Research on the Application of Supportability Analysis Technology in Ejection Seat

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Abstract. Ejection seat is a complex system that can be both one-time-used and continuous-used, in which the supportability analysis technology plays an essential role. Supportability analysis includes Reliability-Centered Maintenance Analysis (RCMA, for short), Corrective Maintenance Analysis, Level of Repair Analysis (LORA, for short), Operation and Maintenance Task Analysis (O&MTA, for short), Support Equipment Requirement Analysis and Spare Parts Requirement Analysis (shortened as “6A”). Firstly, in this paper, the concept of “6A” technology and their relationship are introduced. The general “6A” working process of a certain type of ejection seat is then studied. In the end, the “6A” work is carried out on a certain type of ejection seat according to the analytical steps and requirements to “6A”.

1. Introduction
Ejection seat [1] often serves as relatively comfortable seat and provides necessary restraints for pilot during normal flying. While it can automatically initiate ejection rescue program after activating the ejection handle when an irreparable fault happens to the aircraft, and the pilot will be safely catapulted out of the aircraft, remaining survival and waiting for rescue based on the conditions provided by the seat. Therefore, supportability analysis [2] is an important part that affects the design of ejection seat, determines the support resources, and improves the operational efficiency of ejection seat. The “6A” constitutes the main content of supportability analysis [3-5], and is the main basis that affecting equipment design and support resource [6]. The application of “6A” technology in the ejection seat can provide clear requirements of preventive maintenance and repair maintenance, determine resource requirements, so as to provide reliable data for the formulation of a reasonable and effective maintenance scheme for the ejection seat. With urgent research requirement and reliable technological support, the “6A” technology shall be effectively applied to the development of ejection seat [7, 8].

2. “6A” Technology
The “6A” technology is the core of supportability analysis technology. RCMA keeps the inherent reliability and safety of equipment with minimal resource consumption, and determines the preventive maintenance requirements of equipment based on logical decision method [9]. On one hand, it provides necessary input for design modifications, on the other hand and more importantly, it helps to identify work items that require preventive maintenance and to provide input data for O&M TA.
Corrective Maintenance Analysis determines the type of repair maintenance and the possible working frequency, and proposes recommendations of maintenance level. LORA performs non-economic or economic analysis for a product that is expected to fail [10], so as to determine the level of viable repair or end of service. O&MTA guarantees the resource requirements for application and repair tasks (including preventive maintenance tasks, remedial repair tasks, and application tasks), provides support for determining related transport requirements, provides data for evaluating alternative support plan, and provides raw materials for the formulation of various support documents and schemes. Support Equipment Requirement Analysis determines the project and technical requirements of necessary support devices (including tools) during operation and maintenance of equipment, providing a basis for the formulation of supportive plan and equipment development. Spare Parts Requirement Analysis determines the required spare parts items and quantities for the equipment during application and repair, especially for initial application and maintenance.

As an important analytical work in supportability analysis, “6A” shows inseparable relationships between each item. First of all, the work of “6A” should be carried out on the basis of fault mode and impact analysis in obtaining information generated by Failure Modes and Effects Analysis (FMEA, for short), such as "failure mode", "failure cause", "failure effect", "severity", "design and improvement measures" and "application and compensation measures". RCMA is mainly used to determine the important function product of ejection seat, and the logical determination is applied to determine the type of preventive maintenance and the maintenance interval. Corrective Maintenance Analysis mainly determines the required repair type of ejection seat. LORA mainly decides the site for ejection seat repair. O&MTA, based on the requirement of preventive maintenance and repairable maintenance, determines the support resource required for ejection seat repair. Support Equipment Requirement Analysis mainly determines the type and quantity of support equipment at each maintenance level. Spare Parts Requirement Analysis mainly decides the items and quantity of spare parts required in application and maintenance. In short, the “6A” items are interdependent and mutually influential, they can optimize the support plan and determine required support resource by analyzing the supportive designs that affect the operation of equipment.

3. Application research of "6A" in a certain type of ejection seat

3.1. The Composition of a certain type of ejection seat
A certain type of ejection seat is mainly composed of seat structure, seat system and seat power device. Seat structure includes comfort component, umbrella box, chair basin, slide rail component and personal survival kit. Seat system includes ejection control system, separation system, shoulder belt control system, lower limb restraint device, arm limit system, belt control system, high-speed airflow protection system, electrical system, remote ignition system, oxygen supply ventilation and anti-load pipeline system, stability system and rescue umbrella system. The seat power unit consists of a twin-barrel ejector, a rocket motor, an attitude rocket and an umbrella mechanism.

3.2. The “6A” working flow of a certain type of ejection seat
The general “6A” working flow of a certain type of ejection seat is shown in Fig. 1, including collecting the functions, structures, and other data of the analyzed objects (ejecting seats, sub-systems or parts, etc.). Carrying out FMEA works at corresponding function or hardware levels, carrying out RCMA based on FMEA work and the characteristics of the certain type of ejection seat, determining the type of preventive maintenance, performing repair maintenance analysis based on FMEA results and carrying out, LORA, carrying out RCMA, repair maintenance analysis, LORA, and other product data (such as inspection, packaging, handling, storage, transportation, etc.) for O&MTA, determining the required support resource for application and repair tasks, determining the support resource requirements at each maintenance level based on the required support resources.

3.3. The “6A” characteristics of a certain type of ejection seat
Support analysis is highly targeted, which means the prioritized logistics support analysis should be carried out in accordance with the supportive characteristics of different types of equipment. The
analysis results will be more reasonable, and will provide better service to the supportive design of equipment. A particular type of ejection seat is composed of electro-mechanical and initiating explosive device, and has high reliability requirement, many parts of which are not used in normal flying, but only used in emergency ejection. Therefore, great differences remain between the ejection seat and other machinery, frequently used equipment, forming unique characteristics of the seat in application and maintenance support.

**3.4. The “6A” working of a certain type of ejection seat**

The failure mode, influence and harmfulness of a certain type of ejection seat have been analyzed before supportability analysis. In order to ensure the comprehensiveness of the supportability analysis, the failure mode, influence and hazard analysis of a certain ejection seat are started from its...
components. Due to the complex structure of a certain type of ejection seat and the limited space of this paper, only the supportability analysis of ejection control system is talked about by considering the complicated structure of the ejection control system which contains not only electromechanical parts but also initiating explosive devices.

3.4.1. Reliability-Centered Maintenance Analysis. According to the FMEA analysis results of the ejection control system, the first layer of logic decision map is used to determine whether the impact of the functional failure of the ejection control system is of obvious security, mission, economy or of concealed safety, mission and economy. The cause of each functional failure is considered afterwards by using the second-level logical decision diagram in determining the type of preventive maintenance for the ejection control system. The RCMA record diagram of the ejection control system is obtained through logical decision diagram analysis, as shown in Table 1. The impact of the failure mode of the ejection control system is analyzed as a safety impact, so the “mission impact” and “economic impact” are not listed in Table 1. The types of preventive maintenance work for the ejection control system obtained from Table 1 are functional detection, application inspection, timed scrap, and timed repair.

3.4.2. Corrective Maintenance Analysis. According to the results of the FMEA analysis of the ejection control system, the corrective maintenance analysis was carried out. The result shows that only disassembly and replacement were performed for ejection control system maintenance, seeing Table 2.

3.4.3. Level of Repair Analysis. When determining the repair level of the ejection control system, non-economic analysis should be carried out at first in determining the reasonable repair level. If it cannot be determined, economic analysis will be performed to select a reasonable and feasible repair level or directly scrap. Based on the non-economic impact factors (safety, confidentiality, current maintenance options, mission success, handling, transportation and transportation, support equipment, manpower and personnel, facilities, packaging and storage) as specified in GJB2961, the perform non-economic analysis to the ejection control system was performed. The result shows that the replacement of central gripper, spring, program control box and seal ring were completed at base level and the replacement of detonation bomb is completed at grass-roots level due to the technical requirements of maintenance personnel, seeing Table 3.

3.4.4. Operation and Maintenance Task Analysis. When determining the tasks for an ejection control system, the work profiling in the expected working environment should be clarified. Since a certain type of ejection seat is disposable during emergency ejection, the operational tasks of the ejection control system mainly include storage, transportation, operation inspection and normal pre-flight operation. According to the results of RCMA, repairability maintenance analysis and operation analysis of the ejection control system, the application and maintenance analysis table of the ejection control system is obtained. Due to the limitation of space, only the O&M T of central pull ring pull-out force inspection is given in Table 4.

3.4.5. Support Equipment Requirement Analysis. The requirements of support equipment is determined according to the O&M T, while the preliminary plans for the support equipment and tools required are made based on the progress of the product development. The existing or common support equipment and tools of the force are encouraged to be used, only can the new equipment and tools be designed and manufactured when the existing equipment and tools fail to meet the requirements of the application and maintenance of new research equipment. According to the O&M T of the ejection control system, the special support equipment and tools required for the ejection control system are determined, seeing Table 5.
Table 1 ejection control system RCMA record sheet.

| Product name | Failure mode and reason | Fault impact | Security impact | Failure consequences | Job type | Working time | Maintenance interval | Maintenance level |
|--------------|-------------------------|--------------|-----------------|----------------------|----------|--------------|----------------------|-------------------|
| Ejection control system | Start the ejection delay | Central pull ring pull-out | Y | N | N | Y | N | N | Y | Covert security | Function detection | Regular work in use | 10 years | D |
| | Firing mechanism pin pull force inadequate | N | | | | | | | | | | | |
| | Detonation bomb not working | Y | N | N | N | Y | Y | Covert security | Use check | Regular work in use | 2 years | D |
| | Abnormal connected switch on and off of program control box | Y | N | Y | N | N | Y | Covert security | Use check | Regular work in use | 10 years | D |
| | Initiating ejection function drops significantly | Y | N | Y | Y | N | N | Y | Covert security | Timing disassembly and repair | Regular work in use | 10 years | D |
Table 2 Corrective Maintenance Analysis.

| Product name | Failure mode and reason | Maintenance work Numbering | Work type code | Work explanation | Technical basis |
|--------------|-------------------------|----------------------------|----------------|------------------|----------------|
| Ejection control system | Start the ejection delay | Central pull ring pull-out force excess | 1 | G | Disassembly and replace the central pull ring | Design requirements |
| | | Firing mechanism pin pull force inadequate | 1 | G | Disassembly and replace the spring | Design requirements |
| | Unable to start ejection | Detonation bomb not working | 1 | G | Disassembly and replace detonation bomb | Design requirements |
| | | Abnormal connected switch on and off of program control box | 1 | G | Disassembly and replace program control box | Design requirements |
| | Initiating ejection function drops significantly | Leakage of the pipeline components | 1 | G | Disassembly and replace the seal ring | Design requirements |

Note: G - disassembly and replace.

Table 3 ejection control system LORA.

| Serial number | Failure mode and reason | Maintenance level (O, D) | Remarks |
|---------------|-------------------------|--------------------------|---------|
| 1             | Start the ejection delay | Central pull ring pull-out force excess | D | D | |
|               |                         | Firing mechanism pin pull force inadequate | D | D | |
| 2             | Unable to start ejection | Detonation bomb not working | O | O | Subject to technical requirements of maintenance personnel |
|               |                         | Abnormal connected switch on and off of program control box | D | D | |
| 3             | Initiating ejection function drops significantly | Leakage of the pipeline components | D | D | |

Note: O – grass-roots level; D – base level.
Table 4 O&MTA of central pull ring pull-out force inspection.

| Operation sequence number | Operation description                                      | Spare parts, Consumables, fuel, Oil material and Pyrotechnics | Ground support equipment and tools | Precautions |
|---------------------------|-----------------------------------------------------------|---------------------------------------------------------------|-----------------------------------|-------------|
|                           |                                                           | name/ model | quantity | attribute s | name/ model | quantity |                             |                         |
| 1                         | Disconnect the connector plug under the program control box | Cotter pin   | 1        | spare parts  | Central blasting mechanism insurance pin, needle-nosed pliers, spring balance, detonation craft bomb | When using the spring balance to pull the central pull ring for measure force, two people should cooperate with each other. One person pulls the central pull ring and one person observes the pull pin. so as to ensure that when the central pull ring pulls the pin, it shall immediatly stop pulling the spring scale. |
| 2                         | Disassemble the detonation bomb according to the disassembly and decomposition steps of the firing mechanism in the “Disassembly and Disassembly Procedure” |                                            |                            |                          |                          |                         |
| 3                         | Replace the detonation bomb with the detonation craft bomb, and complete the installation of the firing mechanism and the craft bomb according to the assembly and installation steps of the firing mechanism and the detonation bomb in the “Assembly, Installation Procedure” |                                            |                            |                          |                          |                         |
| 4                         | Pull-out the ejection handle insurance pin                 |                                            |                            |                          |                          |                         |
| 5                         | Pull the central pull ring along the direction of the central pull ring with a spring balance to check whether the tension meets the requirements of “135N–225N” |                                            |                            |                          |                          |                         |

3.4.6. Spare Parts Requirement Analysis
Spare parts are required for the preventive and repair maintenance of the catapult control system. The corresponding maintenance tasks cannot be completed if the required spare parts are not sufficiently provided. Therefore, in order to ensure the in-time maintenance of the ejection control system, required spare parts should be prepared according to the result of the application and maintenance analysis seeing Table 6.
Table 5 the special support equipment and tools required for the ejection control system.

| Serial number | Name                                      | Quantity | Remarks                      |
|----------------|-------------------------------------------|----------|------------------------------|
| 1              | Electrical system function detector of ejection seat | 1        | Special support equipment    |
| 2              | Ejection seat airtight checker             | 1        |                              |
| 3              | Central blasting mechanism insurance pin   | 1        |                              |
| 4              | Detonation craft bomb                      | 1        |                              |
| 5              | Firing pin prominent amount template       | 1        |                              |
| 6              | Upper spring top                           | 1        |                              |
| 7              | The primer seat                            | 1        | Special support tool         |
| 8              | Rocket motor craft bomb                    | 1        |                              |
| 9              | Plug                                       | 2        |                              |
| 10             | Airtight inspection joint                  | 1        |                              |
| 11             | Steel needle                               | 1        |                              |

Table 6 Spare Parts Requirement Analysis for the ejection control system.

| Serial number | Name                             | Quantity | Remarks                      |
|----------------|----------------------------------|----------|------------------------------|
| 1              | Cotter pin                       | 1        |                              |
| 2              | Insurance wire                   | 0.5 m    |                              |
| 3              | Seal ring                        | 21       |                              |
| 4              | Spring                           | 1        |                              |
| 5              | Primer                           | 2        |                              |
| 6              | Cut copper wire                  | 1        |                              |
| 7              | Gasket                           | 1        |                              |
| 8              | Cut pin                          | 1        |                              |
| 9              | 7012 extreme low temperature grease |         |                              |
| 10             | 734 epoxy adhesive               |          |                              |
| 11             | Thread locking sealant 243       |          |                              |

4. Conclusions
The “6A” work is an important method in synchronizing the development of support resources during the development of a certain type of ejection seat, and is capable of regulating support resource during equipment deployment, which plays an irreplaceable role. Through the 6A work carried out to the certain type of ejection seat, the preventive and repairing maintenance of a certain type of ejection seat was clarified, and the requirements for the equipment, tools, spare parts and other support resource for the application and maintenance were determined. The determined support resource also plays their function during the test process, thus further providing a guarantee for the establishment of a cost-effective guarantee system for the host machine or for the troops. In view of the importance of the supportive analysis technology in a certain type of ejection seat, it is recommended that: ① supportability analysis should be carried out as early as possible, and should be hold throughout the development of the certain type of ejection seat; ② FMEA is an important foundation for 6A work, so it is necessary to clarify the information connection between FMEA and 6A before conducting the supportability analysis; ③ Due to the complex structure of a certain type of ejection seat, emphasis should be clarified during supportability analysis; ④ The process of supportability analysis is
cumbersome and complicated. Manual analysis is time-consuming and laborious and has poor results, so computer-aided technology can be considered for analysis.

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