DETERMINATION OF AIRBORNE RECORDED PARAMETERS FOR COMPREHENSIVE FLIGHT DATA MONITORING PROGRAM

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Abstract

The paper proposes an approach of extending safety assessment process to deal with airborne recorded parameters directly. It develops a general guideline and analysis process to determine the requirements for airborne recorded parameters. The approach is applicable for development of Comprehensive Flight Data Monitoring (CFDM) program, taking into account the need of various stakeholders. The research shows that determination of airborne recorded parameters is closely related with the process of aircraft development and safety assessment. Further, it suggests that, the method described by SAE ARP 4761 and the results of system safety analysis should play an important role in determining the requirements for airborne recorded parameters.

1 Introduction

At the development phase of an aircraft, through Development Assurance process defined in ARP4754[1] and ARP4761[2], levels of confidence can be established that development errors that can cause or contribute to identified Failure Conditions have been minimized with an appropriate level of rigor. Nevertheless, as aircraft are operated, the level of safety still need to be monitored, proved and maintained through a continuing process of monitoring service experience. Hence, Flight Data Monitoring (FDM) is deemed as one of key factors in achieving improved continued airworthiness levels and reducing operating cost. Therefore, various FDM type programs have been developed and widely deployed all over the aviation world [3-6].

To a great extent, the success of FDM type program depends upon a predetermined event set and airborne recorded parameters. An *event set* is a collection of events designed to measure all aspects of normal flight operations for a particular aircraft type at a particular operator. *Airborne recorded parameters* are defined here as the measurable variables that provide sensory data information of the aircraft and associated environment, which are recorded by the hardware and software onboard aircraft.

Unfortunately, ever since the FDM program was first implemented, the air carriers have long been puzzled by the following problems concerning event set and parameters:

- The event set for a particular fleet may be limited by the available parameters on the aircraft;
- What is being recorded is not exactly what is needed;
- Appropriate parameter data are not being recorded at the proper resolution;

In practice, there are no 'one size fits all' event sets though there is normally some core events that are fairly standard across operators. Depending on the aircraft type and Ground Data Replay and Analysis System (GDRAS) used, events selected to be included and analyzed in FDM can be simple or complex. To solve above-mentioned problems, event sets will usualy have to be fine-tuned after data from the first flights are analyzed. Fine-tuning event sets is a time-consuming and reiterative process. Failure to properly fine-tune the event sets can yield information of no use to stakeholders or worse, data unreliable and invalid. On the other hand, once the aircraft type is certified, it is usually very difficult, or even impossible, to change faulty sensors modify Logical Frame Layouts (LFLs) for the purpose of obtaining needed parameters.

The underlying reasons for the problems are involved with the 'event-event' and 'event-parameter' relationships:

- For an operator, the FDM program for a particular aircraft type was usually not outlined and developed at the same time of aircraft development, resulting in 'out of joint' between FDM-needed event set and designer-concerned events;
- For an aircraft designer or manufacturer, the requirements for the airborne recorded parameters are usually determined following an 'bottom up' rather than 'top down' process at first, lacking of consideration at systematic and integrated relationship between events and airborne recorded parameters;
- ARP4761 gives an illustrated safety assessment process in a systematic way, and points out that safety requirement include monitoring requirements. As to the issue of parameter determination, it is not addressed by the current standard properly and systematically.

Therefore, a systematic process is needed, which establishes the requirements for airborne recorded parameters, taking into account of the need of FDM type program early at the stage of aircraft development. This paper presents a tentative work on this issue, aimed at the goal of 'Right information, to right people, at right time'.

2 Brief Description of CFDM Program

The CFDM Program is assumed to be outlined at the same time of a new aircraft development.

2.1 Definition and Characteristics of the CFDM Program

The Comprehensive Flight Data Monitoring (CFDM) program is a program to be used by various users with the help of objective airborne recorded data, which involves event analysis and the analysis of flight data on a routine basis on the Ground-based Data Replay and Analysis System (GDRAS) to reveal situations requiring corrective actions before problems occur. The information flow of CFDM program is illustrated in Figure 1 [5].

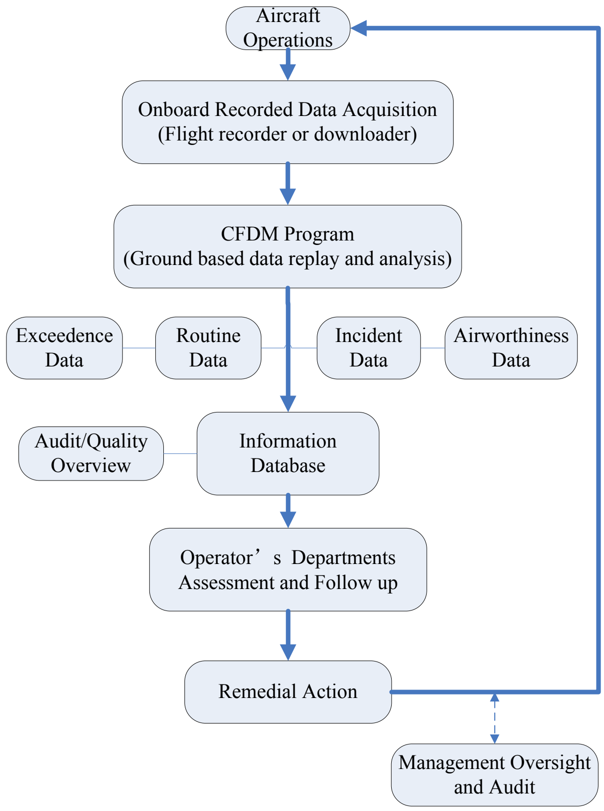

Fig. 1. System Outline - Information Flow

The focus of the FDM-type programs is to use as much as possible the objective data from airborne recorded parameters for decision making. Nevertheless, compared with current FDM-type programs, CFDM program has the following characteristics:

- *Proactive.* Being different from current FDM-type programs, which were usually developed or modified after delivery of aircraft, this program is outlined and developed at the same time of aircraft development. Hence, the top–level requirements of the stakeholders for airborne recorded parameters can be considered at the early stage, taking into account the needs of data capture over the duration of the flight. In other words, the development of FDM program and aircraft are considered in an integrated frame.

- *Multiple-purpose.* The anticipated users of CFDM program is multiple, who are provided with various data and analyses which are used for safety, operations, training, maintenance, engineering and other applications. In other words, the needs of various users are considered in an integrated frame.

2.2 Main Functions of CFDM Program

Typically, FDM-type programs are perceived as resources for monitoring safety of the aircraft. Whereas as mentioned above, CFDM program is of multiple-purpose, which main functions are as follows:

- Identify and correct (or mitigate) performance or airworthiness problems before they compromise safety;
- Improve flight crew performance and decision support;
- Enhance aircrew training and operating procedures, air traffic control (ATC) procedures, and aircraft operations, maintenance, and design;
- Perform trend analyses to identify problems, implement and evaluate corrective actions, and assess performance over time;
- Assist condition-based maintenance and logistics support.

2.3 Core Functions of Airborne Recorded Parameters

Airborne parameters data can be used by the various users in different way depending on their own objectives and operation procedures. Regardless of the way airborne data are used, experience and analysis have shown that the core functions are relatively stable, which define the need for aircraft recording capability, airborne recorded parameters, GDRAS hardware and software capabilities. The core functions of airborne recorded data can be divided into the following categories:

- Flight operational quality monitoring;
- Structural integrity monitoring;
- Fault diagnostics；
- Performance and life monitoring;
- Configuration management.

3 Methodology

3.1 Requirement Engineering

This issue falls into the category of Requirement Engineering, which addresses USER-CENTRED requirements for airborne recorded parameters as objects all along aircraft and CFDM program development process, and focuses on defining customer needs and required functionality of comprehensive monitoring early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the wide-ranging problems and constraints concerned. The whole research process will be conducted under the guideline of Requirement Engineering (System Engineering Approach), which is illustrated in Figure 2 [7].

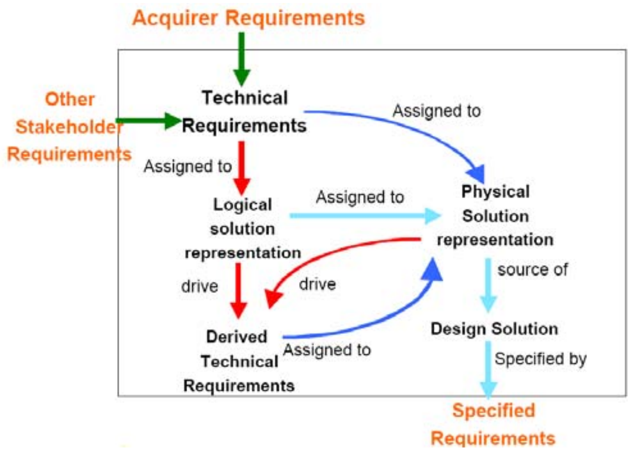

Fig. 2. Requirements Flowchart

Among USER-CENTRED requirements, safety requirements for aircraft, system, and item level are the core of acquirer requirements. Besides, other stakeholders' requirements should also be considered.

3.2 Safety Assessment Process

The safety assessment process is used by the designer and manufacturer to show compliance with certification requirements (e.g. 14CFR/CS Parts 25, section 1309) and in meeting operator's own internal safety standards. The primary safety assessment processes are detailed in ARP 4761 and are summarized at the right part of Figure 3.

The process starts with aircraft and system functional hazard assessment (FHA) where the system failures and combinations of system failures that would prevent safe flight are defined. These system failures are then used as top-level events in a structured analysis, often using fault trees, that examines how equipment and component failure can lead to the top-level failures in the preliminary system safety assessment (PSSA). As more detail is known about the system design, failure rates for the equipment and components are introduced into the lower levels of the fault tree. These rates are found using historical data, failure modes and effect analysis (FMEA), and other means. With these failure rates and Boolean algebra, the failure probabilities of the top-level events are calculated; this is the system safety Assessment (SSA). Along with the SSA, a common cause analysis (CCA) is completed to show the independence of redundant systems. This addresses the need to demonstrate that additional failures are extremely improbable.

Through analyzing the processes, we found that, the process in ARP 4754, and associated guidance in ARP 4761 mainly focuses on safety of technical systems. However, the top down iterative approach from aircraft level downwards hereinto is key to initiating the processes, and the results of analysis, especially the aircraft and system level FHA results (considering the environmental and emergency/abnormal configuration) of failures conditions and its severities, as 'by-products', are very important inputs for determining requirements of airborne recorded parameters.

3.3 Guidelines for Research Process

To identify requirements for airborne recorded parameters which will guide further development of the design, the basic guidelines of research process are determined as follows：

- As a kind of derived requirements from safety assessment processes, the basic requirements for airborne recorded parameters are outlined along the decomposition process of qualitative functional and safety requirements defined in ARP4761;
- As more detail is known about the system design, the basic requirements are modified and updated by analyzing historical data, reviewing regulatory guidance material, using previous design experience;
- Combined with iterative analysis and related tests, the parameters are finalized before certification.

The left part of Figure 3 diagrams a process for determination of onboard recorded parameters and how this process relates to safety assessment process, both being inherent parts of aircraft development process.

4 Research Process

Determination of airborne recorded parameters is directly related to aircraft system development process and safety assessment process, and follows a 'top-down' procedure, mainly including identification of events, identification of parameters, allocation of parameters, and determination of requirements for recording interval and accuracy.

4.1 Identification of Events

When establishing the CFDM program, identification of events concerned should be a starting point. Events represent the conditions to be tracked and monitored and are based on the airborne recorded parameters available on the aircraft. There is normally a set of core events that cover the main areas of interest that are fairly standard across operators. Nevertheless, the event list should be suitable for the specific operator and aircraft type.

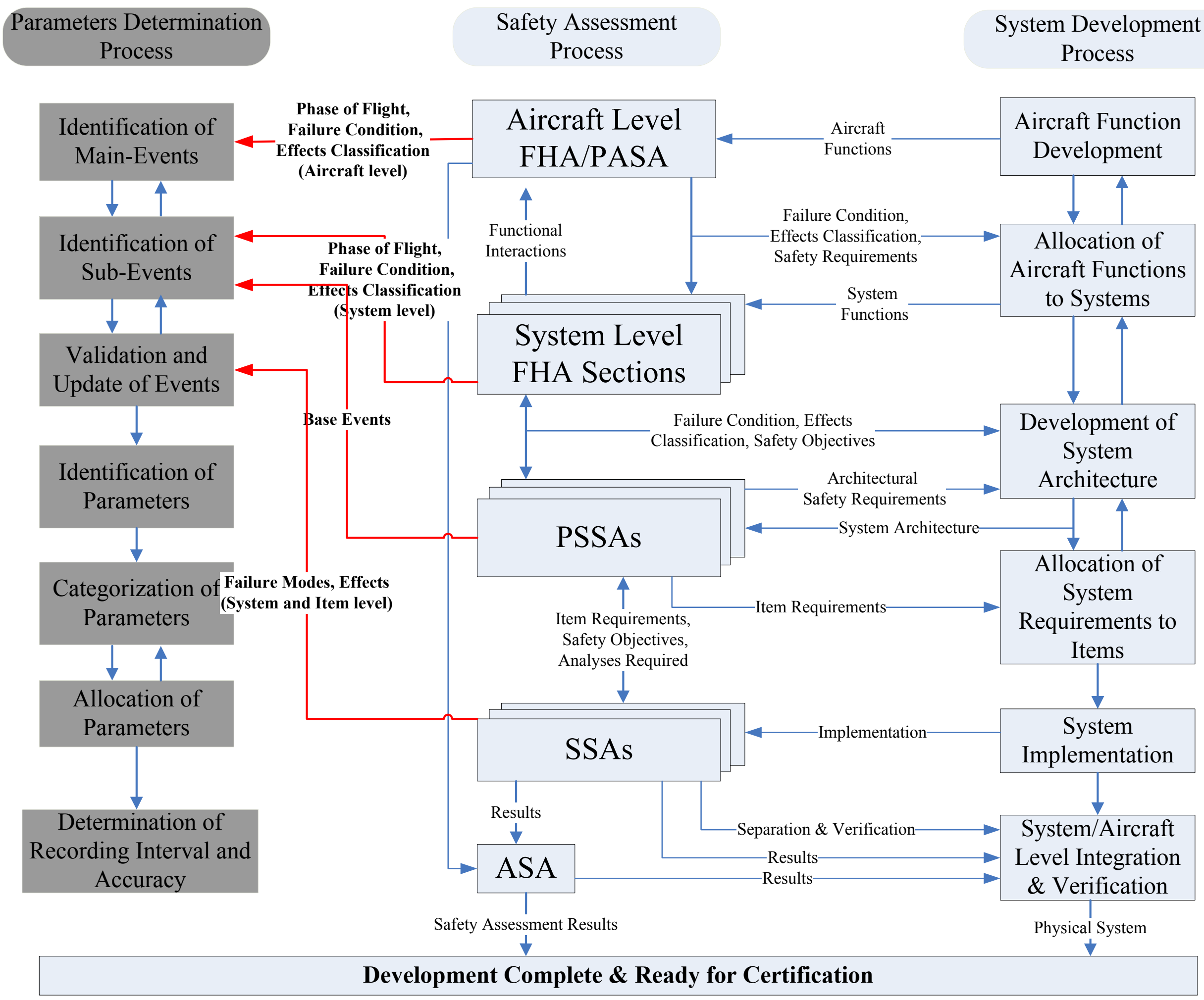

Fig. 3. The Process for Determination of Airborne Recorded Parameters

4.1.1 Identification of Main-Events

The aircraft level FHA is a high level, qualitative, systematic and comprehensive assessment of the basic functions of the aircraft to identify and classify failure conditions of those functions according to their severity.
The initial goal in conducting aircraft level FHA is to establish the safety requirements that an aircraft must meet. However, the aircraft level FHA and associated aircraft fault tree give a preliminary set of failure conditions along with the rationale for its severity classification, including failure conditions.
Extending aircraft level FHA for identification of events, we obtain *failure conditions* as main-events. Whereas *phase of flight*, *severity classification* and other related factors are used for determining the event-triggers later to be monitored in CFDM program.

4.1.2 Identification of Sub-Events

The system level FHA is also a qualitative assessment and considers a failure or combination of system failures that affect an aircraft function. Moreover, the PSSA identifies possible contributing factors leading to *significant* failure conditions identified in the system level FHA. PSSA may be either qualitative or quantitative. There can be more than one level of PSSA, from system level to item level.
The initial goal in conducting system level FHA and various PSSAs is to complete the failure conditions list, get derived safety requirements

and establish more detailed lower level safety requirements.
Extending system level FHA and qualitative PSSAs for identification of events, we obtain *base events* of the PSSA fault tree as sub-events to be monitored in CFDM program. (The extent of analysis is extended to Class Ⅳ events)

4.1.3 Validation and Update of Events

For each system analyzed, the SSA summarizes all *significant* failure conditions and their effects on the aircraft and to show compliance with the safety requirements. The results of FMEA are usually used to support the other analysis techniques of the SSA process such as Fault Tree Analysis (FTA). The FMEA must account for *all* safety related effects and any other effects identified by the requirements. The methods of analysis used may be either qualitative or quantitative. The analysis level may be functional or piece-part, and a functional FMEA may be performed at any indenture level.
Here, various *failure modes* and *effects* of Line Replaceable Unit (LRU) and Shop Replaceable Unit (SRU) levels from qualitative functional FMEAs of various indenture levels are used for validation and update of events to be monitored in CFDM program. At the same time, the results can also be used to determine the detection method (if any) for each failure mode, and establish the airborne recorded parameters.

4.1.4 Severity Classification of Events

Based on the method of failure condition severity classification which is defined in ARP4761, the events are classified into 4 levels according to severity of potential effects (‘no safety effect’ level not included):

- Catastrophic (Class Ⅰ) — Event which prevent continued safe flight and landing;
- Hazardous (Class Ⅱ) — Event which result in large reduction of safety margins or functional capabilities, higher workload or physical distress such that the crew could not be relied upon to perform tasks accurately or completely, adverse effects upon occupants;
- Major (Class Ⅲ) — Event which result in significant reduction of safety margins or functional capabilities, significant increase of crew workload or in conditions impairing crew efficiency, some discomfort to occupants;
- Minor (Class Ⅳ) — Event which result in slight reduction of safety margins, slight increase of crew workload, some inconvenience to occupants.

The events of class Ⅰ and Ⅱ should be assigned a event marker onboard aircraft. It should be noted that, when assigning levels to an event, consideration is given to compliance with Authority regulations, aircraft limitations, company policies and procedures, and past operational experience or lessons.

4.2 Identification of Parameters

A parameter is a measurable variable that provides information regarding the event. The relationship of parameters to events is shown in Figure 4 [7].

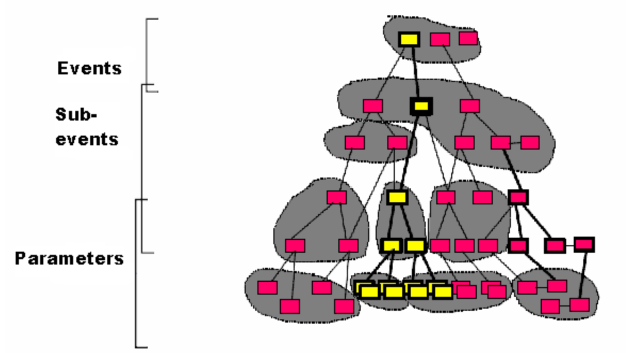

Fig. 4. Relationship of Parameters to Events

There are three principles to be noted here:

- One event may corresponds to various parameters, and one parameter may be used as a factor to define different events;
- Some parameters regarding events are derived, meaning they are not directly measured by sensors in the aircraft, but are calculated as part of the processing done by the analysis software;
- Under some circumstances, an event can also be considered as a derived parameter.

Based on above-mentioned principles, the parameters can be pre-identified from main-events or sub-events.

4.2.1 Grouping by Function

As the 'raw parameters' are directly captured or derived from different main-events and sub-events, duplication and nonconformity among them are inevitable. Therefore, the 'raw parameters' should be reasonably grouped to form different parameter categories according to the functions and the events to be defined. Generally, they can be categorized into the following 10 groups:

- Recorder, system and task setting;
- Actual aircraft aerodynamics;
- Aircraft environment;
- Actual configurations of flight control surfaces;
- Actual operating condition of power plant;
- Aircrew control input;
- Status information of airborne systems;
- Warning, advisory and reporting;
- Flight phase;
- Event marker.

4.2.2 Categorization by Importance Level

According to the severity of corresponding events, the importance levels of parameters are categorized into the following three groups:

- High (Class A) — Parameter which corresponds to the events of Class Ⅰ and Ⅱ;
- Medium (Class B) — Parameter which corresponds to the events of Class Ⅲ;
- Low (Class C) — Parameter which corresponds to the events of Class Ⅳ.

If a parameter corresponds to multiple events with different severity levels, then its importance level is decided by the event with the highest severity level.

4.3 Allocation of Parameters

The issue of allocation will answer the questions of where to record, when and where to process the parameters.

4.3.1 Recording Equipments and/or Media

According to various purposes such as for aircrew operation, accident investigation, flight operation monitoring, maintenance, air traffic control, etc., the parameters can be allocated to different recording equipments and/or media, including mandatory Flight Data Recorders (FDR, or 'black box'), Quick Access Recorders (QARs), and Central Maintenance System (CMS), etc.

As to recording equipments and/or media, we recommend the parameters are allocated as follows:

- FDR — Parameters of importance level A;.
- CMS — Parameters of importance level A, B;
- QARs — Parameters of importance level A, B and C.

At present, only for FDR the minimum parameters list is limited by ED-112[8], PART 121 [9] and other regulatory documents, which should be cross-referenced.

4.3.2 Occasion of Processing

The recorded data may be processed entirely by a ground station or processed on-board the aircraft using complex equipment. With the introduction of CMS and Aircraft Communication and Reporting System (ACARS), the added on-board complexity offers some attractive benefits such as reduced time to identify problems, retrieval process simplification, and flexibility in program modifications. However, on the other hand, the onboard processing ability will cost more money and time for airworthiness certification. Ground station still has its advantage for performing complex processing with relatively cheaper total cost of hardware and software, besides owning large quantity of historical data for trending analysis. So the better way is to use on-board analysis as the trigger mechanism for a quick or immediate action, and download all necessary data recorded onboard for ground analysis.

As to occasion of processing, we recommend the parameters are allocated as follows:

- Cockpit — Parameters with importance level of class A;
- ACARS — Part of parameters with importance level of class A and event marker;
- GDRAS — Parameters with importance levels of class A, B and C.

4.4 Determination of Recording Interval and Accuracy

For the same parameter corresponding to different events, the requirements for its recording interval and accuracy may be different in order to define the event adequately, which mainly depend on its importance level. There are three basic principles to be considered here:

- The more important a parameter, the shorter recording interval and higher accuracy is required for it;
- A relatively shorter recording interval for corresponding parameters is required for the key flight phases such as take-off and approaching, whereas the same parameters may be recorded in a longer interval or even in an intermittent way for cruising phase;
- If possible, in case of 'event marker' for significant events, the recording interval should be shortened automatically afterwards.

Based on above-mentioned principles, the recording interval and accuracy of parameters are determined by considering the severest conditions.

4.5 Summary of Parameter Determination

Space does not permit the inclusion of a detailed example, but the key related elements are summarized in Table 1.

It is worthy to note:

- As the development process and safety assessment process, the process of parameter determination is also iterative in nature and becomes more defined and fixed as the system evolves;
- To determine the Recording Interval and Accuracy of a parameter, other factors has to be taken into consideration, such as the ability of recording and processing equipments, the accuracy of sensors, and the capacity of storage media;
- When the list of airborne recorded parameters and related requirements has been produced, it may be worth checking how the list compares with lists from previous similar projects as an extra aid to guard against overlooking some of the less encountered parameters.

Table 1. Key Elements for Parameters Determination

Element	Source	Note
Main-event	Aircraft level FHA	Failure conditions
Phase of flight	Aircraft level FHA	
Severity classification	Aircraft level FHA	
Sub-event……	System level FHA	Failure conditions
……	PSSAs	Base events
……	FMEAs	Failure modes & effects
Parameter	Main-events and Sub-events	
Group of Parameter	Primary events to be defined	
Importance level	Severity classification	
Occasion of Processing	Severity classification/ Event marker	Cockpit/ ACARS/ GDRAS
Recording Interval	Importance level/ Phase of flight/ Event marker	
Recording accuracy	Importance level/ Phase of flight/ Event marker	

5 Conclusion and Future Work

Based on ARP4754 and ARP4761, we propose a tentative approach and outline a process to determine requirements for airborne recorded parameters, which is an extension to the safety assessment process. Through our work, we drew the following conclusions:

- It is necessary to define requirements for airborne recorded parameters from the stakeholders' view in the early stage of aircraft development. FDM program for an aircraft type should be outlined and developed integrated and at the same time with aircraft development, building harmonization between FDM-needed event set and designer-concerned events.

- The requirements for the airborne recorded parameters should be determined following an 'top down' process at first, taking into account the systematic and integrated relationship between events and airborne recorded parameters.
- The process of determination of airborne recorded parameters is closely related with that of aircraft system development and safety assessment, and should act as one of design drivers, especially to ensure that the architecture design takes into account airborne parameters to be recorded. The issue of parameters can be addressed more directly and in detail for ARP4754 and ARP4761.

The process builds on existing techniques. Nevertheless, there is several future works to be addressed before the full benefits of this approach can be realized:

- The validity and utility of this work is strongly dependent on the quality of the underlying design process and safety analysis process, and the guidelines need to be updated under related suggestions;
- By our practice, developing a list of events from scratch can be extremely time-consuming, particularly during event validation, so we hope to see more appropriate tools, such as model-base safety analysis [10], adding value to these activities.

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