6. ANKARA INTERNATIONAL AEROSPACE CONFERENCE
14-16 September 2011 - METU, Ankara TURKEY
AIAC-2011-034

A CONCEPTUAL DESIGN STUDY OF A FLIGHT DATA/VOICE RECORDING SYSTEM ARCHITECTURE WITH ACCIDENT/INCIDENT STATISTICS

Y. Kaygusuz[1], T. İnal[2], S. Uyar[3], S.S. Ersoy[4], and Z. S. Mor[5]
TAI, TUSAŞ Türk Havacılık ve Uzay Sanayi A.Ş. (Turkish Aerospace Industries) AEYM
Ankara, Turkey

ABSTRACT

In civil aviation CVR (Cockpit Voice Recorder) and FDR (Flight Data Recorder) installation and usage are mandatory for aircrafts which have 5700 kg or higher of take-off mass [6][11][8]. Below this mass, flight data recorder is not mandatory and it is up to customer, program management or operational requirements to decide whether to install or not to use a FDR. It is obvious that the CVR is the only avionics equipment that can provide recorded audio and the FDR alone can provide recorded flight parameters after an accident/incident. The parameters that an aeroplane must record are given as advices in international authorities' guidance material. While designing FDR architecture, avionics system designer must use recommendations and also may analyze accidents/incidents (i.e. events) in order to obtain a complete set of flight data parameter list. In this study, a design of flight recording system architecture and formation of an optimal flight data parameter list is discussed for an aircraft that has take-off mass below 5700 kg. It is also aimed to show a systematic way of FDR system designing for all masses of aircrafts. Some accident/incident records from different sources are analyzed to derive additional parameters and some previously published analyses are used to support the idea. Additionally, in this study a design of cockpit voice recording system architecture is discussed. The study is performed upon avionics system architecture to be used on general category aerobatics aircraft with a single turbo-propeller engine.

INTRODUCTION

First voice recording avionics was developed in 1939 by Francois Hussenot and Paul Beaudoin under the name "Type HB" in Marignane Flight Test Centre located in France. The reason for people calling "Black Box" to CVR/FDR systems comes from this prototype. In those years, films were the only recording media and they had to be kept in a dark box in order to protect films from light. The first prototype for combined CVR/FDR equipment was developed by Dr. David Warren and his colleagues in Melbourne Aeronautical Research Laboratories in 1956. After an accident/incident that happened in Australia in 1960, Australian government mandated civil aircrafts to carry a CVR/FDR [9].

The ref. [6] is a European Union Council regulation publication, including recommendations for parameters to be recorded in an aeroplane which has a take-off mass less than 5700 kg. This parameter list includes 17 different parameters that are collected from different aircraft systems and other avionic equipments. The ref. [6] is very commonly used by the European developers, since the European type certification regulations do not include any FDR installation details [11]. The EASA (European Aviation Safety Agency) general category aircraft certification regulation CS 23 gives some obligations for the FDR and CVR only for the cases that the installation is preferred due to the operational needs [11]. I.e. For this category of aircraft the CVR/FDR installation is not mandatory in CS 23 and no parameter suggestion is given in details. Briefly, it can be told that the EASA CS 23 puts some references for a certifiable aircraft design but the recorders chapter of this guideline is not in detail and cannot show a complete way to the avionics systems design engineers.

[1] Avionics Systems (AS) Design Specialist in TAI AEYM, Email: ykaygusuz@tai.com.tr
[2] AS Design Specialist in TAI AEYM, Email: tinal@tai.com.tr
[3] AS Design Specialist in TAI AEYM, Email: suyar@tai.com.tr
[4] AS Design Leader of HÜRKUŞ Project in TAI AEYM, Email: ssersoy@tai.com.tr
[5] AS Design Engineer in TAI AEYM, Email: zsmor@tai.com.tr

This study is primarily focused to the conceptual design of flight data recording system architecture. The designed architecture will be used on an aircraft project which is desired to be certified by EASA in general aviation/aerobatics category. In the mentioned indigenous air vehicle design project, a trainer aircraft with a single turbo-propeller engine is being designed by TAI since 2006. The aircraft which is subject to this study uses a state-of-the-art 1600 Hp turbo-propeller engine and is a step-up tandem seated training aircraft. Since the aircraft's take-off mass is below 5700 kg, customer demands and operational requirements are required for a CVR/FDR installation. For a better understanding of the FDR system architecture, here an introductory level description of the aircraft general avionics architecture may be given.

The aircraft avionics system is an integrated (i.e. central) architecture organized around 2 dual hot-backup redundant central control computers (CCC). Each of these computers receive almost all of the sensor data in the aircraft, processes these data, makes the required navigation, communication and control calculations, runs all the algorithms and generates the video signals (i.e. symbology) for the cockpit displays. This is the idea behind the central or integrated avionics architecture. When one of the computers is failed, the backup one becomes functional as the master computer. This integrated architecture (a star topology with 2 centres) has a big effect on the development of the FDR architecture. Since most of the data is processed in the CCC, the designer shall also make a "trade of" analysis of the recording type as raw data from the sensor or processed engineering units from the CCC. Notice the designer always have a chance to record some data from the CCC after or before the process. But in case of any CCC loss, the source of FDR records will also be lost. When the aircraft architecture allows the recording of the raw data, this method will be preferred instead of using CCC as source.

In this study, avionics architecture for a CVR/FDR installation is analyzed with all major aspects. All integration and design process is analyzed with regard to interface conformity problems, parameter list optimisation, product properties and statistical accident/incident research aspects. Some potential properties due to the signal types are included for some parameters. Additionally some statistical data is given depending on military and civil aircraft accident/incident records. The statistical results are used in the selection of additional record parameters. The CVR architecture is also discussed in another chapter.

FDR PARAMETERS AND ARCHITECTURE DEVELOPMENT STUDY

At the beginning of the FDR architecture development process, avionics designer team responsible for FDR system design, examined [6] and [8]. These regulations include recommended minimal recording parameter lists for aircrafts below 5700 kg take-off mass. The designers used these recommended lists and started evaluating interface needs for this list. The ref. [6] includes 2 primary lists for subject aircraft type (i.e. below 5700 kg). The first list includes mandatory parameters. The designers used this list as a start point. The second list includes some additional parameters which shall also be used in aircrafts including electronic displays. Since the subject aircraft includes electronic flight displays (driven by the CCC with video signals), this second list parameters also added to the recording parameters list. Table 1 given below includes a complete set of FDR parameters depending on [6].

Notice some of the given parameters in [6] may not be applicable to all aircrafts. For example, the subject aircraft of this study does not include a thrust reverser system, originally the [6] contains the thrust reverser as a recording parameter, but due to the aircraft properties the designers eliminated the parameter and it is not included in Table 1.

The ref. [6] does not include recording accuracy or resolution for parameters number 21, 22, 23 and 24 which are in fact derived parameters from a generic parameter named as "thrust in each engine". Since the engine does not include an engine thrust transducer, the designers preferred to record all data relevant to the engine power setting or engine torque. So the refresh rates for these items are preferred to be used as installed in the aircraft. In this very beginning the focus is on the parameter determination.

The Table 1 includes some parameters depending on the regulation given in [6]. But also the Table does not conflict with the very basic suggestions given in [11].

For all safety critical systems, the designer will of course need to verify their design preferences with real data. The testing phase is a mean for the verification of the system. Additional to the tests, here the designers used some accident/incident reports to derive statistical data to compare with Table 1 since this statistical data will give the designers a chance to see if the parameters are enough to perform an after-event record analysis.

Table 1 *Complete set of FDR parameters list depending on [6] and [8].*

ID	Parameters	Minimum Recording Range	Recording Accuracy	Maximum Recording Interval	Recording Resolution
1	Time	24 Hrs	±0.125% Per Hour	4	1 sec
2	Pressure Altitude	−1000 ft /Max.Alt.+5000 ft	±100 to ±700 ft	1	5 ft
3	Indicated Airspeed	50 Kt/Max Vso	±5%	1	1 kt
4	TAT (Total Air Temperature)	−50 °C to +90 °C	±2 °C	2	0.3 °C.
5	Heading	0–360°	±2°	1	0.5°
6	Normal Acceleration	−3g to +6g	±0.09	0.125	0.004g
7	Pitch Attitude	±90°	±2°	0.25	0.5°
8	Roll Attitude	±180°	±2°	0.5	0.5°
9	Longitudinal Acceleration	±1g	±0.015 g	0.25	0.004g.
10	Manual Radio Transmission Key (PTT)	Discrete(s)		1	
11	Power Control Lever (PCL) Position	Full Range	As installed	Each engine each second	0.2% of full range
12	Flap Position Cockpit Control Selection	Full range or each discrete position	±3 degrees	2	0.5% of full range
13	Speed Brake Selection	Full Range or Each Position	±2°	0.5	0.2% of full range
14	AOA (Angle of Attack)	As installed	As installed	0.5	0.3% of full range
15	Selected Barometric Setting	As installed	As installed	64	0.1 mb/0.01 in-Hg
16	Selected Heading	As installed	As installed	1	Sufficient to determine crew selection
17	Selected Decision Height	As installed	As installed	64	Sufficient to determine crew selection
18	EFI Display Format	Discrete(s)	As installed	4	-
19	Selected Course	-	As installed	1	-
20	MFD/Alerts Display Format	Discrete(s)	1	4	-
21	Generator Speed	As installed	-	-	-
22	Propeller Speed	As installed	-	-	-
23	Torque	As installed	-	-	-
24	Torque/Propeller Speed	As installed	-	-	-

In this study there are 3 types of data and the accident/incident reports used. The first type of data depends on the civil records[6] of Australian Transport Safety Bureau (ATSB) [3]. Also the ATSB web site contains various event records, and the design team analysed a group of selected serious events form this reference [1]. Since the Australia is the first country which regulates the usage of the FDR as an obligation, the ref. [1] and [3] are accepted as a mature resource for this type of analysis [9].

The second source is the USA National Transportation Safety Board event records for aircraft incident or accidents [2]. USA NTSB records are also very useful due to the huge amount of professional, amateur and experimental aircraft and pilot numbers. Since USA is a country with a very big aviation industry and crowded flight zone, NTSB is a very good resource for event analysis.

[6] The references [1] and [3] are not restricted material and are distributed in the web site of ATSB (http://www.atsb.gov.au). But it shall be noted that the document is protected under copy right laws, and due to the note in the beginning of the document, details of the events are not sharable without the permission of the airlines. Here only the statistical data distributed by the ATSB is used in [3].

The next data is the results of analysis contained in some books previously published. Various researchers results are used in parallel to ATSB web site results [4][7][10]. The details are given in following paragraphs.

In fact additional data from various military records are used in some other surveys in comparison with the ATSB, NTSB and published analyses, but these are not taken under the coverage of this manuscript. So only the civil data and results will be declared and included in this study.

Statistical Approach to FDR Parameter Derivation

The designers used ATSB records in a classification of accident/incidents relevant systems. The method is called “keyword analyse” by the designers. Classifying the events regarding only their root cause (i.e. the exact subject of the event) will be useless for this type of study. Because in many events, the accident/incident is a result of multiple factors. So the aim here is not to list the root cause of many accidents. What is done is to see which systems data are needed to be recorded to reach to root cause. In this study, the designers give some keywords to each subject event, such as “hydraulics”, “flight controls” or “engine”, regarding the event reports. As stated above, most of the events are results of multiple system failure or human factors so that the total number of keywords derived is greater than the total number of accidents. Then it became possible to compare each keyword class’ total number with the number of all keywords. A similar classification and selection of keywords are performed for the USA NTSB records. A different designer group analysed the NTSB records via using the same method. The results will be given in the following chapters.

As mentioned in the first chapter of this study the Australian authority have a very big amount of flight accident/incident records due to the relatively long history of Australian FDR applications. Since this study is mainly focused on the FDR architecture, the complete Australian records could not be analysed. The scanning of the event records are started from the newest one at 2009 and followed towards past until the year of 1991 [1].

The ATSB flight records covers 3743 training flight accident/incidents in between years 1999-2009. Each year, total hours of training flights is about 400.000 hours. The most fatal occurrences are given by an average number of 2 per year [3]. Most of the trainer accident/incidents are not taken into fatal category by the authorities since trainers generally contains not more than 2 pilots. The ref. [3] includes a Table with number 29 which gives the total numbers of the records for each year regarding the event types for the general aviation category, the given classification is not performed for training aircrafts. Notice these statistics does not gives any data suitable for FDR parameter determination. So the design team decided to make a survey of serious events from the ATSB and NTSB web sites and make a keyword analyze.

Table 2 *The ATSB records keywords analyze results.*

KEYWORD	NUMBER	PERCENTAGE
Crew Human Factors	27	22,69%
Engine	16	13,45%
Landing Gear (L/G)	12	10,08%
Hydraulics Power System (HPS)	7	5,88%
Flight Control System (FCS)	29	24,37%
Icing / Clouds / External Reasons	3	2,52%
FPS (Fire Protection System)	1	0,84%
Avionic Systems	9	7,56%
Fuel System	7	5,88%
Pressurization Systems (ECS)	8	6,72%
TOTAL	119	

A total number of selected 100 events (with most clear report) are analyzed in the time interval of 1991 to 2010. A total number of 119 keywords are determined for these 100 major selected events. The greatest portion of these keywords is the aircraft systems with 52.94% of weight (HPS 5.88%, L/G 10.08%, FCS 24.37%, fuel system 5.88% and ECS 6.73%). The avionics and avionics related issues take only a part of 10,92% of all keywords [1]. The main reason here is that ATSB records contain some data relevant to maintenance of the aircraft systems, so that analysing these maintenance relevant issues under the header of the aircraft systems have an effect of increasing the percentage of the aircraft systems keywords. In other words, the human factors is the leading cause of the aircraft crashes or events [10] and the ATSB data holds a great note of the maintenance of the aircraft systems, so it is possible to tell that the human factors errors are mostly hidden under the aircraft systems title. In fact it is possible to make another classification by taking the human factors issue under the scope and this approach may lead to further developed results. But the human factors and maintenance systems is out of the scope of this study so that these results are underestimated. The main idea here is that ATSB records contain many aircraft systems related issues which point toward a need of recording these systems' parameters. So parallel to the ATSB records, the designers preferred to add some additional parameters especially belonging to the aircraft systems since they are underestimated and left out of scope for aircraft with mass below 5700 kg (Light aircrafts) by the ref [6] and [8]. On the above Table 2, the details of the ATSB keyword analysis percentages and numbers are given. Also a graphical representation is given in the Chart 1.

The Table 2 includes 5 types of aircrafts systems, making a total of 52,94% of all keywords. But notice in a classification considering the human factors issues and errors, most of these could be recovered under the header of human factors or maintenance but not in the systems. But the main point about the analysis is that whatever the name of the class is, the failed system as the result of the error is an aircraft system. I.e. one cannot tell that the 10.08% of the subject 100 event is the result of a landing gear failure, but one can clearly say that 10.08% of the events can be better analyzed if the landing gear data is recorded in a FDR by using Table 2. With a more clear description, whatever the root cause, the human fault or unattended system fault, in any case, the accident/incident contains a relevance to the landing gear system and a recording of this data will support the event analysis.

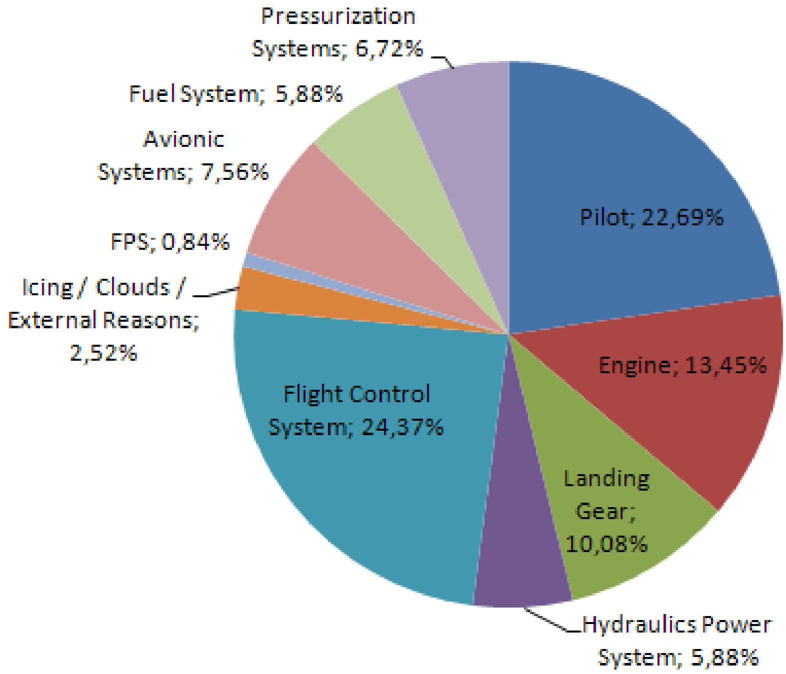

Chart 1 Percentage distribution of the ATSB records event keywords.

Notice the Table 1 includes many avionics systems parameters, some engine parameters and cockpit controls, but there is not any of the aircraft systems data recording demanded by the authority. Clearly the list does not require the aircrafts systems data recorded [6][8] except the engine parameters. But in the Chart 1 above it is clearly seen that the FCS, L/G, fuel system and ECS have a great percentage in the total number of ATSB records percentages.

One reason behind that the regulations left the aircrafts systems parameters out of the scope for light aircrafts, may be the simplicity of these aircrafts at past. The ancient aircraft which does not have a retractable landing gear, ECS or HPS, can of course not provide the complex aircraft systems data to FDR and so these are not needed to be recorded. But today modern trainers include on board oxygen generating systems, complex ECSs or HPSs and similar high technology aircraft systems.

Most of the studies performed in the area of the aircraft safety analyze pre-flight design workload. Each aircraft design process contains a system safety assessment or functional hazard analysis phase which is performed continuously during all design phase and it is a mandatory part of the process due to the type certification requirements [5][11]. But different then the system safety analysis works crash analysis is clearly a useful tool to increase the system or aircraft safety. The lessons taken from the previous events are extremely important feedbacks to the designers. As it is seen in the Chart 1 very big part of the events are caused by the aircraft systems designs [7]. The engine, fuel, hydraulics, landing gear and environmental control systems designs can prevent many future undesired events. The aircraft systems can be root causes of many events for not only the transport category aircrafts but there are various small and light aircraft failures due to these systems [4].

The ref. [10] includes many real event analysis, while the document does not give any statistical approach, gives the root cause types under 5 main headers. The mechanical systems (in this study, aircraft systems name is preferred) is the 5th highest rate group of the event causes. All of the analysis given for this group contains more than single cause each containing some of the aircrafts systems such as landing gear or FCS. The ref. [10] approach is similar to given here, the only deviation is that the [10] made a classification including human factors and mostly preferred fatal events to underline the importance of aviation safety studies. The ref. [7] gives that small general aviation aircrafts such as the subject aircraft of this study crashes more than the bigger aircrafts[7]. Even only this fact can be a good reason to increase the number and quality of the recorded parameters and develop a better FDR architecture. The ref. [7] gives a total number of 26 fatal accidents between the years 1983 and 2000. The given classification of events contains that 45% of the events occurred during the landing phase. Almost half of the given data shows a relevance to engine systems. Also some fatal events include fire or engine fire situations. Anyway, the aircrafts systems have a great contribution to the given fatal accidents.

The last chapter of the ref. [7] includes a brief description of some events and the lessons learned from these events. Total number of 14 lessons about the FCS is grouped separately from the other events caused by the system design lacks or faults. Additionally there are 37 events analyzed and found results of HPS, ECS or similar aircraft systems design faults. Notice in this study FCS is covered under the header of the aircraft systems and the events contained in the [7] also support the idea pointing the criticality of the aircraft systems.

A selection of 100 newest events is analysed in the NTSB data base [2]. Different from what have been done for the ATSB, the selection is done for choosing the newest event records. The ATSB records were scanned for the most severe or fatal accidents or events. Here the method is to choose a different set of data to see if the time created any deviation in the general type of the results. As it is clearly seen in the below Table 3, the effect of the human factors, similar to previous data ATSB or ref. [2], is very big. The NTSB data keywords classification shows that the L/G, fuel system and general aircraft fire holds a connection to 23.12% of keywords belonging to the set of 100 newest NTSB event records[8]. The Table 3 classifies the engine keywords as a different class then the aircraft systems but in general one can easily tell that the systems problems or faults holds a role in the 45.51% of all the events contributing to Table 3 and Chart 2. Chart 2 includes a graphical demonstration of the Table 3. The NTSB analysis covers a given 134 keywords for 100 events. The 12 "*maintenance*" keyword are not taken in to the Table 3 but covered under the header human factors.

Table 3 *NTSB records keywords summary.*

CLASS	# of Keywords	Percentage
Crew Fault / Human Factors	62	46,27%
Engine / Thrust Loss / Engine Fire	30	22,39%
L/G	25	18,66%
Icing / Clouds / External Reasons	11	8,21%
Fuel / Tanks	4	2,99%
Fire	2	1,49%
TOTAL	134	

The keyword analyses performed via using ATSB and NTSB records, both shows that the aircraft systems data have a clear and direct connection to many accident/incidents [1][2]. Additionally some common publishing in the literature shows that the systems design can be further developed via the

[7] The authors of this study made a survey of 252 military accident/incident records. The results are different then the civil records of the ATSB. The military records are not taken under the scope of this study, since they are subject to another study. But the military analysis results show that the aicraft systems keyword percentage is just about 27.75%. This big difference can be the result of very systematic and good quality maintenance procedures in the air forces. This fact underlines the human factors aspect given in the [10]. Also this can describe why the small general aviation aircraft crashes more often, the reason may be the maintenance human factors [4][7]. This deviation between the civil and military records can be a subject for a future and more detail study.

[8] The NTSB results numerically shows a similarity to the military results. The percentages are closer to army results. This is the main deviation between the NTSB and ATSB statistics.

feedback which can be derived from the accident/incident analysis [4][7][10]. The authors thinks that the above given analyses results and tables shows a lack in the general lists of recording parameters given for light aircrafts [6][8].

Notice the name "aircraft systems" does not cover only the ones given in this manuscript. Regarding the type and function of the aircraft, there may be many different aircraft systems. The aircraft systems term is used in many aerospace companies as a term covering the entire propulsion, powerplant, mechanical (such as structure or landing gear), fluidic (such as hydraulics power or waste water drainage), flight controls or similar systems. Other systems which are mostly electric-electronic ones, such as avionics, electrical power and lighting systems are named as pilot systems. The systems in an aircraft are analyzed mostly under these 2 headers. The authors' company also uses this classification, so the term is used here as accepted in the aviation industry.

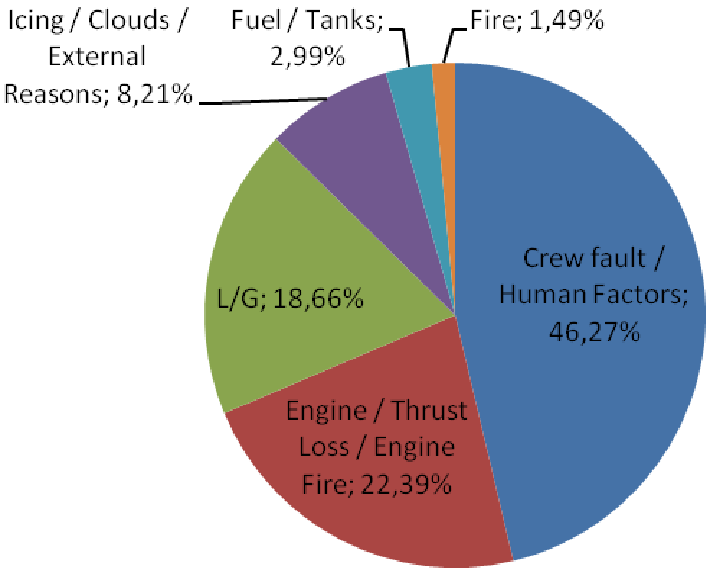

Chart 2 NTSB results graphical demonstration.

The Table 4 includes 14 additional aircraft system parameters to be recorded. This modification makes an important change in the FDR system architecture. Details will be given in the following chapters. The additional data to be recorded is to be collected from the FCS, landing gear system, fuel system and hydraulics power system. The environmental control system data may not be taken into consideration due to the very low value of percentages inside ATSB records. Notice the ECS data may be used as a proof of cabin or canopy hazards in the post-accident analysis. Also the subject aircraft includes a digital/smart, electronic environmental control system (ECS) and the data is available via ARINC 429, so it is preferred to take the ECS data into recording lists.

Table 4 *Additional parameters selected from keywords analysis.*

#	Parameter Name	System
1	Landing Gear Position	Landing Gear
2	Elevator Trim Position	Flight Control System (FCS)
3	Rudder Trim Position	FCS
4	Aileron Trim Position	FCS
5	Flap Position	FCS
6	Nose Wheel Steering Active Signal	Landing Gear System (L/GS)
7	Park Brake Position Signal	L/GS
8	Main Hydraulics System Pressure (for each system)	Hydraulics Power System (HPS)
9	Hydraulics Pressure Low Warning Signals	HPS
10	Fuel Pressure	Fuel System
11	Fuel Tank Quantities (For Each Tank)	Fuel System
12	Cabin Pressure Altitude	ECS
13	Cabin Pressure Rate of Change	ECS
14	Cabin Pressure Differential	ECS

Notice the above list given in the Table 4 contains 14 additional parameters, but this does not mean only 14 additional recording is needed. The parameter 8 contains a notation of “for each system”. The subject aircraft contains two installed HPS, so that in fact two different set of data is recorded for parameter 8. Similarly parameter 9 makes 2 different warning discrete signals. Parameter 11 demands each fuel tank level shall be recorded, and the subject aircraft contains two different wing tanks. So with a clearer description, the 14 parameters in the Table 4 may require that a total of 20 or more parameters are recorded or at least found preferable for a recording system for the subject aircraft by the authors of this study.

A Brief FDR Architectural Analysis and Development

The first step of the architecture development of the system has to be selection of the data sources and interfaces. In ancient aircrafts with non-central architectures, all of the data have to be interfaced from the source sensor, equipment or transducer. But in the subject aircraft there is a modern integrated architecture with a central control computer and most of the above data can be transmitted to the FDR via the CCC or the source sensor. The selection is an important part of the FDR system design. Segregation shall be done in between raw data or processed data of CCC too. The bulk data transmission from the CCC via an avionics data bus will be a very simple solution but the system behaviour shall be considered at this point.

The Table 1 parameters can be grouped into some main groups. The air data parameters (Table 1 parameter 2, 3 and 4) is the data which are calculated by the air data computer (ADC) and transmitted to the CCCs for video generation for the displays. Here the preference is to collect those parameters directly from the ADC, since the equipment transmits these data via ARINC 429 data bus. Due to the continuous and relatively high refresh rates of the ARINC 429, the recording interval will not be a problem. The ref. [2] asks for a recording of 4 times per second for some of the air data parameters. But the ARINC 429 defines the refresh rates of the air data about 31.3 to 62.5 mseconds i.e. more than 16 times per second, so the recording frequency cannot be a problem [12].

The Table 1 parameters 5, 6, 7, 8 and 9 are mostly data which are directly calculated via a gyroscopic system including accelerometers. In the subject aircraft the used equipment is an embedded global positioning system including an inertial navigation system, i.e. an embedded GPS/INS or briefly EGI. Some aircrafts may include attitude and heading reference system (AHRS) installation. Most of the commercial AHRSs have also ARINC 429 outputs in the market. So the argument in the previous paragraph which suggests that the ARINC 429 refresh rates are already better then the ref. [6] recording rates is valid for AHRS too. Similarly due to the deterministic structure of the ARINC 429 bus, the splitting of the data bus lines will also not be a problem. ARINC 429 allows using 19 receivers with a single transmitter. So the connections between EGI or AHRS and the CCCs can be splitted in to 2, and the second line can be connected to the FDR [12].

The Table 1 parameter #1 which is UTC or GMT time is generally used as a reference in the recording process, and downloaded data after flight or event. The important point is that the there shall be a specific time source in the aircraft. In some architecture a digital time clock with ARINC 429 output may be used. Or alternatively this reference can be taken from CCCs. Here in this study, the subject aircraft includes a digital clock which can supply GMT time via ARINC 429 output.

Table 1 parameters 15 to 19 are pilot selectable flight parameters. In an aircraft the pilot selects these controls via some means on the cockpit. In an integrated architecture this selection data is transmitted to the CCCs in some different signal types, and applications or navigation calculations are performed in the CCCs. So various pilot selections shall be recorded, the selection can be done from different equipments or systems such as Up-Front Control Panels (UFCPs) or Control and Display Units (CDUs), so the preference here will be to generate a more generic solution which can be applied to many different architectures. The pilot selection data will be taken from the CCCs via ARINC 429 outputs. Table 1 parameters 10 and 14 are also similarly pilot selective data which can easily be collected from the CCCs. Notice these can be also recorded with direct connections to the source switches. An exception here is the parameter 11 in pilot selective data. The Power Control Lever (PCL) position signal is a Rotary Valve Differential Transmitter output (RVDT) and is not transmitted to the CCCs, but transmitted directly to the digital engine control unit (FADEC) and the powerplant system. So the good solution is to make a splitting of this line and connecting to FDR. The second solution can be capturing the RVDT data from a repeater output of the FADEC. The parameter 20 which is a set of alerting signals and also a result of the processes or calculations performed inside the CCCs. So they will be directly taken from the same buses in CCCs.

Another exceptional set is Table 1 parameter 12 and 13. The regulations ask directly what the pilot selected shall be recorded. So the signal shall be taken from the cockpit control switches but not from the CCCs.

Last big group is the engine parameters group; most of the engine data is taken via using ARINC 429 output on the engine digital control unit (FADEC). Only the parameter 24 in Table 1 will be used via an analog signal (frequency type signal as magnetic pick up output).

In the below Table 5 the sources of all parameter in Table 1 and Table 2 and connection details are given.

Notice the addition of the Table 4 parameters increases the total number of FDR interfaces, total number of wiring workload, wiring weight and clearly the total cost of the system. Here one shall notice that the Table 1 parameters are briefly enough to create a compliance with the regulations and here in this study, when adding the Table 4 parameters, the goal of the authors is to create an increased after-event analysis option to the designers or analysers in order to be able to get the root cause of the event easier.

Analog data recording can be more problematic in comparison to the digital data bus data. This is another main reason of for preferring to record the Table 4 parameters over the CCC. But the designers prefer to record these data via using the original system sensors, not the CCC. When the data is not taken from the CCC, the data will be a converted data from analog to digital. In this case the designers shall perform a correlation study showing that the converted data is not deviating from the original raw data [11]. In fact the ref. [11] asks for a correlation of the primary flight values such as airspeed, altitude or attitude. But a common sense, of course will say that the correlation may be needed for each analog displayed data which is converted into digital before recording. I.e. one shall be sure of that the digital records are close enough to original analog values. Taking of the recording data from the first pilot's sensor will clearly decrease the correlation needs.

Table 5 *Connection lists for recording parameters.*

Parameters	Source	Signal
Table 1, #1	Digital Clock	ARINC 429
Table 1, #2, 3, 4	ADC	ARINC 429
Table 1, #5, 6, 7, 8, 9	EGI (Embedded GPS/INS)	ARINC 429
Table 1, # 10, 15, 16, 17, 18, 19, 20	CCCs	ARINC 429
Table 1, #12, 13	Cockpit Control Switches	Discrete
Table 1, #11	PCL	RVDT
Table 1, #14	AoA Computer	ARINC 429
Table 1, #21, 22, 23	Engine Digital Control Unit	ARINC 429
Table 1, #24	Engine Analog Sensor (Magnetic Pick Up)	Frequency
Table 4, #1, 6, 7	Landing Gear System Discrete Sensors	Discretes
Table 4, #2, 3, 4	FCS Analog Transducers	Analog Voltage
Table 4, #5	FCS Discrete Sensors	Discretes
Table 4, #8	HPS Analog Transducers	Analog Voltage
Table 4, #9	HPS Discrete Sensors	Discretes
Table 4, #10, 11	Fuel System Digital Control Unit	ARINC 429
Table 4, #12, 13, 14	ECS	ARINC 429

After interface analysis, preliminary interface centred architecture was designed. By this architecture, the designers detected interface conformity problems and a detailed ICD (Interface Control Document) study is done. As can be seen from Figure 1, that all of the data busses are ARINC 429 and there are some discrete and analog data from different sensors. The most challenging interface while integration process is the interface between FDR and PCL (Power Control Lever) sensor. This interface is used for recording number 11 parameter in the given Table 1 above. Sensor's output is an unusual analog type signal, and some calibration and conversion study had to be done. And the runner up in challenging interfaces are interfaces between flight control system and FDR which are all discrete interfaces.

While forming an optimised parameter list, some parameters are not taken from regulations' recommended lists. These parameters are generator speed, propeller speed, torque and torque/propeller speed. These four parameters are added to list, after a long period optimisation study which is studied with test pilots, flight system design engineers, certification specialists and functional hazard assessment specialists. The final FDR architecture is given in the above Figure 1.

In the Figure 1 below, a description of the complete conceptual architecture is given. Notice some lines are shown with red colour for reader's attention. The first set of red lines is the controls line between the CVR/FDR and its control panels and the test results lines (as CVR FAULT and FDR FAULT) in between the CVR/FDR and CCCs. This test line logic is added not only due to the system health purposes but also due to the regulations [11][5].

Another complex important issue is the starting and stopping of the recording function. The regulations demand that the FDR starts to record automatically and that the pilots cannot have a chance to stop it. So in the subject aircraft a logic gate is prepared via using relays which can function using Ground/Open or 28 VDC/Open type discrete signals. The inputs of this logic device are the engine stop signal and weight on wheels signal (WoW). The FDR stops recording only when the engine is stopped and the aircraft is on ground. The line is shown with red colour on the Figure 1. Similarly when there is an accident or incident in the air due to the power loss, the FDR shall be able to continue recording, so a 10 minute Remote Independent Power Supply (RIPS) is used. The RIPS power line is also shown with red colour on the Figure 1.

Notice in the market there are many types of FDR equipments. In some installations for bigger aircraft types, there may be needs of independent FDR and independent CVR needs. But for USA DoT FAA (Department of Transportation, Federal Aviation Administration) Part 23 and EASA CS 23 aircrafts, there may be unified equipments which perform both FDR and CVR duties [11]. For this study, in the subject aircraft, single CVR/FDR equipment with both functions is used.

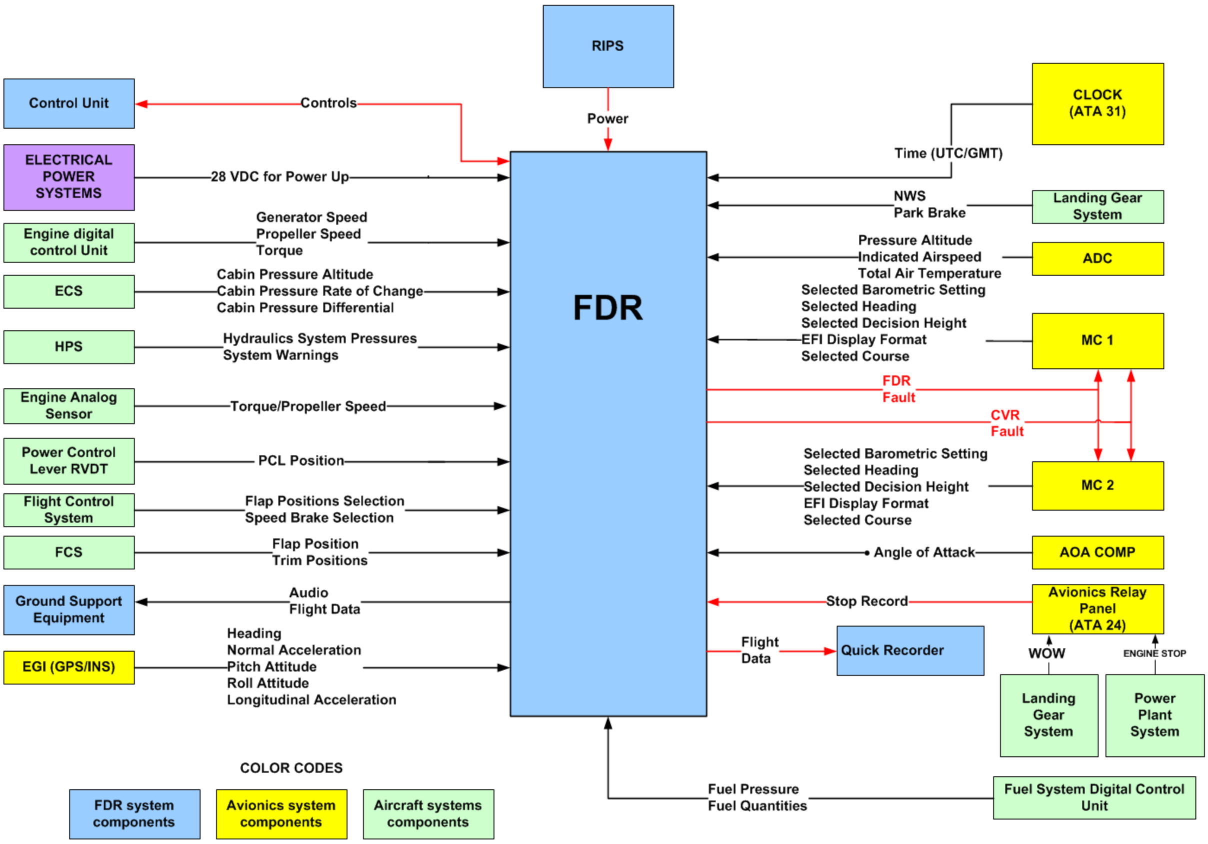

Figure 1 The FDR conceptual architecture for subject aircraft.

Cockpit Voice Recorder (CVR) Architectural Analysis and Development

A cockpit voice recorder often referred to as a “black box” is used to record the audio environment in the flight deck of an aircraft for the purpose of investigation of accidents and incidents. Under the three conditions given below; unless CVR is equipped, the aircraft cannot be operated:

1) If the aircraft was first issued with an individual certificate of airworthiness, on or after 1April 1998 either it is multi-engine turbine powered and has a maximum approved passenger seating configuration of more than nine; or it has a maximum certificated take-off mass over 5 700 kg
2) If the multi-engine turbine aircraft was first issued with an individual Certificate of Airworthiness, on or after 1 January 1990 up to and including 31 March 1998 and it has a maximum certificated take-off mass of 5 700 kg or less and a maximum approved passenger seating configuration of more than nine.

3) If the aircraft with a maximum certificated take-off mass over 5 700 kg was first issued with an individual certificate of airworthiness, before 1 April 1998 [6] (Requirements 1.700,1.705 and 1.710 of [6])

It is compulsory for the installation of the Cockpit Voice Recorder if the aircraft satisfies any one of the three conditions given above. If not, it is not obligatory but for the after flight analysis and investigations; each aircraft can install CVR. No matter what is the reason for the installation of the CVR; if it is installed in the aircraft; these audios given below must be recorded in the CVR:

1) External communication audio (transmitted audio by communication radios or received audio from communication radios in the aircraft)
2) Flight Deck communication audio between flight crew members on the flight deck without interphone system (when the flight crew members share the same cockpit, they can communicate without microphone but it is impossible for the tandem seat cockpit aircrafts)
3) Internal communication audio (Communication between flight crew members by using interphone system)
4) Navigation audio (Received audio from the navigation radios)
5) Internal Communication audio between flight crew members via the passenger loudspeaker system, if there is such a system [11] (Requirement 23.1457 of [11])

The External communication audio, Internal Communication audio and Navigation audio can be recorded by the CVR output pin of the each Intercommunication System (ICS) equipment. External communication audio coming from the communication radios to the pilot headset and transmitting from pilot microphone to the communication radios, navigation audio coming from the navigation radios to the pilot headset, and Internal communication audios sending from one pilot stations microphone to the other pilot stations headset are collected on the CVR output of the ICS System equipment and send to the related CVR channel (channel 1,2,3,4) that is explained in the following paragraphs.

Recording the Flight Deck communication audio between flight crew members on the flight deck without interphone system can be met by installing a cockpit-mounted area microphone, located in the best position for recording voice communications originating at the first and second pilot stations and voice communications of other crewmembers on the flight deck. For the tandem seated aircrafts like HÜRKUŞ, T38, KT1T; installation of the cockpit area microphone and recording the Flight deck communication is useless because without ICS the pilots cannot communicate with each other [11]. (Requirement 23.1457 of [11])

The cockpit voice recorder must be capable of recording the necessary audios during at least the last 30 minutes of its operation. but this has been found to be insufficient in many cases, significant parts of the audio data needed for a subsequent investigation having occurred more than 30 minutes before the end of the recording [6]. (Requirement 1.710 of [6])

Before the aircraft moves by its own power, automatically the cockpit voice recorder must start to record and continue to record until the end of the flight when the aircraft is no longer capable of moving by its own power. Moreover, if there is a crash impact; there will an automatic system in the CVR to stop the recording function and prevent each erasure feature from functioning at the same time within 10 minutes; and there must be an aural or visual clue to test for the proper operation of the Cockpit Voice Recorder before flight [6][11] (Requirement 1.700 of [6], requirement 23.1457 of [11]).

Regulation compliant Cockpit Voice Recorder architecture installed in the subject aircraft is given below Figure 2. A modern standard CVR is capable of recording 4 channels of audio data. Each communication and audio signal source data is recorded in separate channels. Which CVR channel is separated for which audio data is given below:

- For the first channel, first pilot station audio coming from microphone, headset, or speaker used. (First pilot station CVR output pin is used for the first channel of the CVR)
- For the second channel, second pilot station audio coming from microphone, headset, or speaker used. (Second pilot station CVR output pin is used for the second channel of the CVR)
- For the third channel, audio coming from the cockpit-mounted area microphone (if the cockpit area microphone is installed in the aircraft).
- For the fourth channel the third and fourth crewmembers station audio coming from microphone, headset, or speaker used (If necessary) [11] (Requirement 23.1457 of [11])

Design Process

- As it can be seen from Figure 1, most of the recorded parameters are taken directly from sensors themselves, not from any converter unit or processor. This architecture concept is used for protection from a loss of recording function due to a total loss of CCCs. By collecting the data directly from dedicated sensor gives the advantage of failure discrimination. If one sensor fails to provide data to FDR, all the other remaining data will still be available to be recorded. If the designers are aimed to collect most of the data from CCCs, then by just losing a CCC, there would be a lot of data loss for FDR. And also, if MC's manipulate raw data while digitizing or data processing, then a correlation study must be done by the user to compare the difference between the raw data and the processed data by the CCC. This correlation study also is a complicated and time consuming process. This is another reason for avoiding collecting data from CCCs rather than sensors themselves.

- For the CVR case; it is also the same as seen from the Figure 2 given below. Audio sources for CVR recording are Audio Control Panels and Microphones. There is no data taken from the CCC so total loss of CCCs has no effect to the audio recording to the CVR.

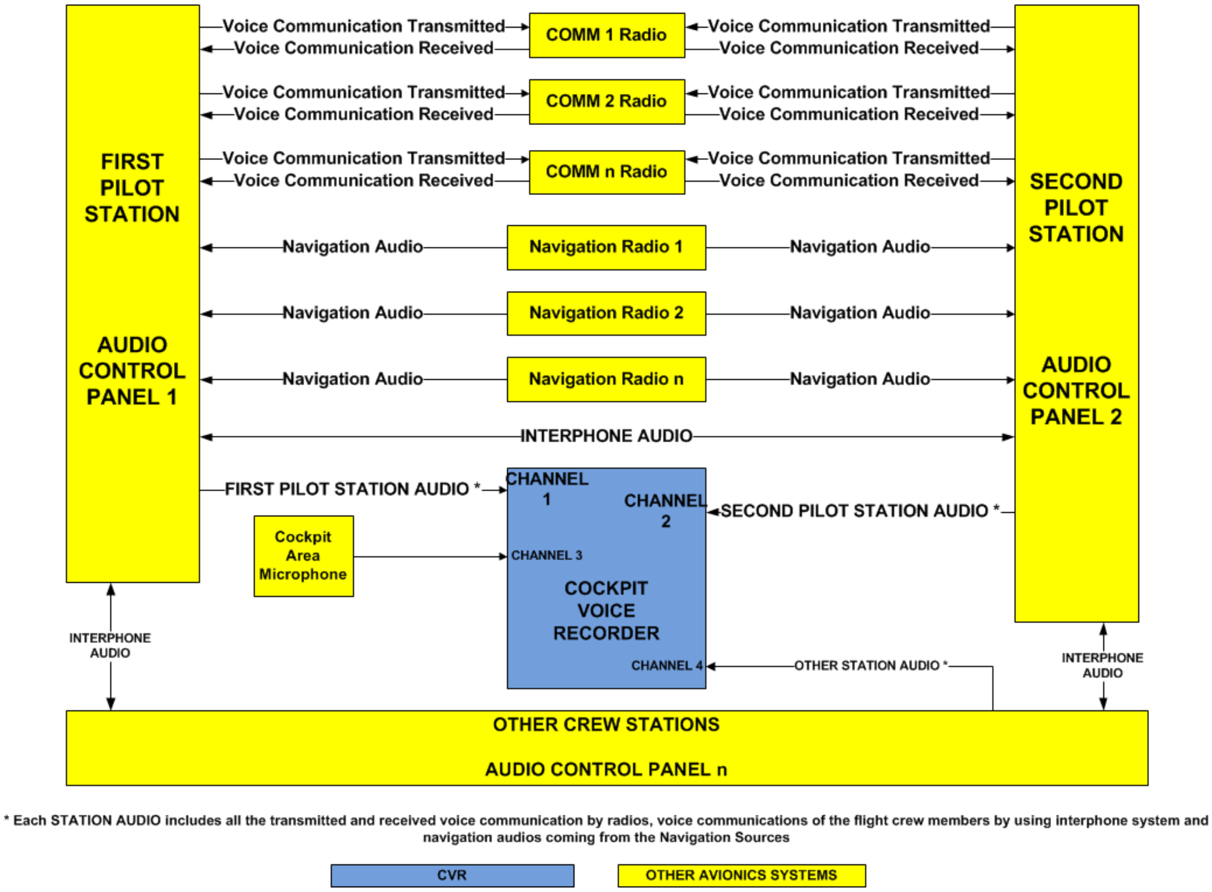

Figure 2 CVR architecture compliant with the regulations in subject aircraft.

DISCUSSION AND CONCLUSION

In this study the authors described the FDR and CVR systems architectures designed and implemented in a single turbo-propeller engine state-of-the-art trainer aircraft and the methods used. Since the aircraft weight is lower than 5700 kg, the regulations do not mandate a FDR installation. On the other hand, if the aircraft fall into one of the three categories mentioned in the "Cockpit Voice Recorder (CVR) Architectural Analysis and Development" section then CVR installation becomes as mandatory otherwise optional. But the operational and customer requirements demanded the installation of the equipment. The designers used unified CVR/FDR equipment which can perform recording of both audio and the flight data. Since the applicable operational standard does not seem containing a complete set of parameters which can be used for a detail after-event analysis, designers made a survey of some common references and event records [1][2][3][4][5][6][7]. Some extra parameters, especially about the aircraft systems are added to the parameters lists as given in Table 4. Regulations recommend these additional parameters for aircraft which has a take-off mass over 5700 and under 27000 kg. Unlike most of the operating civil aircrafts below take-off mass of 5700 kg aircrafts, new tandem seated modern trainer aircrafts, like our project, mostly have complex and technological systems just like airliners and fighter jets. These different properties put the modern trainer into a category that recommended parameter lists for mass below 5700 kg becomes inadequate for proper accident/incident analysis. These additional parameters have an increasing effect in the cost, and the authors believe that these extra parameters will increase the affectivity of the accident/incident analysis options and similarly will increase the future aviation safety for aircrafts with mass below 5700 kg. Also, the authors believe that the methodology of deriving additional parameters from international event records is a very effective method. The main focus of this study is to see whether the regulations for the subject aircraft are complete guidelines or not. Clearly, regarding the Table 2, the ref. [6] does not contain parameters needed to be used in the accident/incident analysis for a modern aircraft of mass below 5700 kg. Some additional parameters are used due to the event keyword analysis given in previous chapters.

As previously given, a keyword analysis depending on a statistical survey of Australian accident/incident records is made by the design team. The analysis is constituted of a survey and tabulation of keywords from the event records data and then making a percentage calculation of the system keywords. A sample Table from the tabulated record format of the design team is given in below Table 5. Notice each record may be assigned with multiple or single keyword.

Today, the number of passengers for airways is highly increasing. Due to this increase, the number of aircrafts, airways, aviation companies, pilots and new designs are also increasing, and the authors thinks that this positive trend will continue too. Due to the enormous enlargement of the air traffic, a need of more advance or developed aviation safety occurred. The CVR/FDR accident/incident analysis is very important and effective method of concluding more mature and better design solutions. Notice all around the world day by day the usage of data recording systems is increasing and for a wide variety of aircraft this usage is mandatory [6][8]. Here in this study, the hope is to design an advance FDR architecture which is beyond the needs of the regulations and helps the event analysis advancement for aircrafts with mass below 5700 kg such as trainers. For the CVR case whatever the category of the aircraft is; CVR installation and recording the audio parameters given above helps the event analysis advancement for aircrafts. The authors wish this study to be a small brick in the road going to safer future world aviation.

Table 4[9] *A sample of event record keyword tables*

NO	A/C	DATE	SUMMARY	ANY LIFE LOST?	Keyword 1	Keyword 2	Keyword 3
Event 24	B company CDE model	26th Sep. 2007	Ditching, Terrain Collision When the aircraft was about 46 km north-east of Gurney, the engine lost power and the pilot conducted a ditching into shallow water adjacent to a beach. The aircraft was reported to have sustained minor damage and none of the occupants were injured.	NO	Engine	Flight Controls	
Event 6	A Company BCD model	17th Feb 2001	Suspected flight control problem The crew reported that, as the aircraft was climbing through flight level (FL) 180 (18,000 ft), they noticed the stabiliser trim wheel moving opposite to the direction of the control column (elevator) movement. The crew considered that the trim movement was uncommanded and consequently completed the non-normal procedure for a runaway stabiliser.	NO	Undefined	Flight Controls	
Event 45	D Company EFG Model	14th Oct. 1976	Soon after lift-off the engine started to run rough and lost power. The instructor took over control and, maintaining between 50 and 100 ft above ground level, turned the aircraft towards another runway. Near the end of that runway the aircraft pitched nose-up, stalled and collided with the ground, seriously damaging the aircraft and injuring the occupants.	YES	Engine	Flight Controls	Avionics

[9] The Table does not reflect any real data but is given only to provide a demonstration of the classification methodology of the study. The names of the companies and aircraft models are changed or event forms are all changed and are not real due to the copy right issues with the companies due to the ATSB notices on the [3].

The statistical approach in this study is not covering the human factors issues of the accident/incident analysis. Notice this is an enormous area for future study. It is clear that a more detail study including the human factors which in result covers parameters considering the human errors will very effectively help to increase the aviation safety. Additionally the civil aviation records are so large that a small design team cannot scan all these items in short periods of time. An extended future study can be an international workshop on scanning the complete civil and military records and deriving requirements for increased event analysis tools. This international workshop can be a good project also for developing the international aviation safety corporation.

There may be some arguments opposing the idea of using additional recording parameters for the CVR/FDR equipment. Probably the most common reasons for not recording the extra parameters in Table 4 can be the cost and system complexity. But one shall notice, the authorities worldwide day by day increase the safety requirements and in close future it is highly probable that most of the Table 4 parameters of this study or other similar parameters may become mandatorily recorded.

References

[1] Australian Government, Transport Safety Bureau ATSB web site, Accident/Incident reports: "*http://www.atsb.gov.au/publications/safety-investigation-reports.aspx?mode=Aviation*", 2011.

[2] USA, National Transportation Safety Board, NTSB web site, Accident/incident Data Base Query Tool: "*http://www3.ntsb.gov/aviationquery/index.aspx",* 2011.

[3] Australian Government, Transport Safety Bureau ATSB, "*Aviation Occurrence Statistics, 1999 to 2009*", ATSB, Canberra, Australia, 2010, ISBN 978-1-74251-058-3.

[4] Bibel G., "*Beyond the Black Box, The Forensics of Airplane Crashes*", The John Hopkins University Press, Baltimore, Maryland USA, 978-0-8018-8631-7, 2008.

[5] USA DoT FAA, FAR CFR.14.23 "*PART 23-Airworthiness Standards: Normal, Utility, Aerobatic and Commuter Category Airplanes"*, 2008.

[6] Official Journal Of European Union, EU-OPS 1: "*Commission Regulation (EC) No 859/2008 of 20 August 2008 Amending Council Regulation (EEC) No 3922/91 as regards common technical requirements and administrative procedures applicable to commercial transportation by aeroplane",* Brussels, Belgium, 2008.

[7] Roskam J., "*Lessons Learned in Aircraft Design, the Devil Is in Details*", DARCoporation, Lawrence, Kansas USA, 978-1-884885-58-7, 2007.

[8] Joint Aviation Authorities, "*JAR-OPS 1: Commercial Air Transportation (Aeroplanes)",* Saturnusstraat, Holland, 2007.

[9] Campbell N.A.H., "*The Evolution of the Flight Data Analysis"*, Proc. Australian Society of Air Safety Investigators Conference, 2007.

[10] Krause S.S., "*Aircraft Safety, Accident Investigations, Analysis and Applications*", McGraw-Hill, New York, 2003, 0-07-140974-2.

[11] EASA, "*Certification Specifications for Normal, Utility, Aerobatics and Commuter Category Airplanes CS 23*", European Aviation Safety Agency, Cologne, Germany, 2003.

[12] Aeronautical Radio Incorporated, ARINC, "*MARK 33 Digital Information Transfer System, (DITS) Part 1, Functional Description, Electrical Interface, Label Assignments, Word Formats*", ARINC Specification 429 Part 1, ARINC Airlines Electronic Engineering Committee, Maryland USA, 2001.