

Cockpit Voice Analysis and Diagnostic Based on Conditional Rules & Fault Tree Analysis

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Abstract

The characteristics of cockpit voices (sounds) recorded by Cockpit Voice Recorder (CVR) are key evidences in investigating accident causes for wrecked airplane. In order to analyzing and diagnosing wrecked airplane causes through cockpit voices in CVR, some researchers are made as followings in this paper: Firstly, some typical background sounds of cockpit voices, such as wind shear audio, near-earth audio warning, take-off form of audio warning, fire alarm and so on, are obtained and classified through listening and distinguishing by adobe audition audio software in laboratory. Then, the characteristics of these background sounds are extracted by signal analyses methods such as Fourier Transform (FT), Wavelet Transform (WT), and so on. Through these methods, the special characteristics are deparated, such as frequency value, spectral density, and frequency line numbers. Thirdly, as the key part of the paper, conditional rules and fault trees principles focuses on and applied in order to distinguish and diagnose these special characteristics for approximate or different background sounds of cockpit voices. And some available results are obtained finally. Through all these above researches, new analyzing and diagnosing approaches are put forward, which are suitable for accurate grasping the cause of flight accident and analyses and diagnose flight accident. All the researches and conclusions have a certain reference for analysis and diagnosis of flight accidents, and protect flight security.

Keywords: Aircraft; Cockpit voice; Conditional rules; Fault trees; Signal analysis and diagnosis

Introduction

Both CVR and Flight Data Recorder(FDR) are composed the Aircraft Black Box (Figure 1) [1], which is essential airborne equipment for modern commercial aviation aircraft, and plays an irreplaceable role in the aircraft accident investigation and wrecked airplane' cause analyses.

The Cockpit Voice Recorder (CVR) records many kinds of sounds during flight, which is called as cockpit voice in the professional. Cockpit voice is mainly composition by the sound signal, which is often called as the cockpit sound information in engineering. Research shows cockpit voices are often divided into three different: including voices (phonetic), noise and background sounds in details. Their frequencies of different background sounds are different, and frequencies ranges are between 150Hz and 6800Hz, and such wide frequency range is difficult to analyze. At the same time, frequency characteristics are important features for different background sounds. It is very important for us to obtain and accurately analyze the different characteristics of background

sounds in the investigation of flight accidents and incidents, which are directly related to the safety of aircraft flight.

In order to obtain basic information of cockpit voices, especially the frequency characteristics, some analyzing ways are utilized (such as by the experience of flight and accident investigation professionals, or through their ears, or other tools). These are the traditional methods of investigation of the causes of aircraft accidents. However, due to the complexity of the cockpit voice, part of the cockpit voice is not "understood" or recognized by traditional means. In recent years, some modern speech signal processing, computer audio technology and sound signal processing technologies are used to extract, interpret the part cockpit voice to obtain the different characteristics of the cockpit voice. It is very important to accurately judge flight accident by different methods to refine, analysis and diagnosis the cockpit voice characteristics to distinguish the approximate cockpit voice.

In order to analyze and diagnose cockpit voices, the researchers are made as followings in this paper: 1) typical background sounds of cockpit voices are obtained & classified; 2) the characteristics of typical background sounds are extracted; 3) approximate or different typical background sounds of cockpit voices are distinguished & diagnosed.



Figure 1: Aircraft Black Box.

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Listening and distinguishing cockpit voices by adobe audition software

Adobe audition is a professional audio editing and mixing environment software, which provides advanced audio mixing, edit, control and effects processing function for audio and video professionals in the photographic rooms, broadcast facilities and post-production equipment. Listen and distinguish cockpit voice based on adobe audition is a traditional cockpit voice recognition method. It has been widely accepted in the aviation industry.

Here, the flow chart of listening and distinguishing the cockpit voice is given [2] (Figure 2) as followings:

Firstly, we synchronously download four channels' cockpit voice information through computer sampling, quantification and storage as certain the sound file format. And then, investigators play, listen, and distinguish them by abode audition audio software for some couldn't hear or in doubt cockpit voice. Finally, processing, analyses and diagnoses are made with the FDR or other sources of information to complete the investigation of aircraft accidents.

Time-frequency analysis for cockpit voice based on MATLAB [3-8]

Analysis signal based on time and frequency for joint parameters called signal time-frequency analysis. It is made in both time field and frequency field. In order to get more characteristics information of cockpit voice, Time-frequency analysis is selected. Time-frequency analysis is evolved by the Fourier Transform (FT), Fast Fourier Transform (FFT), Short Time Fourier Transform (STFT), Linear FM Transform (of CZT), Wavelet Transform (WT) and other modern analytical methods. Here, the principle of FT, STFT, CZT, WT are briefly given in the followings.

Fourier transform: For periodic signal, it is asserted that any function $x(t)$ is the sum of sine and cosine of its Fourier series.

$$x(t) = a_0 + \sum_{k=1}^{\infty} (a_k \cos kt + b_k \sin kt) \tag{1}$$

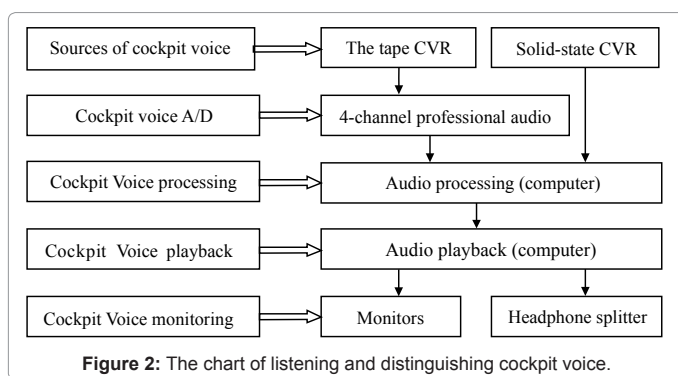


Figure 2: The chart of listening and distinguishing cockpit voice.

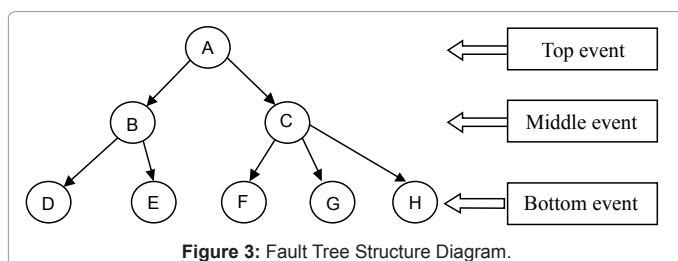


Figure 3: Fault Tree Structure Diagram.

Where: the coefficients are calculated by

$$a_0 = \frac{1}{2\pi} \int_0^{2\pi} x(t) dt$$

$$a_k = \frac{1}{2\pi} \int_0^{2\pi} x(t) \cos(kt) dt \tag{2}$$

$$b_k = \frac{1}{2\pi} \int_0^{2\pi} x(t) \sin(kt) dt$$

Its FT is:

$$X(\omega) = \int_{-\infty}^{\infty} e^{-j\omega t} x(t) dt \tag{3}$$

Short time fourier transform (STFT): For no periodic signal, it is asserted by STFT, which is one solution to the problem of better representing the no periodic signal through artificially extending the signal to make it periodic.

Through STFT, the $X(t)$ can be expressed by equation:

$$X(\omega, t) = \int_R x(t) \bar{w}(t - \tau) e^{-j\omega \tau} d\tau \tag{4}$$

The Fourier transform's STFT utility lies in its ability to analyze the periodic signal in the time domain for its frequency content. STFT can be used to give information about no periodic signals simultaneously in the time domain and in the frequency domain.

Mathematical background of CZT: CZT is also called Bluestein FFT algorithm, and the algorithm can be formed from z-transform on a circular or spiral contour.

The basic equation for z-transform can be expressed:

$$X(z_k) = \sum_{n=0}^{N-1} x(n) z_k^{-n} \tag{5}$$

$$z_k = AW^{-k}, k = 0, 1, \dots, M-1$$

Let's consider

Where: A and W denote arbitrary complex numbers.

$$A = A_0 e^{j\theta_0} \quad W = W_0 e^{-j\phi_0}$$

Combine formulation (4) with (5), we can get CZT algorithm $X(z)$:

$$X(z_k) = CZT[x(n)] = \sum_{n=0}^{N-1} x(n) z_k^{-n} = \sum_{n=0}^{N-1} x(n) A^{-n} W^{Rk} \tag{6}$$

Mathematical background of WT: Wavelet analysis algorithms are applied because wavelet transform can cut up data into different frequency components with a high resolution matched to its scale. The key point of WT for $x(t)$ is that what kind of wavelet function and wavelet decomposition scales should be chosen. Here, the binary system Daubechies series four scales one-dimension discrete wavelet transform (DWT) is adopt to analyze the signal $x(t)$.

The reasons are that:

- 1) The signal is a one-dimension data file.
- 2) Binary system is the computation system of computer; and DWT can decrease computation time, increase computer memory, enhance signal computation speed.
- 3) Daubechies series wavelet functions also have many advantageous

The name of the Cockpit Voice	Distinguish and listening	the length of time Unit: s	Characteristic Frequency (Hz)		Frequency Range: Hz	Lines parallel (YES/NO)	Spectral density (Dense/parsed)	The number of lines
			f1	f2				
Wind shear audio	Audio clarity	0.523	880	672	0-1000	YES	Sparse	multiple
Near-Earth audio warning		0.623	768	1968	0-3000	NO	Sparse	multiple
Take-off form of audio warning	Crisp, like whistle	0.224	1280	1712	0-7000	YES	Dense	multiple
Fire alarm	Alarm clarity	4.9	2176	3712	0-6000	YES	Sparse	multiple
Automatic driving disconnect audio warning	Like engine startup sound	1.058	1888		0-5000	NO	Dense	multiple
Flap warning,	Crisp, like whistle	1.473	1280	640	0-8000	YES	Dense	multiple
Stick shaker background noise	Like sound of a motor	7.2	2000	560	0-2000	NO	Sparse	multiple
Over speeding audio warning	Similar switch sound	0.103	2912	2352	0-3000	NO	Sparse	multiple
High speed with the translation Background noise	Like engine startup sound	2.36	992	576	0-1000	YES	Sparse	Single
Low speed with the translation Background noise		0.15	604	1760	0-4000	NO	Sparse	multiple
Highly hints	Crisp	1.492	774	645	0-1000	YES	Sparse	Double

Table 1: Summarizes of many cockpit voice background sound.

attributes, such as orthodox, approximate symmetry, smoothness, astringency, and so on.4) the signal has a wider frequency range about from 0~4KHz, and its energies concentrate on 1.5~3.5kHz.

To the signal $x(t)$, its Daubechies $\psi_{j,k}(t)$ ordinary binary system algorithm and formula is described by:

$$\psi_{j,k}(t) = 2^{-j/2} \psi(2^{-j}t - k) \quad (7)$$

Its DWT is presented by:

$$W_j(j, k) = (x(t), \psi_{j,k}(t)) \quad (8)$$

Where: j denotes scale, k denotes shifting; t means time.

Through the figure 2, listening & distinguishing, and above time-frequency analysis principle under the environment of MATLAB, we can get the information of a variety of cockpit voice background sound characteristics (Table 1).

From table 1, there are many different aspects to represent the characteristics of the cockpit voice. These aspects are:

- 1) Through the listen and distinguish to reflect the different sound;
- 2) The size of the characteristic frequency;
- 3) Parallelism, dense, or sparse of spectral lines;
- 4) The numbers of characteristic spectral lines and so on.

From table 1, we also know: The characteristics of different typical cockpit voice are not exactly the same. So, it is very important and focused on how to distinguish the similarities and differences of characteristics of typical cockpit voice, contrast to the standard cockpit voice samples, in order to analyze & diagnose unknown cockpit voice, and provide the basis for analysis and diagnosis the causes of aircraft accidents. And all these are necessary and very meaningful. The following research through fault tree analysis principle based on conditional rules is put forward to analysis and diagnosis the cockpit voice.

Fault tree analysis based on conditional rules [9,10]

Conditional rules

Rules: Objective things or knowledge are not usually isolated, there exist various complex relations. Some causes and results is the most

common, the most simply. The rule is a very suitable form for this relationship. Experts use rules' heuristic solve problem to ensure the satisfactory solution in most cases without having a lot of operations. At present, the rule is one of the most perfect knowledge representation methods, its general form as follows: if <premise> then <conclusions / action>.

Conditional rules: Rules with a set of conditions of operation can be performed, so the rule is often called conditions rule "if-then-else style". Here, "if" is judgment conditions (conditional statement). When the condition "if" is judged to be true, "then" is executed at run time, otherwise "else".

Relying on the value of the conditional expression, conditional statement (if) specify strategy statement of which is enabled or disabled (namely the kernel. And it is to carry out the execution or not).The complete conditional statement syntax is as follows:

If (condition expression) {true value list} [else {false value list}]

In fact, the conditional statement is conditional rules to determine.

Fault Tree Analysis

Fault Tree: The fault tree (FT) is a special kind of inverted tree logic of cause and effect diagram (Figure 3). According to the Boolean logic diagram, the relationship is shown between the system-specific failures (top event).

Fault tree analysis: The fault tree analysis is a analysis method of using the overall to part according dendrites gradually thinning graphics to interpret the causes of a system failure. It is an effective tool to analysis the reliability and safety of complex systems, which aims to identify the basic fault, determine the causes, impact and probability of occurrence.

Characteristics of the fault tree analysis: The fault tree analysis is the logic of deductive reasoning method of failure event under certain conditions, which can analysis some specific fault condition-by-level, and analysis the inter-linkages and constraints relations between the various elements at all levels.

Various factors and the logical relationship sometimes might lead to many disaster or functionality of accidents. Fault tree analysis has many advantages: 1) make a comprehensive, concise description for them 2) provide a basis for improving the design, and develop security

technology 3) do qualitative and quantitative analysis for system failure 4) analyze the system failure caused by a single component, and also analyze the system failure caused by the different modes of multiple components.

Fault tree analysis based on conditional rules: When conditional rules on the basis of the fault tree analysis are used, we can continue to narrow the scope of diagnosis. At the same time, the conclusion of the fault diagnosis will be surer, and range will be narrower. So these can greatly enhance the rate and improve the accuracy of fault diagnosis.

In order to accurately analyze and diagnose the fault and learn the accurate fault causes and fault location, some certain condition rules should be added in the middle and the bottom events of the Fault tree. Sometimes, some physical and logical judgment should be also added to determine the choice of each branch of the fault tree,

The fault tree analysis based on conditional rule's applied in the analysis and diagnosis of the cockpit voice

Building fault trees based on conditional rules: Here, some typical cockpit voice background are chosen, such as wind shear audio, near-earth audio warning, take-off form of audio warning, fire alarm and so on. Based on the principle of the fault tree of conditional rules, the following four conditions rules are put forward to build up the fault tree according to table 1 and figure 3,

Number one: cockpit voice audio spectral line is or not parallel

Number two: The scope of cockpit voice audio spectrum characteristic frequency (once frequency, secondary frequency)

Number three: The number of cockpit voice audio spectrum (single, double, multiple)

Number four: The density of cockpit voice audio spectrum (sparse, dense).

In order to diagnose the cockpit voice background, we regard the number one as the first level of conditional rules, and combine with number two, three, and four composed of conditional rules for building fault tree based on conditional rules (Figure 4).

Analyzing & diagnosing cockpit voices based on conditional rules of fault tree: Based on the principle of conditional rules of the fault tree, we obtain the flow chart to diagnosis the cockpit voice (Figure 5).

The top event is variety of cockpit voice background in the figure 5. Through the first level conditional rule -whether spectrum line

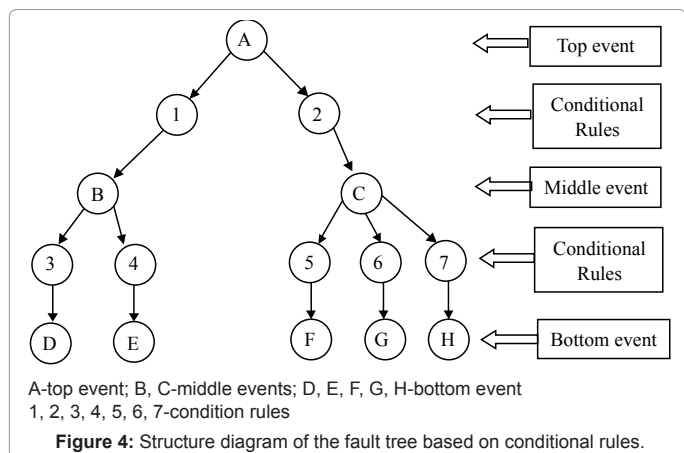


Figure 4: Structure diagram of the fault tree based on conditional rules.

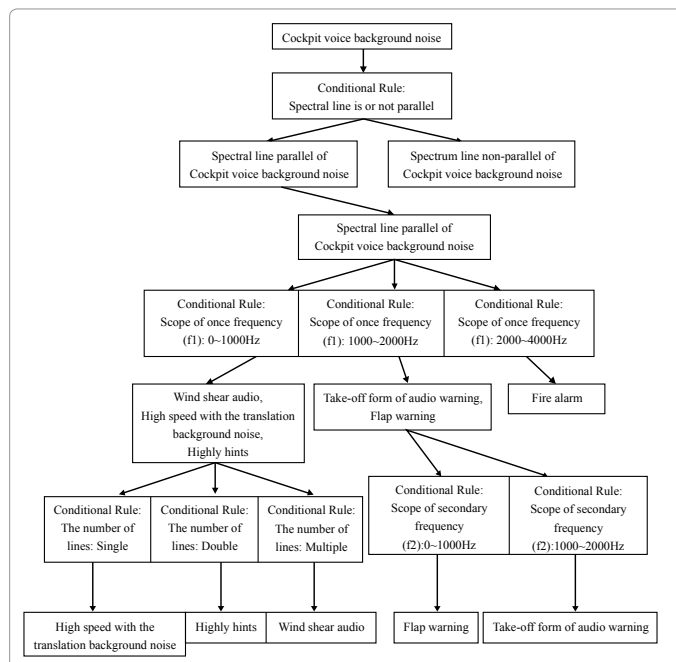


Figure 5: The flow chart to diagnosis the Cockpit Voice based on the conditional rules of the fault tree analysis.

parallel, we can divided variety of cockpit voice background into spectrum line parallel and not. And so the big Fault tree can split into two. Through the secondary conditional rules-the scope of once frequency and multi-level conditional rules (including the scope of secondary frequency, the number of spectral lines, spectral density), we can get specific cockpit voice background of the bottom event.

To judge the middle events by conditional rules and improve the efficiency of the analysis and diagnosis, we can reduce the middle event other branches. First, start from the cockpit voice spectral lines parallel; and then the main frequency of the cockpit voice and so on. We can analyze and diagnose a number of cockpit voice background sounds and get results according conditional rules as follows:

1) If cockpit voice spectral lines is parallel

Then wind shear audio, take-off form of audio warning, fire alarm, flap warning, high speed with the translation background noise, highly hints

Else near-earth audio warning, automatic driving disconnect audio warning, stick shaker background noise, speeding audio warning, low speed with the translation background noise

End

2) Conditional Rules is a multi-branch, and is constantly progressive.

When the cockpit voice spectral lines is parallel,

If The once-frequency of cockpit voice, $f_1 \leq 1000\text{Hz}$

Then wind shear audio, high speed with the translation background noise, highly hints

Else take-off form of audio warning, fire alarm, flap warning

End

3) Take the once-frequency of cockpit voice for example,

When the once-frequency $f_1 \leq 1000\text{Hz}$,
If the cockpit voice spectral lines is single
Then the cockpit voice background noise is high speed with the translation background noise
Else
If the cockpit voice spectral lines is double
Then the cockpit voice background noise is highly hints
Else
If the cockpit voice spectral lines is multiple
Then the cockpit voice background noise is wind shear audio
End

There are has a lot of advantages through the fault tree analysis based on the conditional rules to analysis and diagnosis the cockpit voice: First of all, we can reduce the difficulty and shorten the time of analysis and diagnosis the cockpit voice, which can effectively improve the efficiency of analysis and diagnosis the cockpit voice information; Secondly, the fault tree analysis based on the conditional rules makes the analysis and diagnosis of the cockpit voice orderly and effectively to prevent misdiagnosis and misdiagnosis, which can improve the accuracy of analysis the diagnosis; Finally, we can build a analysis and diagnosis database of cockpit voice based on conditional rules of fault tree analysis; and can combine with the rapid development of network technology to easily help related working staff for grasping techniques of analysis and diagnosis of the cockpit voice.

Conclusion

The characteristics of cockpit voices (sounds) recorded by Cockpit Voice Recorder (CVR) are key evidences in investigating accident causes for wrecked airplane. In order to analyzing and diagnosing wrecked airplane through cockpit voices, the researchers are made, and some conclusions are acquired as followings in this paper:

1) Through listening and distinguishing by adobe audition audio software in laboratory, some typical background sounds of cockpit voices are obtained and classified. These typical background sounds are wind shear audio, near-earth audio warning, take-off form of audio warning, fire alarm and so on.

2) Through signal analysis methods (such as the Fourier Transform, Fast Fourier Transform, Short Time Fourier Transform, Linear FM Transform, Wavelet Transform), characteristics of typical background sounds are extracted. The special characteristics are frequency value, spectral density, frequency line numbers, and so on.

3) Through conditional rules and fault trees methods, these cockpit voices with approximate or different typical background sounds' characteristics can be different and selected.

All researches and their conclusions in the paper are put forward new approaches for accurate grasping the cause of flight accident, analyzing & diagnosing flight accident, protecting flight security.

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