fatigue analysis mainly is analysis on fatigue damage tolerance, including fracture toughness, crack propagation threshold level and crack propagation rate. Fatigue test consists of fatigue performance test and fatigue life test.

3.4.3.5 Verification of fatigue assessment conformance

At last, verify whether the fatigue performance of the significant modification design meets the airworthiness requirements or not. According to CCAR 27.571, carry out certify process of fatigue assessment to modification installing site structure.

CHAPTER 4:

Maintenance support problems on aging MSRHs

After more than ten years development, old and new MSRHs coexist. Problems Aging MSRHs face increased year by year. As the growth of use of time, the airframe structure and system gradually slow death influenced by long-term internal and external alternating load and environmental stress, which results in the strength decrease, aging and failure of some accessories. Entering the stage of aging, MSRH dissipative failures increased obviously. In raising the guarantee capacity of new helicopters, we should also focus on excavating aging helicopters' potential to improve aging helicopters' airworthiness. Therefore, according to the characteristics of the aging helicopters maintenance support, strengthening the maintenance of aging helicopters can prevent multiple risk failures to ensure flight safety and give better play to its maximum effectiveness.

4.1 The problems influence aging MSRHs

Collision

Metal material is widely used in helicopters. Most of the components and devices from the structure of materials to the engine accessories are made of metal materials. However, metal materials can produce corrosion such as rust of iron, verdigris of copper, white frost of zinc due to influences by environmental media in the process of long-term use and storage. Analysis from the body structure characteristics, the riveting of skin on the majority of old helicopters is butt riveting. This structure is vulnerable to damp air and water. In addition, some areas such as engine compartment, the main reducer gear compartment and checking cap where it is easy for water remain also prone to corrode.

Abrasion

All components under dynamic work inevitably generate abrasion. The abrasion is mainly embodied in the combination of moving parts and gaps such as bearings, automatic tilting joint and transmission gears. Conduit pipes are easy to wear and tear as a result of small gap with surrounding parts. In addition, parts susceptible to wear and tear like rotor brake disc, manipulating cables, rotor axial joints, longitudinal turning joint and interconnected parts of the connecting rod and rocker of control system.

Aging of non-metallic materials

Non-metallic materials such as plastic, rubber, paint, leather and fabric are used in helicopters. They are easy to ageing in the sun or under high temperature or in some solvents. For example, Rapid changes in temperature, organic glass could produce silver grain. Refraction occurs and lower the light transmittance. Sunshine will accelerate the oxidation of organic glass. There will be a fog phenomena occurring on organic glass after solvent erosion. In addition, ageing always happens in those parts the lubricating oil duct, hydraulic oil duct hose, wire insulation parts, gaskets and fire prevention cloth after using for a long time. Aging of components will lower the sensitivity of equipment. Aging of wire insulation leads to short circuit and open circuit fault. And the aging of hose can easily cause oil leakage.

Crack

Helicopters will produce different loads during parking and flight, produced by, especially the impact load of taking off and landing makes the body or parts encounter tensile force, shear force, torsion force and extrusion force. During rotor rotates at high speed, hub and automatic tilting devices can produce stress concentration. When the stress is too large, it is easy to cause crack. When engine is working, the moving parts and bearings will produce thermal stress due to the higher temperature. Enough thermal stress may cause fatigue, result in crack in such position of turbine blades and the compressor blades. In addition, the structure characteristics of helicopters determine the large vibration at work, and vibration makes main stressed components cause fatigue, seriously cracks produce on the parts and even rupture.

4.2 Maintenance countermeasures for aging MSRHs

Failure rate increased significantly after MSRHs entering aging stage. The helicopter maintenance personnel shall actively take effective measures to complete aging helicopters maintenance work.

Control the flight rate

Well control of aging helicopters' flight rate is an effective way to reduce the failure rate and lower maintenance costs. Maintenance personnel can't simply make the maintenance plan according to the number of flight hours. The number of helicopters' landing and taking off, load and the length of time of continuous flight have an effect on the life of helicopters. Therefore, we should do the followings to control the flight rate. The first is properly extending the flight time interval of aging helicopters. Fully consider the aging helicopters' status while making flight plans. Do not ignore the helicopters' security to complete the training task blindly. The second is reducing the continuous flying time properly. The longer time helicopters fly for continuously, the greater the heat load and dynamic load of parts. For aging helicopters, it is easier for the parts to appear deformation, crack and fracture. Decrease of the continuous flying time properly can greatly reduce the failure rate of parts and extend the service life relatively.

Maintenance regularity and preventive maintenance

Because of the faults like crack, corrosion, leakage and abrasion of aging helicopters is increasing. In order to improve the effectiveness of maintenance, maintenance personnel must ascertain the regularity of faults and formulate feasible technical countermeasures. The first is to carry out general survey of performance and quality appraisal, and make flight strength limit and eliminate phase for aging helicopters on the basis of mathematical analysis of failure data. The second is to make maintenance and management measures suitable for aging helicopters. Organize technology backbone to clean up the maintenance regulations and technical measures over the years. Study on the characteristics and fault regularity, sum up experiences and formulate corresponding management and maintenance measures. The third is to strengthen preventive maintenance for aging helicopters. Accomplish preventive inspection and maintenance for those main accessories abrade severely in advance. Accomplish moisture and rust removal for those corrode seriously in advance. The fourth is to strengthen specific inspection and maintenance for aging helicopters. Strengthen the inspection and maintenance of the main accessories those are easy to corrode, abrade and stress concentrate.

Quality improvement of maintenance personnel

The quality of maintenance personnel is of vital importance in the maintenance. Highly qualified maintenance personnel are prerequisite to ensure flight safety. Especially for aging helicopters maintenance personnel, the standards and requirements should be more strict and higher. Following are measures to improve the quality of maintenance personnel. The first is to improve the ideological understanding, eliminate the idea of attaching importance on maintenance for advanced technology and equipment, despising the maintenance for old technology and equipment. There are many types of MSRHs in rescue and salvage flying services, the new and old types are both in use. Maintenance personnel should focus on their duty and then study advanced technologies and equipment based on good maintenance of existing equipment and technology. The second is good training of maintenance for aging equipment. Before the implementation of ageing equipment maintenance, maintenance personnel should be practically trained, especially in the aspect of characteristics and maintenance regularity. The third is creating good working atmosphere to motivate maintenance personnel. Maintenance department should pay attention to create good working atmosphere, correctly guide the maintenance personnel to handle the relationship between the individual efforts and the pursuit of goals. Some people think that there is no use maintaining old equipment. But in the long run, the use of old equipment is a transitional period, proficient skills on the maintenance of old equipment lay good foundation to meet the new technology and equipment.

CHAPTER 5:

Conclusion

Skillful helicopter technology has been applied in many ways. Because helicopters have the various characteristics above, the application in maritime search and rescue is particularly important. As discussed above, China is a country with long coastline in the world, but the number of search and rescue helicopters is too little compared with that of other countries. China should improve the input of rescue helicopters and attach great importance to training of pilots, maintenance personnel and lifeguards.

In improving safety guarantee of MSRH, weather conditions have significant effects on search and rescue operation, this paper introduces all kinds of extreme weather's influence on helicopter and put forward solutions which are of importance to the helicopter safety. The requirement of the maintenance staff is also the important factors that influence the safety. In order to ensure the safety of search and rescue helicopter, maintenance personnel must go through strict and unified training. Cultivating skilled maintenance personnel is a precondition for safe operation of MSRH. As the most important factor, human factors affecting the safety of aviation in the article accounted for a large proportion. Of course, all of the accidents are directly or indirectly related to human. Human errors must be reduced to the minimum. This paper puts forward human error analysis framework of maintenance personnel based on MEDA and ADAMS system to reduce and prevent human errors. In addition, rescue helicopters need to do some modification to meet the need of application. These modifications may affect the strength and toughness of original structure, so the important modification to helicopter must have the fatigue assessment to avoid secondary accidents.

In terms of maintenance for aging MSRH, maintenance personnel should do well in maintenance tasks to make aging helicopters more valuable.

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