RESEARCH ON THE TRIGGERING CONDITIONS OF EJECTABLE RECORDER FOR CIVIL AIRCRAFT

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Abstract

The survivability of the Flight Data Recorder (FDR) is of great importance when air crash happens. Compared with the traditional recorder, the ejectable recorder can enhance the survival ability when aircraft hits the ground or plunges into water, which can facilitate the accident investigation. In this paper, we are devoted to simulating the whole process of the recorder`s ejection in case of ground crash and summarize an inductive triggering condition, aiming to offer some references to the Original Equipment Manufacturer (OEM) to improve the FDR design and test.

With many factors being considered, the overload threshold is used as the triggering condition. Taking the Modern Ark 60 (MA60) as the researched item, we apply the unstructured dynamic chimera grid technology coupled with the 6-DOF equation to simulate the ejecting trajectory. The consequences show that the ejectable FDR can safely separate from the vertical and horizontal stabilizers without colliding with each other. At last, according to the ground impact speed and location, the ejectable FDR meets the no-damage strength requirements.

Keywords: Ejectable FDR, Parameter planning, Separating Simulation

1. Introduction

On 1 June 2009, a flight of Air France (AF447) flying from Rio de Janeiro, Brazil to Paris crashed over the Atlantic Ocean, causing all the passengers and flight crews to die. Unfortunately, it was not until two years later that the investigator recovered the FDR from the sea. On 8 March 2014, 1:20 am, Malaysia Airlines flight MH370 flies from Kuala Lumpur International Airport to Beijing Capital International Airport losing the connection with everything that can find it. A couple of years later, with some wrecks of the flight found and the further investigations, the MH370 flight is proved to fall into the sea. The worlds` attention was taken over the catastrophic accidents.

However, for both above accidents, the FDR that can offer the true reasons why the flight crashed can`t be easily found, even disappear, causing the difficulty to find out the truth. What`s more, it prevents the further actions from eliminating the identical accidents. Both of the accidents show that it is an expensive, long time job to find the FDR, and expose that some corresponding technologies need to be upgraded to face challenges of the growing frequent cross-sea and overwater flight missions.

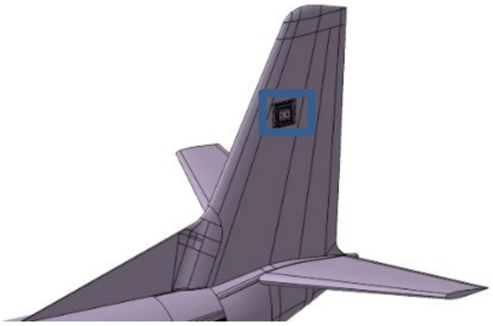
When air crash happens, it is urgent to find out why it happened and what we can do to prevent the resembled accidents in the future from happening again. There is no doubt that the FDR plays an important and indispensable role in the accident investigation. Although the satellite and mobile communication can solve the transmission of the flight data to the ground base, the FDR is still the most reliable, scientific, effective way when air crash happened. The traditional FDR`s anti-crash standard is constantly improving, but according to the survey, the survivability of the FDR when severe crashes happened on the ground is only 82%. For example, on April 15,1999, 4:04, PM, a flight of Korean Air Flight 6316 crashed and resulted in the severe destruction of the FDR. In order to enhance the survivability of the FDR and facilitate the accident investigation, the ejectable recorder comes into being.

The ejectable recorder has been used in the military and air carrier aircraft because of overwater missions. And the Search and Rescue (SAR) record for ejectable recorder is excellent while the SAR record for traditional recorder has been relatively poor [1]. The reason is that when crash happened, the ejectable flight recorder can automatically separate from the flight, and safely land on the ground away from the accident site or float on the surface of the water. At the same time, on March 2016, the International Civil Aviation Organization (ICAO) Council adopted the Annex 6 to the Convention on International Civil Aviation about the International Commercial Air Transport, containing the requirements about the automatic deployable flight recorder (ADFR), such as deployment shall take place when the aeroplane structure has been significantly deformed or deployment shall take place when an aeroplane sinks in water so on [2]. Taking the merits of the ejectable FDR and requirements of the airworthiness regulations into consideration, it is necessary and rightful for civil aircraft to be equipped with the ejectable FDR.

2. Concept Design

2.1 installation location

The traditional FDR is fastened underneath the rear floor, which has the advantages in installation and maintenance. However, it will bring about the massive difficulty in accident investigation when fuselage belly impacts on the ground causing severe damage to the FDR. However, ejectable FDR is usually installed at the vertical stabilizer [3], in this paper, which is designed at the left side of the MA60`s vertical stabilizer, without the further study about the influence on the structure layout and strength of the vertical stabilizer. Figure 1 shows the location of the ejectable FDR in the Body Axes System.



$$x_0 = 12.774\text{m}$$
$$y_0 = 4.586\text{m}$$
$$z_0 = 0.107\text{m}$$

Figure 1-The location of the ejectable FDR in the Body Axes System

2.2 The way of ejecting

In this study, we take the references from the process of the military aircraft canopy ejected from the cockpit. When the military aircraft underwent the irreversibly fatal breakdown, in order to survival, the aircraft canopy needs to be ejected for the pilot`s escaping preparation. After the ejection, the canopy is ejected upward and backward, with the aerodynamics and own gravity applied. Therefore, in the real experiment, the explosion bolt can be used to offer the initial power for ejection. Figure 2 shows the explosion bolts` location. However, in the subsequent simulation, we prescribe that the linear velocity is 3.1 m/s and the angular velocity is 15 rad/s at the beginning of separation, in accordance with the corresponding explosion bolt effect.

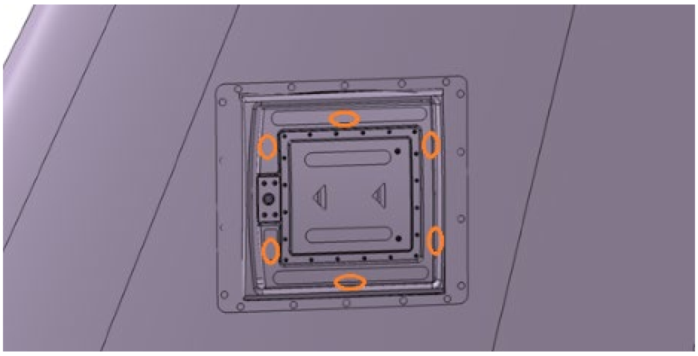


Figure 2-The explosion bolts` location

3. Parameter Planning

The FDR is ejected when the crash sensor or the water immersion sensor transmit the corresponding signal to the ejection device [4]. When crash happens on the water surface and aircraft sinks up to 1.8 meters, the flight recorder will be ejected immediately through the trigger signal from the water immersion sensor. At the same time, the water immersion sensor is installed at the crucial parts of the aircraft so that it can help to distinguish the situation of ditching or the catastrophic fall into the water. In other words, the ejectable FDR can`t be ejected when the ditching happens.

However, we take many flight parameters into consideration to decide which is the relatively more suitable trigger condition when crash happens on the ground, such as the flight altitude, airspeed, aircraft attitude angle, aircraft vertical rate of descent, and the overload etc. First of all, when crash happens, the distance between aircraft and the ground is zero so that it`s tough to differentiate the falling on the ground from the take-off and the taxi process. Secondly. As for the airspeed, the range of the normal flight speed contains the airspeed magnitude when crash happens. Therefore, if taking this factor as the trigger signal, the false ejection will occur. Thirdly, if the aircraft crashes in a normal attitude, the crash sensor will lose its function so that some catastrophic crash happens without the flight recorder ejected. Then, the abrupt change of aircraft vertical descent velocity can be caused by the strong airflow or the pilot`s wrong operation. It will also increase the false ejection.

At last, according to the previous accidents of the hard landing and the overweight landing for civil aircraft, when these happen on the ground, it usually causes the corresponding structure damage, especially for the severe overweight landing and the massive overload landing [5]. Therefore, it is reasonable for us to use the crash structure sensor to recognize this overload, then trigger the ejection device.

Based on the international ejecting safety regulation of deployable flight recorder, the Chinese standard improves the regulation and add some content. Therefore, according to this Chinese regulation called “minimum performance standard of airborne flight data recorder”, it requires that when the deployable flight recorder is subjected to a forward inertial load of 5 to 6g, the recorder can be automatically ejected [6].

At the same time, the technical solutions of deployable flight recorder for civil aircraft requires the ground impact speed should be lower than 46.33 m/s. Both of the requirements offer the preliminary references for the subsequent simulation of the ejecting trajectory. All of these can help us to design a reasonable overload threshold to trigger the crash structure sensor to transmit the trigger signal to the ejection device.

4. Separation Simulation

4.1 MA60 Model

In this separation simulation, the simplified MA60 model is used to simulate the whole process without considering the propellers and actuators` effects. In order to better match the real simulation situation, the model uses a ratio of 1:1. And the whole process is finished in the Body Axes System. The Figure 3 shows the panorama of the simplified MA60 model.

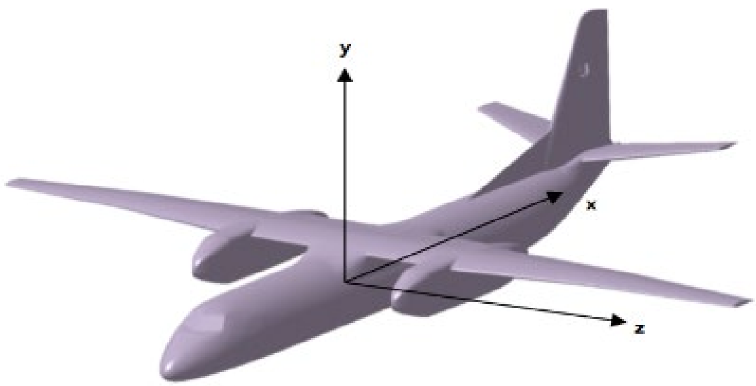


Figure 3 - The panorama of the MA60 model

4.2 Computational States Condition

The extreme accident state with the aircraft pitch angle of -60° and the initial ground impact speed of 0.15 Ma is selected to finish this simulation. Simultaneously, this accident state couples with four different forward inertial loads of 0.0g, 5.0g, 5.5g, 6.0g in aircraft`s longitudinal axis. We prescribe that when the overload increases up to the above overload threshold, the ejectable FDR will be ejected immediately.

4.3 Unstructured Dynamic Chimera Grid

In this study, we adopt the unstructured dynamic chimera grid technology to realize the separation simulation because of its outstanding performance in multi-body turbulence problem with relative motion [7-8]. According to the chimera grid`s methodology, it aims to divide the multi-body separating model into corresponding numbers of computational subsystem, decreasing the grid generation difficulty about the multi-body separating simulation with complex geometry. At the same time, among the different computational subsystems, the necessary information exchange is fulfilled through the corresponding interpolation method. After these, the full low field solution can be obtained, which is high in reliability and accuracy.

In this separating simulation, the ejectable FDR grids are embedded in the MA60`s surface grids.

Figure 4 shows the MA60`s surface grids.

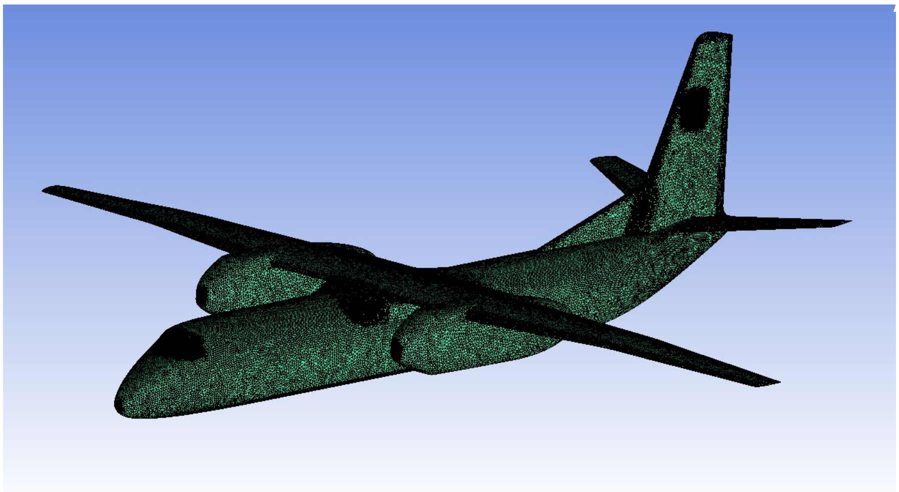


Figure 4 - The MA60`s surface grids.

Figure 5 shows the chimera grids of the ejectable FDR in the installation slot, red stands for the ejectable FDR`s surface grid, green stands for the External flow field boundary grid of the ejectable FDR, yellow stands for the aircraft vertical stabilizer`s surface grid.

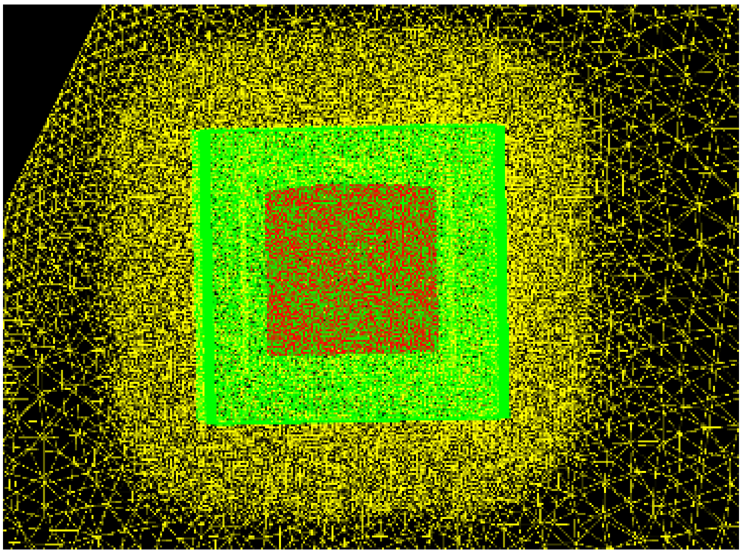


Figure 5 - The chimera grids of the ejectable FDR in the installation slot.

4.4 The ejecting trajectory

As for the multi-body separation, its`s pretty import to confirm the relative location and distance among the subsystems. Therefore, we apply the custom software development (CSD) function of Computer Aided Three-dimensional Interactive Application (CATIA) to simulate the ejecting trajectory, so that it`s easy to ensure whether the separation process is safe or not.

The ejecting trajectory simulation is fulfilled by the translation and rotation function of CATIA, and we make use of the macro function of CATIA to automatically fulfill the data import at every single simulation step, up to 1000 times. Because every ejecting trajectory consists of 1000 ejectable FDR model, it`s too dense to observe the corresponding trajectory clearly. Therefore, every trajectory is simplified without losing its fidelity. Figure 6 shows the ejecting trajectory coupled with four different forward inertial loads.

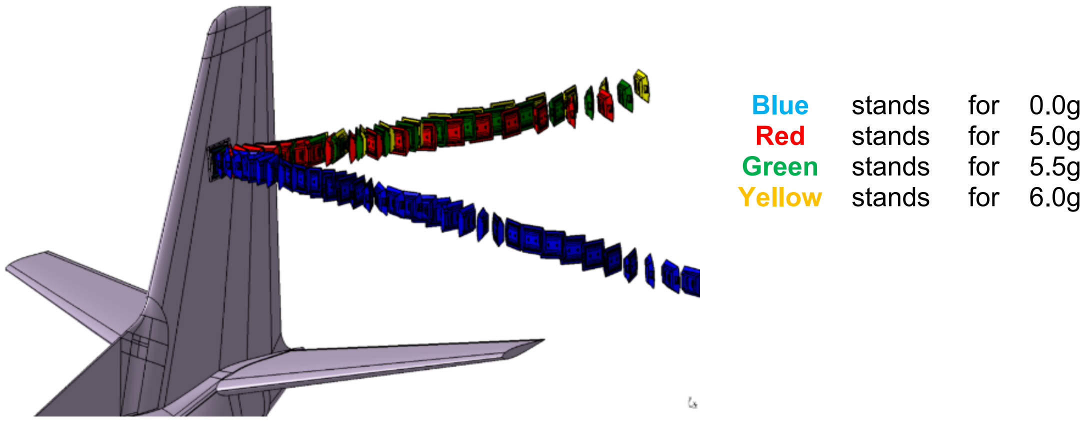


Figure 6 - The picture of the ejecting trajectory.

As shown in the Figure 6, the consequences show that ejectable FDR can`t collide with the MA60`s vertical and horizontal stabilizers. Figure 7 shows the Line velocity and displacement of the ejectable FDR`s barycenter.

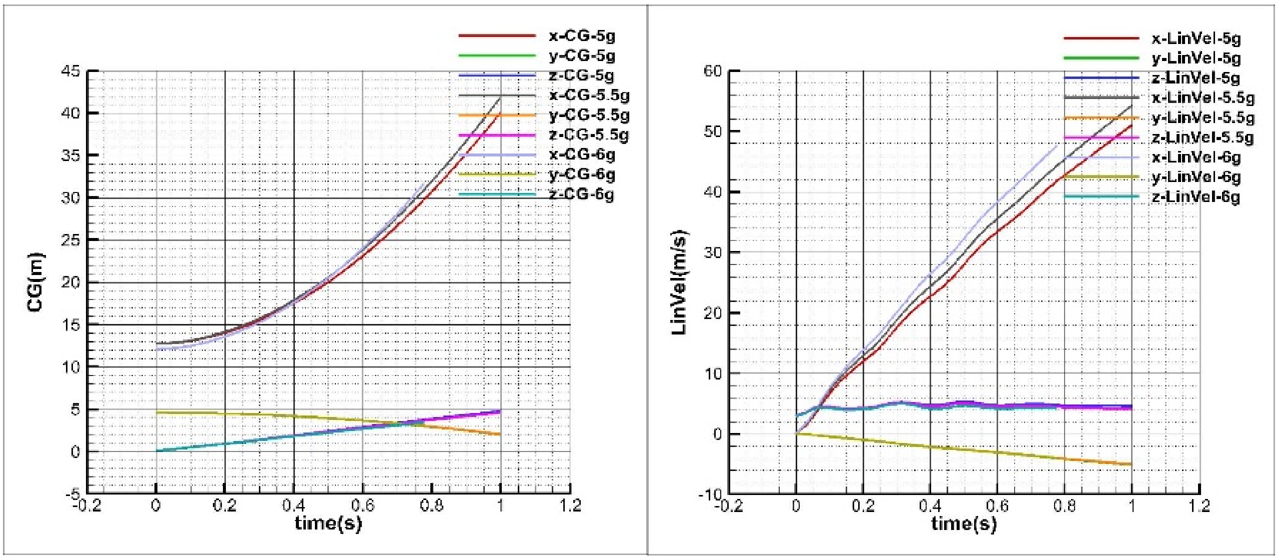


Figure 7 – The line velocity and displacement of the ejectable FDR`s barycenter.

As shown in the Figure 7, the consequences show that once the ejectable FDR is ejected, the displacement and line velocity in the x direction is proportional to the applied inertia load. The forces in the y and z direction almost stay the same with the previous value, so the barycenter displacement and line velocity in the y and z direction almost stay the same. At last, the computational consequences are almost in accordance with the theorical analysis.

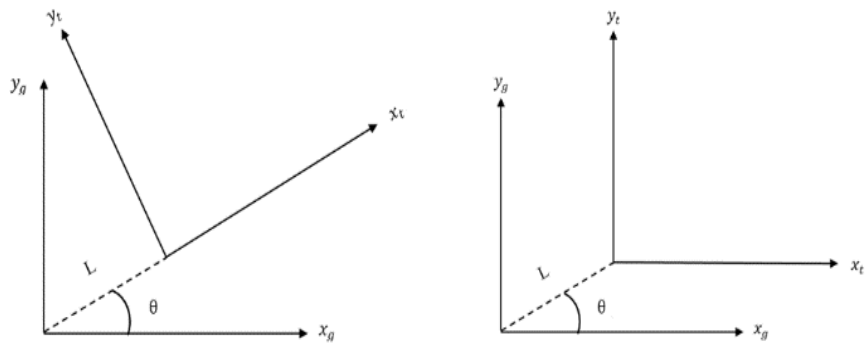
5. The Ground Impact Speed and Location

As for this simulation, because of the accumulative error alongside the time, the simulative time is designed to 0.3 seconds. Simultaneously, during the 0.3 seconds, we assume that the air flow of 0.15Ma is always applied on the ejectable FDR. After the 0.3 seconds` simulation is finished, the corresponding speed (v_{x_1}, v_{y_1}, v_{z_1}) and location (x_1, y_1, z_1) of the ejectable FDR come into being in the Body Axes System. At the same moment, through the coordinate transform methodology, the corresponding speed ($v_{x_2}, v_{y_2}, v_{z_2}$) and location ($x_2, y_2, z_2$) come into being in the Earth-Fixed Axes System. Given that the influence of the air can be ignored, the forthcoming phase is assumed as a free-fall process without considering the air resistance. The Figure 8 shows the original panorama of the MA60.

Aircraft height = 8.85m
Aircraft length = 24.71m

Figure 8 - The original panorama of the MA60

The details of the calculation process as followed. First of all, convert the Body Axes System into the Earth-Fixed Axes System. Then based on the Body Axes System, the Earth-Fixed Axes System with the nose of the nose as the coordinate origin is defined. Figure 9 shows the relative position between the Body Axes System ($x_t y_t z_t$) and the Earth-Fixed Axes System ($x_g y_g z_g$).



θ = 60°
L = 10.66m

Figure 9 - The relative position between the Body Axes System ($x_t y_t z_t$) and the Earth-Fixed Axes System ($x_g y_g z_g$)

The corresponding transformation matrix as followed:

1) transformation matrix of the barycenter coordinate:

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} = \begin{bmatrix} x_1 \cdot \cos 60^0 \text{-} y_1 \cdot \sin 60^0 + 10.66 \cdot \cos 60^0 \\ x_1 \cdot \sin 60^0 + y_1 \cdot \cos 60^0 + 10.66 \cdot \sin 60^0 \\ z_1 \end{bmatrix} \quad (1)$$

2) transformation matrix of the barycenter speed:

$$\begin{bmatrix} v_{x_2} \\ v_{y_2} \\ v_{z_2} \end{bmatrix} = \begin{bmatrix} v_{x_1} \cdot \cos 60^0 - v_{y_1} \cdot \sin 60^0 \\ v_{x_1} \cdot \sin 60^0 + v_{y_1} \cdot \cos 60^0 \\ v_{z_1} \end{bmatrix} \quad (2)$$

The computational consequences are showed in the Table 1.

Table 1 - The corresponding computational results of the different overload thresholds in the Earth-Fixed Axes System.

states / Computational parameters		5.0g overload	5.5g overload	6.0g overload
simulative time (s)		0.3	0.3	0.3
Initial location (m) of the free-fall process	x_2	9.291	9.397	9.502
	y_2	24.825	25.015	25.188
	z_2	1.388	1.395	1.346
Initial speed (m/s) of the free-fall process	v_{x_2}	-15.323	-14.731	-14.103
	v_{y_2}	-29.752	-28.672	-27.581
	v_{z_2}	5.184	5.137	4.912
ground impact location (m)	x_3	-2.099	-1.958	-1.775
	y_3	0	0	0
	z_3	5.242	5.355	5.274
ground impact speed (m/s)	v_{x_3}	-15.323	-14.731	-14.103
	v_{y_3}	-37.037	-36.227	-35.417
	v_{z_3}	5.184	5.137	4.912
	$\|v\|$	40.415	39.443	38.437
Free-fall time (s)	t	0.743	0.771	0.806

6. Conclusion

In conclusion, the recorder does not collide with the aircraft during the entire ejecting process and the forward inertia load applied on the recorder is adversely proportional with the ground impact speed and the no-damage strength requirements. Especially, all of the speeds contributed by the above three overloads are less than the maximum ground impact speed required by the technical solutions of deployable flight recorder for civil aircraft. In recent years from the official statistics, the MA60 has undergone twice accidents with the accident overloads larger than 5.9g [9-10]. What`s more concerning the simulation results, overload threshold had better at 5.9g. Although the ground impact speed of the recorder ejected by 5.9g is larger than the grounding impact speed of the recorder ejected by 6g, the probability that the recorder cannot be ejected when the aircraft crashes may exist when the overload is 6.0g. Concerning the above situations, it is reasonable to make the 5.9g as the triggering condition of the MA60`s recorder.

References

[1] Watters, D. M. CRASH POSITION INDICATOR/CRASH SURVIVABLE FLIGHT DATA RECORDER: EJECTABLE VERSUS NONEJECTABLE C. Proceedings of the 12th Symposium-Aircraft Integrated Data Systems., (pp. 509-534),1984.

[2] Annex 6 to the Convention on International Civil Aviation.

[3] ED112 Minimum operational performance specification for crash protected airborne recorder systems S. March 2003.

[4] Li Xiaoyu. Research of deployable flight data recorder system C. Chinese Aeronautical Society, Chinese Academy of Aviation. Proceedings of the 2018 (Seventh) Civil Aircraft Avionics International Forum. Chinese Aeronautical Society, Chinese Academy of Aviation: Chinese Academy of Aviation, 2018: 340-343.

[5] Aircraft Maintenance Manual (AMM) TASK 05-51-11-200-004 Inspections after a Hard Landing or a Hard

Overweight Landing for Aircraft with FDIMU Load Report.

[6] People's Republic of China Aviation Industry Standard: minimum performance standard of airborne flight data recorder.

[7] Xu Heyong, Ye Zhengyin. Research, development and application of technique of unstructured rotational dynamic overset grids J. Journal of Northwestern Polytechnical University, 2011,29 (02):171-175.

[8] Xu Heyong, Ye Zhengyin, Gang Wang, Aiming Shi. Improving numerical simulation of rotor forward flight flow field with unstructured dynamic overset grids J. Journal of Northwestern Polytechnical University, 2006, 24 (6):763-767.

[9] Liu Yuanyuan. Analysis of accidents and unsafe events of Modern Ark 60 C. Professional Committee of Aviation Maintenance Engineering of Chinese Society Of Aeronautics And Astronautics, National Defense Industry Press, Air Force Safety Bureau, Field Department of Air Force Equipment Department, School of Equipment Management and Safety Engineering of Air Force Engineering University, Guilin Institute of Aerospace Industry, Guangxi Aerospace Society, 95375 Army Equipment Maintenance Technology-Proceedings of Symposium on Aviation Safety and Equipment Maintenance Technology. Aviation Maintenance Engineering Professional Committee of China Aviation Society, National Defense Industry Press, Air Force Safety Bureau, Field Department of Air Force Equipment Department, School of Equipment Management and Safety Engineering, Air Force Engineering University, Guilin Institute of Aeronautics and Astronautics, Guangxi Aeronautics and Astronautics Society, 95375 Army : Chinese Society Of Aeronautics And Astronautics, 2014 : 424-429.

[10] Liu Kun. The same mistake, the same accident: the initial accident judgement of Modern Ark 60 N. Huanqiu.com, 2015-05-14.

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