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DISPATCH RELIABILITY ORIENTED MMEL FORMULATION TECHNOLOGY RESEARCH

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Abstract:

Approved by Civil Aviation Administration of China (CAAC), proposal of Master Minimum Equipment List (MMEL) is prepared by aircraft manufacturers to permit aircrafts under conditions that some equipment or its function is not available. Effective MMEL can balance the security and profitability of aircraft, which means in premise of security aircraft will maximize the benefits. Aiming to keep dispatch reliability, MMEL is taken into account in all stages of aircraft design and combined with aircraft safety analysis and evaluation process. In design phase, we will make specific components of aircraft more reliable and safer. At the same time, reasonable operating and maintenance procedures are essential to lay down a high reliability MMEL, form aspect of effect of dispatch reliability on operation.

0. Introduction

With the rapid development of china's economy, civil aviation is flourishing. However, conflicts between passengers and airlines are increasing due to flight delays that have become increasingly serious. It becomes a main factor reducing efficiency of airlines and quality of service [1]. At this point, dispatch reliability is considered as a significant indicator for airlines to choose types [2].

As civil aircrafts' main operating targets, dispatch reliability of civil aircraft not only reflects availability of aircrafts and their system functions, but also controls their earnings. In addition, it plays a particular role in operating under customer expectations / requirements. Thus, it is an urgent problem to address how to estimate system's reliability rationally and its impacts on operational efficiency of airlines [3]。

Aircraft failures are ineluctable, though there is a high reliability of different systems and component in aircrafts. If failures occur in these parts, aircrafts stop operating, which definitely causes huge economic losses to operators and passengers [4]. Therefore, requirements ---- some equipment or systems leading certain failures may be off, are presented to increase dispatch reliability on basis of ensuring security. Minimum Equipment List consist of those failure equipment or functions. Selection of MMEL's items, an extreme work, directly links with safety and economy of aircraft operation [5]。

Items in MMEL shall be improved as possible to improve dispatch reliability and operational capacity of aircrafts. In this case, MMEL's items shall be laid down in purpose of achieving a high dispatch reliability with great initiative to request and control in order to improve operational capability of aircrafts under premise of ensuring their safety.

1. General requirements to lay down MMEL's items to increase dispatch reliability

1.1 Right moment to lay down MMEL's items increase dispatch reliability

Design of civil aircrafts mainly consists of three phases: conceptual design phase, preliminary design phase and detailed design phase, as shown in figure 1(flowchart of full life function for civil aircraft) [6].

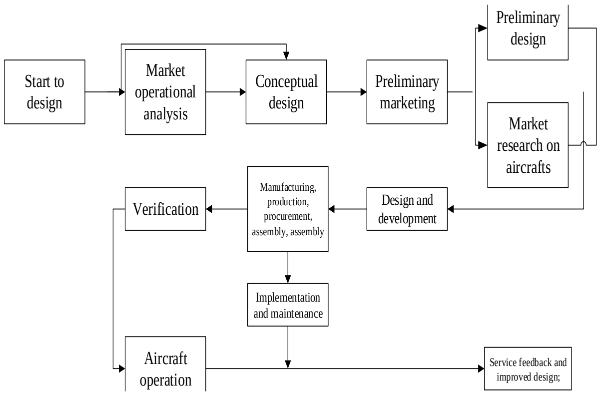

Figure 1：Flowchart of full life function for civil aircraft

Safety assessment is conducted through entire design phase of aircrafts. Safety requirements, obtained in conceptual design phase, will be reappraised and redesigned with the increasing improvement and modification. New safety requirements may be generated during this process, causing changes in designs[7]

Similarly, MMEL to increase dispatch reliability is also carried out during the whole life span of aircrafts. In the design phase, which systems / components of aircraft could be included in MMEL through security analyses; meanwhile, design of maintenance and security should be made more reliable to increase aircrafts' fault operation [8], as shown in table 1:

Table 1:

MMEL formulate for dispatch reliability in different development stages of aircrafts

Phases of aircrafts' life span	**MMEL formulate for dispatch reliability**			
	safety analysis	Reliability analysis in design	Maintainability analysis in design	Safety analysis in design
Conceptual design phase	Conduct FHA analysis to confirm fault effects and classify fault types	Distribute system reliability index according to specified quantitative requirements of reliability in order to let relevant personnel to understand their targets respectively	Determine maintainability ration and qualitative requirements to distribute system reliability indexin order to let relevant personnel to understand their targets respectively	Initial safety scheme（covering alternative stage and optimizing stages, etc.）
Preliminary design phase	Conduct FHA qualitative analysis to confirm the minimal cut set of faults, i.e., determine the combined the failures effects.	With the development of engineering design，establish a more detailed and accurate reliability model to distribute and predict system reliability again，and adjust allocation of system reliability index more reasonably.	Establish a detailed maintainability model to distribute and predict system reliability again，and adjust allocation of system reliability index more reasonably.	Detailed protection scheme（Preliminary support program）
Detailed design phase	Figure out probability leading to catastrophic and dangerous failure through quantitative FTA and FME (C) A	Establish a more detailed and accurate reliability model based on analyzed MMEL alternative items and change reliability design against catastrophic	Establish a more detailed and accurate maintainability model for MMEL items and change maintainability design against MMEL alternative	Obtain a detailed protection scheme through specificity analysis of support system and balance

		and dangerous systems / components caused by faults	items.	evaluation of safeguard scheme
Operation phase	Sort out security events and do safety analysis on specific safety risks; conduct safety analysis again and update the MMEL items.	Conduct statistical analysis and change component / system of low maintainability locally.	Conduct statistical analysis on failure rate statistical analysis and change component / system of low maintainability locally.	Reduce mean time to repair and increase dispatch reliability through making reasonable spare parts plan.

1.2 Principle to determine MMEL's alternative items

MMEL's items are compiled in accordance with number of ATA system, considering the following principle to determine MMEL's alternative items:

1） Items having significant meaning and deciding the safety case of aircrafts and not allowing aircrafts to fly under fault operations due to those reasons, such as equipment controlling to take off, land or climb up, shall be excluded;

2） Equipment or components having great effects on air safety and reliability but allowing aircrafts to fly under certain conditions such as weather, route and day and night, may be included in MMEL after drafting a maintenance procedures and operating procedures；

3） Equipment or components having few effects (or none) on air safety and reliability such as entertainment system, shall be excluded in MMEL；

4） Additive failure shall be taken into account if system and items become invalid or failed, considering whether it will threat air safety, or influence implement of AFM program, or have the crew overload. Strictly limit and list it into MMEL, if necessary [9].

2. Procedure to lay down MMEL's items to increase dispatch reliability

According to relevant regulations of MMEL, content to lay down MMEL's items to increase dispatch reliability shall take safety analysis process as the core and the operational measures and maintenance measures of MMEL project as foundations, and focus on reliability, maintainability and security in designing; development of MMEL project shall be produced under multi interactions. In final, aircraft will get a high dispatch reliability in order to make its profitability better, through reasonable development of MMEL project.

2.1 Identification of fault types of MMEL project

Fault types of MMEL project shall be identified to determine the method to lay down MMEL effectively in the preliminary design phase to lay down MMEL in purpose of increasing dispatch reliability, as shown in figure 3：

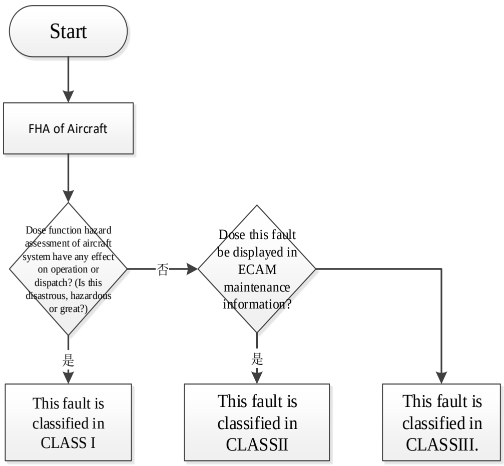

Figure 3： Identification of MMEL items' fault types

At the beginning of development cycle of aircraft / system development cycle, functional hazard assessment shall be conducted and classified to identify failure states associated with aircraft function and function combination. Failure states shall be classified to establish security targets [10].Based on determination of influence level and its impacts on aircrafts, failures influencing dispatch and operations may be figured out. As a result, disastrous, hazardous and great faults, as well as those influencing dispatch and operations are defined as fault of CLASS I fault. Fault state having no effect on operation and dispatch are classified as CLASS II in the light of maintenance hints form central monitoring system of aircrafts of the same models and well-developed models; other smaller or slighter faults are defined in CLASS III.

As for faults in CLASS I, it is essential to do detailed safety analysis to support airplanes under fault operation.

In CLASS II, faults having no effect on operation and dispatch shall be maintained within a certain period.

Faults in CLASS III nearly has nothing to do with aircrafts' safety without affecting operation and dispatch.

2.2 Qualitative analysis on safety of MMEL items

Effect of in-operation equipment on operation of aircraft shall be estimated through qualitative analysis on safety to work out MMEL project. Qualitative analysis shall think about the impacts form flight crew's workload on maintenance and operating procedures, and furthermore shall show previous running status when using MMEL.

Relative qualitative analysis method of safety are used in analyzing qualitatively consequences from failures, form following aspects:

1) Whether there is redundancy in functions or components;

2) Whether some functions may be replaced by other components or / and equipment;

3) Loads of flight crew;

4) Adjust maintenance procedures and operating procedures.

Qualitative analysis of security level is achieved through the following qualitative FTA.

2.3 Safety quantitative analysis on MMEL items

Safety quantitative analysis requests probabilities that disaster or major or dangerous events occur in system, that is, we need the probabilities to figure out which core components or systems may be affected by faults. Thus we shall do quantitative analysis on safety to address this issue.

Impacts of components or systems under fault operation on flying shall be assessed through thinking over characteristics of faults form MMEL's alternative items in safety analysis, so that probability of this event is ensured to meet requirements of model validation process [11].

Safety quantitative analysis has function to identify risks resulting from secondary failure and environmental impacts of some designs when operating under some faults, and determine maintenance deadline in this case.

FMECA and quantitative FTA are used as main ways to lay down MMEL to increase dispatch reliability. FMECA is aimed to identify failure modes of components, systems or functions from bottom to top and determine impacts of failure modes on high level components, systems or functions. Generally, FMECA is adopted to measure effects and hazards of failure caused by component failures [12].

2.4 Establishment of Maintenance procedure and operation procedure

Under fault operations, we shall analyze whether necessary to create the appropriate maintenance procedures and operating procedures to guarantee aircrafts' safety based on actual situations of fault components / systems. In this paper, the author draws up appropriate operation and maintenance procedures against different situations under fault operations as shown in figure 4:

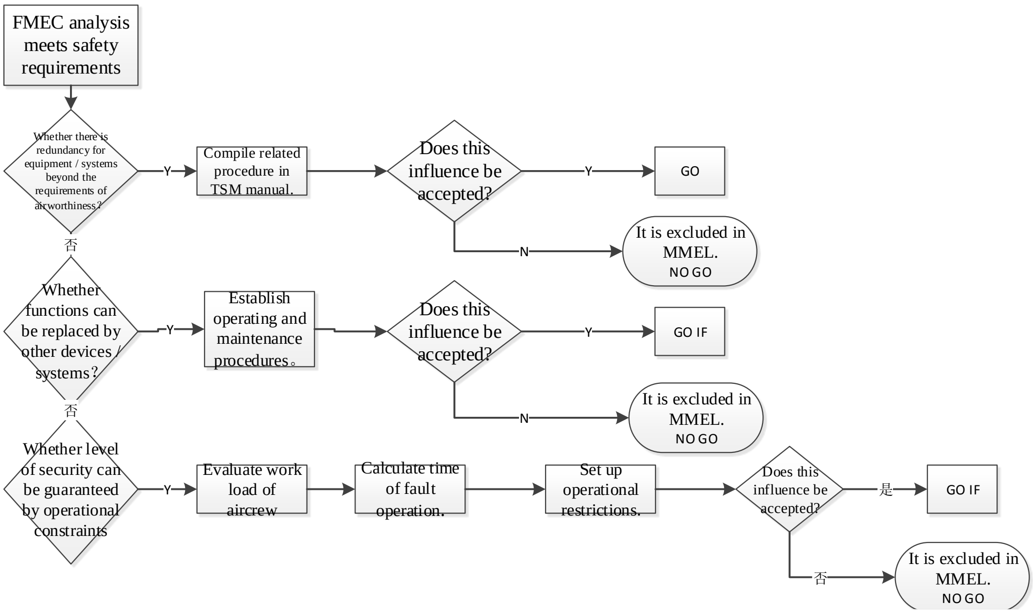

Figure 4: Operating procedures and limit judge MMEL project

When MMEL's alternative items meet security requirements, we evaluate them from the following aspects based on results of FMECA analysis:

1) Whether there is redundancy for equipment / systems beyond the requirements of airworthiness.

2) Whether functions can be replaced by other devices / systems

3) Whether level of security can be guaranteed by operational constraints

Negative answers mean functions can't be operated under faults, so functions are excluded in MMEL. While affirmative acknowledgements indicate that we shall compose relative maintenance procedures and operating procedures.

2.5 Control against design factors of dispatch reliability

In this paper, the author combine creation of MMEL and safety analysis throughout the whole life span of aircrafts. Especially in the design phase, design factors related dispatch reliability may be controlled according to analytic result of MMEL items based on the design of reliability and maintainability in order to increase dispatch reliability of aircrafts.

2. 5. 1 Reliability factor control

From the figure 5, we may obtain MMEL alternative items not satisfied safety requirements. To enhance dispatch reliability of aircrafts as far as possible, it is essential to deign reliability of MMEL alternative items in order to make MMEL cover more as possible。

In this paper, aiming at MTBF, main ways are adopted to design and enhance reliability as follow:

1) Using system /LRU components of high reliability. Reliability of LRU components are usually decided by suppliers and affected by maintenance of air lines. Reliability of components are evaluated by mean time between failures (MTBF). In addition, airlines may revise MTBF according to their own maintenance features and Operating environment. MTBF data may be used as the prerequisite to select LRU components. As for LRU components failing to meet the reliability requirements, we may:

- Choose LRU suppliers of high LRU MTBF and low failure rate
- Ask original supplier for extra service and support

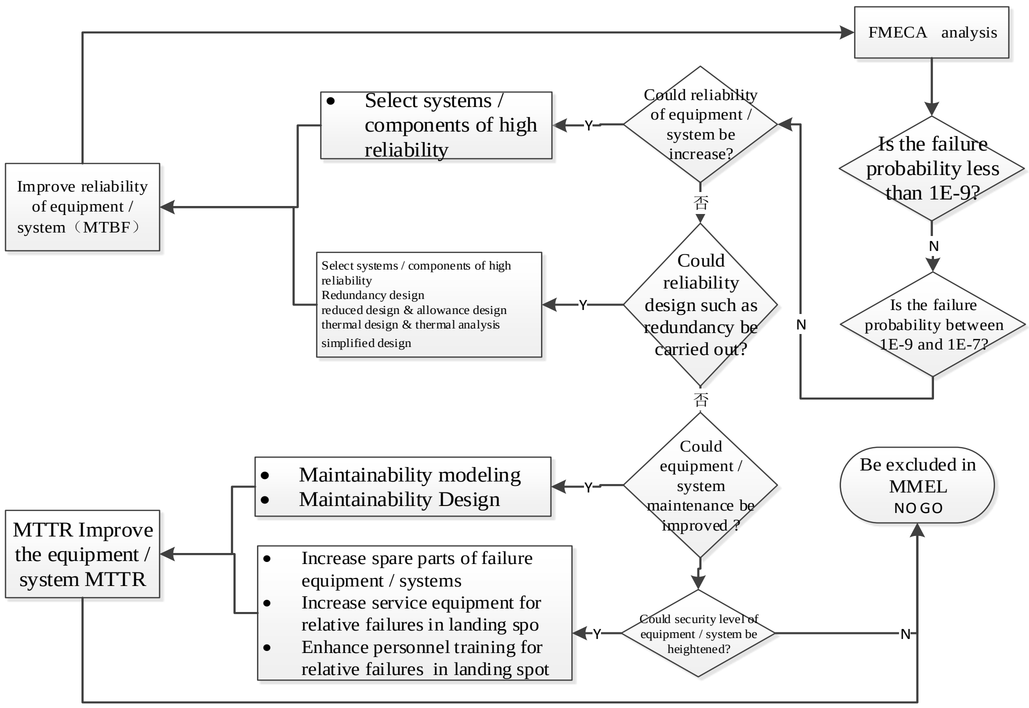

Figure 5： Flow chart of design factors to increase dispatch reliability in laying down MMEL

2) Arranging reliability design。

As for components of low reliability, reliability design including redundancy design shall be organized, which can not only effectively improve reliability of system and aircraft, but also heighten safety level of aircrafts [14]. Meanwhile, this may provide backups for components when they have a breakdown, enable them run under fault operation and be included in MMEL。

After completing reliability design, data shall be reappraised whether meet the safety requirements by put them into FMECA。

2.5.2 Maintainability factors control

Although maintainability has no direct effect on safety level of MMEL alternative items, we could design maintainability of some components whose reliability may not be enhanced in MMEL project analysis, so that MTTR may be cut down as possible to complete MMEL in order to increase dispatch reliability [15].

As for dispatch reliability, maintainability is time limited, which means that if faults are found before aerial navigation, mean repair period shall be less than turn-around time plus specified delay time (delay is defined as a set of events that real departure time is more than planned departure time, which is caused by breakdowns in a plane or its system or components known or unknown). That is:

MTTR(entire aircraft)≤turn-around time+15min

Control of dispatch reliability shall be started with related components and subsystems by controlling MTBF, MTTR and supportability of related LRU components and subsystems[16]

$$DR_i = \frac{MTBF_i}{MTBF_i + MTTR_i}$$

2.6 Determination of MMEL items' repair period

In MMEL, repair time of fault operation must be defined and classified into class A, B, C and D. Maximum maintenance time interval in class A shall be specified, while that in class B, C and D are 3 d、 10 d and 120 d, respectively.

As for faults in CLASS Ⅲ, they have no impacts on operation and dispatch and none prompt message of maintenance in ECAM, which suggest failures of equipment will not increase working load of aircrew. So pilots are independent of this function. Some equipment is excluded in PMMEL, such as Kitchen equipment, film equipment, ashtrays and reading lights. If included in PMMEL, those can be distributed repair interval in the class D.

As for faults having no impacts on operation and dispatch but prompt message of maintenance in ECAM has no effect on safety in CLASS Ⅱ, equipment having no effect on safety shall be distributed repair interval in the class C of 10 days

As for faults in CLASS Ⅰ, repair period and safety level requested shall be determined by the following:

1) Whether there is redundancy for equipment / systems beyond the requirements of airworthiness；

2) Whether functions can be replaced by other devices / systems；

3) Whether level of security can be guaranteed by operational constraints；

If safety level is maintained by 1), repair interval of class D may be allocated to faults related to safety but having no impact on operation and dispatch。

If safety level is maintained by 2), result of qualitative analysis considers that equipment out of work has great impacts on operation; in this case, maintenance and operating procedures will be required to create. So repair interval of class B may be allocated to those fault as maximum maintenance interval.

If safety level is maintained by 3), maximum allowable departure time of equipment shall be determined based on probability. Under this case, repair interval of class A shall be distributed to this type of faults. Calculation of repair interval in class A may refer to the way to compute mean time probability in SAE ARP5107 [17]. Result of repair interval in class A, with a time range, is not always less than that of class B or class C. However, operating time under faults shall be restricted in class A.

Flow chart of determining the repair interval of MMEL's items is shown as figure 6.

3. Cases to formulate MMEL in fuel system

In this chapter, taking the fuel system of a type airplane, the author analyzes the development of MMEL project to improve dispatch reliability, and works out MMEL of safety analysis against a certain type of fuel system to verify feasibility of the method.

3.1 Fuel system FHA

At the beginning of MMEL project, we shall start with function hazard assessment. According to the overview of Fuel system FHA from section, total four faults are selected to analyze due to limited length of this paper, such as disable continuous drainage of fuel tank continuous drainage, low level alarm function of fuel tanks in left or right wings, misdirection of fuel tanks in both left and right wings, two engines lost function to supply fuel, shown as table 2.：

Table 2 Summary of function hazard analysis of fuel system

Risk description	Risk NO. of function	operative mode	failure level	proof technique
Tank can not drain away water continuously	28-1-2	ALL	Ⅳ	Quantitative FTA

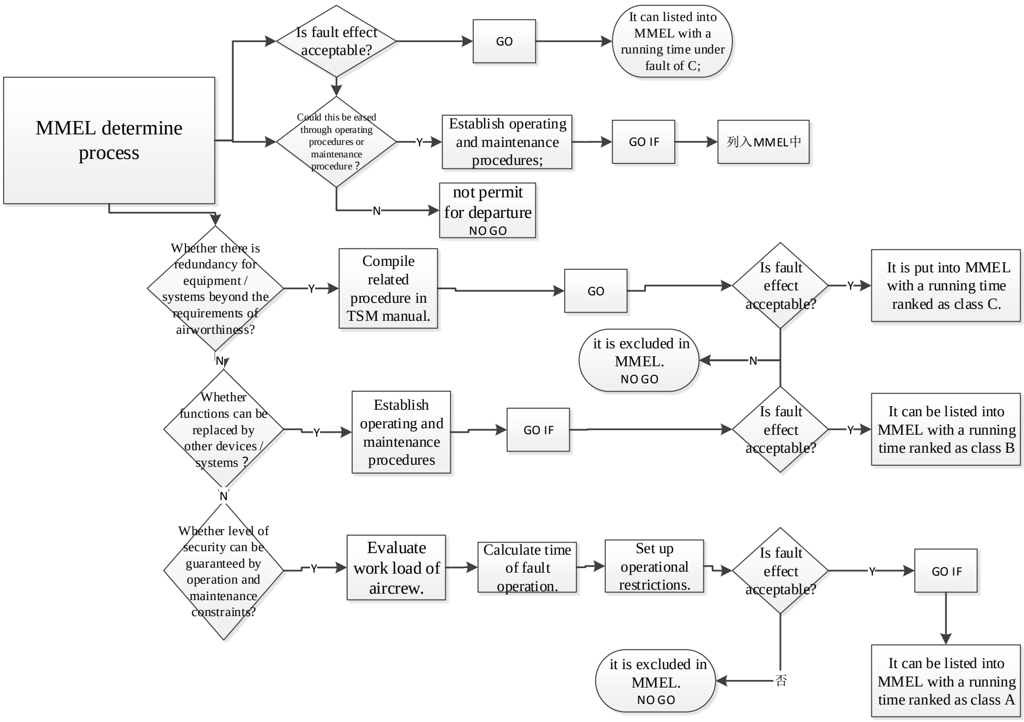

Figure 6： With faults operating time categories

3.2 Tank can't drain away water continuously

We analyze the fault in accordance with process in section 2, and assess the following based on result in table 2-Function Hazard Assessment:

1) Is influence of the fault on operation or dispatch catastrophic, dangerous, or huge? No.

2) Carry out qualitative FTA to this fault as shown in figure 7;

The fault result from two other faults, functional incapacitation of water removal ejector pumps and rupture of water removal pipelines on basis of FTA qualitative analysis.

3) Does this fault display in ECAM's maintenance status? No.

4) This fault is classified in CLASS Ⅲ;

5) Water removal ejector pump and water removal pipelines are listed in MMEL with operating time in class D。

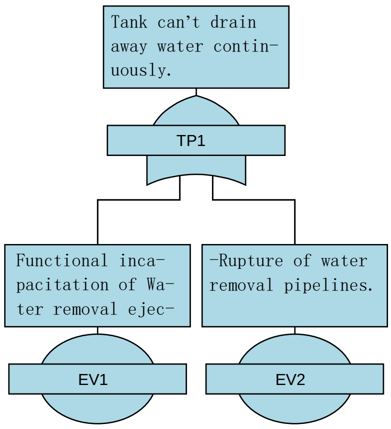

Figure 7 Fault tree analysis that tank can't drain away water continuously.

6) As 4 water removal ejector pumps are installed in fuel system, their function will achieve if one is available. Similarly, there are 12 water removal pipelines, one can guarantee their functions：See table 3--MMEL alternative project assessment below:

Table 3 MMEL alternative item assessment of removal water ejector pump in fuel system

Aircraft	Revision No:	Page
（1） System and serial number	（2）class of repair period	

Fuel system	（3）Quantity	（4）Quantity required to dispatch or discharged	5） Notes and exceptions
Water removal ejector pump	4	1	（M）If meet any condition below, three water removal ejector pumps are allowed not to work: 1. One water removal ejector pump is confirmed to be normal operation。
water removal pipelines	2	1	（M）If meet one condition below, one water removal pipeline is allowed not to work: 1. one water removal pipeline is confirmed to be normal operation。
1. System description: water removal pumps and water removal pipelines are include in water removal system。Their purpose is to clear and drain residual water in fuel tank to guarantee redundancy of pliotherm level in oil feeding tank and make amount of unusable oil within a certain range. 2. Certification basis: based on FHA, qualitative FTA shall be conducted on discontinuous drainage to make sure that such failures are not displaying on the ECAM maintenance information; This failure is classified into as CLASS Ⅲ；In final, water removal pumps and water removal pipelines is listed into MMEL with a running time ranked as class D. 3. Failure effect: functional incapacitation of suction pump may cause residual water in some part of the oil tank, go against cleaning，make the redundancy level in oil feeding tank in a lower status, and increase the amount of unusable oil. Rupture of water removal pipeline will cause that: a. fuel in fuel tank can't be delivered to associated oil feeding tank b. residual water will occur in some part of the oil tank, go against cleaning，make the redundancy level in oil feeding tank in a lower status, and increase the amount of unusable oil.			

4. Conclusion

This paper build a mechanism to lay down MMEL aiming at dispatch reliability and give an account of its general requirements. Starting with function hazard assessment, author of this paper brings safety analysis into the mechanism, analyzes faults determined by function hazard assessment through qualitative FTA, quantitative FTA and FMECA and identify impact of equipment failure on aircrafts' safety.

As for components fail to meet safety flight requirements when equipment goes wrong, their factors affecting dispatch reliability shall be further enhanced in design and operation to make the safety level meet the safety flight requirements. Relative equipment shall be include in MMEL and operating procedures and maintenance procedures shall be determined according to those factors. Corresponding repair period shall be confirmed in the light of classification of MMEL items and the way to maintain the safety level. Hence, dispatch reliability of aircrafts has been increased as MMEL list is enlarged.

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