ARINC 573/717, 767 and 647A: The Logical Choice for Maintenance Recording And IVHM Interface Control or Frame Updates

Michael D. Sudolsky[1]

[1] Michael D. Sudolsky
The Boeing Company
5301 Bolsa Ave
Mail Code 110-SK55
Huntington Beach, CA 92647-2099
562-797-2709
michael.d.sudolsky@boeing.com

ABSTRACT

Recorder utilization of data formatting standards enables abundant life-cycle savings, and this is addressed herein. The ARINC Standards cited in this paper's title (i.e., ARINC 573/717, 767 and 647A) have, in large part, been developed to facilitate Flight Data Recorder (FDR) mandatory data capture requirements. These standards foster important equipment interchangeability or interoperability requirements, and, since they are also applicable to Aircraft Condition Monitoring System (ACMS) recording, critical Integrated Vehicle Health Management (IVHM) applications are supported. The Background material includes ARINC 647A Flight Recorder Electronic Documentation (FRED) definitions of 573/717 subframe and 767 frame recording, and "sets the stage" for following topics; important IVHM operations require the ability to continually improve or update recording, and FRED use as an IVHM Interface can indeed foster continual ACMS improvement/maturation. Additionally, the extension of these standards to any avionics controller or system interface lends itself to improved troubleshooting methods. This enhanced use of ARINC Standards is a crucial element of Health Ready Subsystem implementation, being prototyped in the Boeing IVHM Operational Environment.[1]

Figure 1: Boeing 737, 757, and 767

1 INTRODUCTION

Eight sections follow: Background, ARINC 573/717 Subframes, ARINC 767 Frames, Flight Recorder Electronic Documentation (FRED) Subframe/Frame Definitions, Enhanced Standard Usage, Health Ready Subsystem (HRS) Specification usage of the enhancements, IVHM Prototyping and a Summary.

Following an ARINC Standard overview, the Background describes Regulatory Authority's mandatory versus non-mandatory functionality and associated implementation information – "setting the stage" for following ARINC specific information.

The ARINC 573/717 Subframe information of section 3 focuses on the critical ARINC Standard material relevant to Integrated Vehicle Health Management (IVHM[i]). Subframe based recording has been used for over 40 years, and many associated Commercial-Off-The-Shelf (COTS) data processing & reporting tools exist that can expedite IVHM deployment and mitigate risks.

Section 4 describes ARINC 767 frames, and draws comparisons to subframe based recording.

Flight Recorder Electronic Documentation (FRED, or ARINC 647A) defines ARINC 573/717 subframes or 767 frames, and key FRED implementation features are also described in Section 5.

Section 6 covers ARINC Standard enhancements that further aid IVHM operations. Key features of FRED support rapid Aircraft Condition Monitoring System (ACMS) updates to subframe or frame recording enabling system troubleshooting improvements, especially when used in conjunction with Boeing On-Line Diagnostic Reporting (BOLDR®[2]) techniques. (Note: the PHM 2009 peer reviews of this paper stressed that the most important information commenced with this section, thus the reader may desire initiating their review with this ARINC Standard enhancement material.)

The use of these enhancements is a key part of Boeing Research and Technology IVHM Health Ready Subsystem (HRS) Interface requirements covered in section 7. Utilization of HRS Procurement Specification (PS), Statement of Work (SOW) and Supplier Data Requirements List (SDRL) documents helps to insure receipt of "health ready" delivered subsystems for Boeing vehicles.

Boeing introduced an IVHM Operational Environment to support business unit risk mitigation of health management deployments. This mitigation and HRS IVHM Interface use is described in Section 8.

2 BACKGROUND

ARINC Standards specify the air transport avionics equipment and systems used by more than 10,000 commercial aircraft worldwide[3]. They aid development of equipment designs so standardization of physical and electrical characteristics can result without detriment to engineering initiative. A recent technical publication put it this way: "for any innovative technology to move from the research phase to a market environment, industrial standards must be set… "[ii]. Very common ARINC Standards cover important specifications for electronic unit sizes, connectors and wiring. The FDR Standards that define data stream operation and content are reviewed using the following three figures depicting representative hardware architectures.

In the 1970's, as data collection progressed from single "strip-chart" type-recording to the multiplexing of analog and discrete signals, ARINC 573[4] was developed. This standard specified the Figure 2 "one-way" data stream operation that multiplexed the input signals for either the Flight Data Recorder (FDR, also referred to as the "crash-box" in newspaper publications) or Quick Access Recorder (QAR). Note that ARINC 573 contained many additional requirements for mandatory FDR data collection (e.g., pin-out, connector type and unit size).

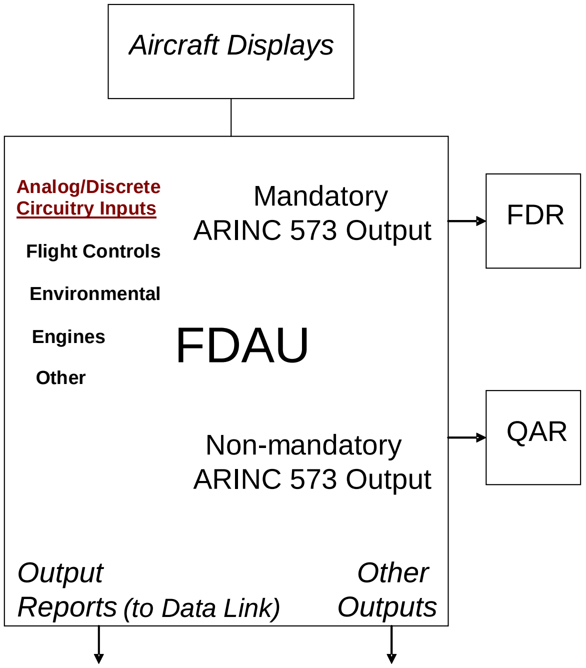

Figure 2: Legacy ARINC 573 Implementations

As can also be seen in Figure 2 the Flight Data Acquisition Unit (FDAU) Line-Replaceable Unit (LRU) acts as a "traffic-cop", directing real-time data from various aircraft systems to mandatory FDR and non-mandatory QAR functions. Note: Data Management Unit (DMU) is another name synonymous with FDAU non-mandatory functions.

The QAR[5] was also introduced in the 1970's for improved aircraft maintenance, and analog four-track cassettes were used to store the Figure 2 ARINC 573 non-mandatory or ACMS data. The italicized figure elements are additional FDAU capabilities: interfacing with Aircraft Displays, Data Link Reports[iii], and Other Outputs.

In the 1980's the need to recognize the progression from primarily analog signals to ubiquitous digital data bus technology led to updating ARINC 573, and the ARINC 717 standard was developed. The complete ARINC 573 FDAU, with access to all of the aircraft's data busses and analog/discrete signals was combined with the QAR and is called an ARINC 717 Digital Flight Data Acquisition Unit (DFDAU) as shown in Figure 3. (The top five listed figure inputs are ARINC

[2] BOLDR® is a registered trademark of Boeing.
[3] Reference https://www.arinc.com/cf/store/index.cfm .
[4] MARK 2 Aircraft Integrated Data System, published Dec 2, 1974.
[5] ARINC 591 is used to define QAR operations.

429 based busses for Figure 1 737, 757, and 767 airplanes[6].) A significant need emerged when the DFDAU was developed: the desire by airlines to have the highest-possible reliability for mission-critical LRU functions, amplified by the need for Extended-Range Operations with Two-Engine Airplanes using longer range twin jets. Thus, mandatory functions are partitioned from ACMS non-mandatory features[iv] so ACMS failures do not need to affect dispatch reliability. (Three different certified DFDAU's exist: the Digital Flight Data Management Unit (DFDMU[7]), Flight Data Acquisition and Management System (FDAMS[8]), and another equivalent device[9].)

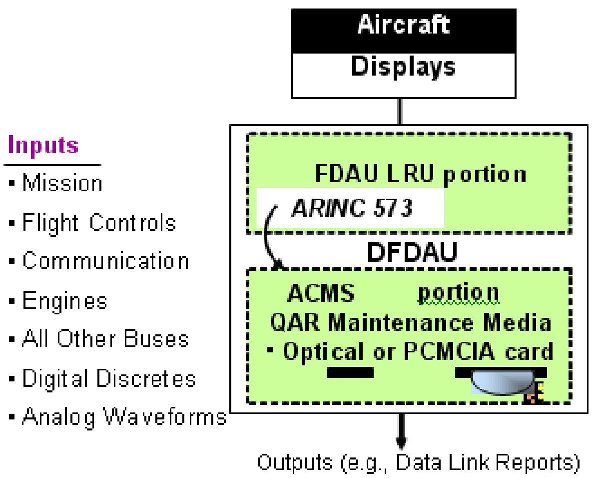

Figure 3: DFDAU and ACMS Partitioning

In the 1990's, digital recording media became very popular since the price per megabyte (MB) of storage decreased rapidly. Figure 3 DFDAU media densities in the range of 100 to 1,000 MB were introduced, and are still commonly used today since Flight Operational Quality Assurance (FOQA[v]), and Engine Condition Monitoring (ECM) requirements are complied with (i.e., ACMS media does not fill even if multiple flights transpire between removals). Since high density media usually precludes the problem of possible data overflow, ACMS recording can either stop or overwrite "newest over the oldest" if media-full does occur (mandatory recording always overwrites). (Note: larger media density in the 10 to 100 GB range has been used for non-ARINC Standard file DFDAU recording, such as for flight testing[10] or other needs.) Also, the Figure 2 and 3 ACMS functionality can be encapsulated within other hardware, called Aircraft Condition Monitoring Function (ACMF) on the 777 airplane.

This decade, ARINC 573 recorded data from either the FDAU or DFDAU can be received automatically using a Figure 4 Wireless Ground Link QAR (WGL-QAR[11]). The data is transmitted (using encryption and compression) with multiple WGL-QAR cell phones and the internet for user receipt, avoiding any manual media handling operations. ("Gate-link" is another similar device.)

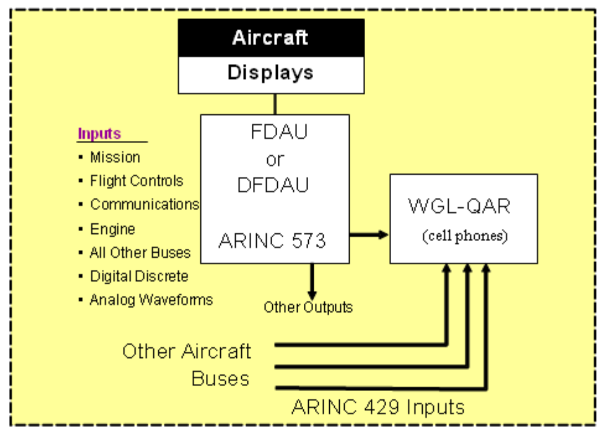

Figure 4: WGL-QAR ACMS Implementation

Also this decade, ARINC 767 and 647A have been developed and will be first utilized on the 787 airplane by Boeing. ARINC 767 has a frame for every recording rate, and is covered further in section 4. FRED is used to define ARINC 573/717 or 767 recording as explained in section 5.

3 ARINC 573/717 SUBFRAMES

In terms of raw data transmission within the one-way recorded data stream, ARINC 573 and 717 are equivalent and the term ARINC 573/717 is utilized for subframe descriptions as shown in Figure 5.

Map with "x2" Data Rate

Word No:	1	2	3	4	…	64	…	128
SF#1:	247	ofctr	ID data	E1 EGT		E1 BP		E1 BP
SF#2:	5B8	pos sel a	(super-	E1 EGT		E1 BP		E1 BP
SF#3:	A47	SW sel	frame	E1 EGT		E1 BP		E1 BP
SF#4:	DB8	pos sel a	based)	E1 EGT		E1 BP		E1 BP

[6] Same DFDAU used on 737/757/767, and an airline MD-11 wiring change accommodated use of the same unit on these tri-jet airplanes too.
[7] Teledyne Controls manufactures the top-selling DFDMU that includes MIL-STD-1553 data bus acquisition.
[8] Honeywell is a leading manufacturer within the avionics industry.
[9] Sagem Avionics Inc. manufacturers a DFDAU that can be used on 737, 757 or 767 aircraft.

[10] Data logging of all bus data is common for flight test, and a portion of the large available density can be regularly used for this purpose.
[11] WGL-QAR supplied by Teledyne Controls.

Figure 5: ARINC 573/717 Recorded Data Format

The ARINC 573/717 frame consists of four subframes shown as SF#1 to SF#4 above. Each subframe has the same number of words, and every word contains 12 bits of data. The number of words used per subframe is a selectable configuration value that can vary between different airplanes. The selected value should not vary while recording and is usually set the same for a specific fleet.

The subframes are recorded in sequence from one through four, and then start at one again for steady recording operation. One second is used for each subframe recording. There is a four second total time for a full frame, consisting of the four Figure 5 subframes, to be recorded.

The number of 12-bit words within a subframe equals the data rate. For example, an ACMS subframe can contain 64 to 1,024 words per second (wps), often called "x1" to "x16", respectively (Figure 5 contains "x2", and note that early ARINC 573 use contained 32 words or a "x.5" rate). The permissible rates are usually even increments of the 64 wps subframe size (i.e., "x4", "x6"… "x14" are other allowable rates), and the most common is "x4" or 256 wps per the mandatory 737 DFDAU FDR rate and frequent QAR use.

Recording rates equal to and faster then 1 Hz are depicted above. Word 4 Engine position #1 Exhaust Gas Temperature (E1 EGT) is acquired once per subframe for the 1 Hz Figure 5 recording rate. Faster rates are often acquired using two different methods. The easiest ACMS method is to occupy consecutive words for high rate recording (e.g., a 12-bit word size at 32 Hz will utilize 32 consecutive subframe words). However, to easier use many data replay tools the Mandatory Frame practice of even subframe separation or scheduling within "x2" or higher data rates should be used. Thus, if the subframe word count is 128, then a 2 Hz parameter would use a separation of 128/2 or 64 words from one value to the next. For example, Engine position #1 Burner Pressure (E1 BP) is shown being recorded in Word 64 and 128 for a 2 Hz rate (with a "x1" E1 BP separation), and, 16 Hz parameter rates can be recorded every 64 subframe words within a "x16" data rate.

Parameter recording rates less then 1 Hz and ARINC 573/717 synchronization and are also illustrated in Figure 5. Word #2 contains Position Select A (pos sel a) every other subframe supporting a ½ Hz recording rate. The word 1 synch 247, 5B8, A47 and DB8 (hexadecimal) values are recorded once per frame or at ¼ Hz rates[12] (steadily recorded data stream assumed[13]). Word 2 Output Frame Counter (ofctr) and switch selection (SW sel) are also shown recorded at ¼ Hz. Even slower rates can be captured using a "superframe[14] approach", and as shown in the figure, word 3 can be used to record Engine S/N (ESN) and other Identification (ID) data per frame multiples determined from the ofctr (e.g., every 64 subframes or 16 ofctr increments ESN's can be recorded with different ID-type data captured in word 3 for the other 63 seconds of superframe data).

A critical feature of recording using an ARINC Standard: ample COTS tool availability. Additionally, 40 years of ARINC 573/717 use has led to many feature improvements along with very mature and reliable tools. Many ARINC 573/717 data processing and reporting tools exist, and each has inherent advantages. The Engineering community often uses a tool with versatile and precise conversion algorithms[15]. A recent tool entrant[16] has features including user-friendliness and animation. DFDAU suppliers have frame processing and reporting tools with features that include ACMS update integration, and legacy system support. Other providers[17] [18] have had success in supporting regulatory agency analysis requirements, & graphing[19] needs. COTS relational database tools have also shown reporting speed and "ad hoc" analysis advantages, especially within the technical community of specific programs[vi]. Often, from the same aircraft ARINC 573/717 data, several of these tools are used throughout the vehicle's support system. Boeing is also performing research[vii] wherein the same database is used for any aircraft data, including subframe recordings, and other related uses.

4 ARINC 767 FRAMES

The ARINC 767 Frame[20] can record data at any desired frequency and consists of Header, Parameter and Trailer sections as analyzed below. The standard also

[12] Figure 2 subframes have contained multiple synch's to aid bit-shift data synchronization; legacy FDAU power-interruptions caused QAR word bits to be spread over two, & synchronization puts them back into one word.

[13] Old analog QAR's often recorded in an "event-trigger" mode (e.g., steady during take-off and off in cruise) to preserve use of limited tape media.

[14] ARINC 647 contains a detailed description. 737 NG rates include 1/8, 1/16, and 1/64 for 8, 4 and 1 samples per superframe, respectively.

[15] Maintenance Analysis & Ground Station (MAGS) by AACO Inc.

[16] Aerobytes Ltd - http://www.aerobytes.co.uk/ .

[17] Austin Digital Event Measurement System (EMS).

[18] Avionica, AVSCAN - http://avionica.com/products_gs_avscan.html .

[19] Flightscape, Insight - http://www.flightscape.com/products/fdm.php .

[20] The USAF and Smiths Aerospace have used Frame recording for a number of US and foreign military recorders.

notes that for a given implementation the sections may differ, and the FRED file is used to specify these variations.

The Header contains five fields and commences with a unique 16 bit or two byte synchronization pattern of EB90[21] hexadecimal. Following the sync, are Frame Length, Time Stamp and Frame Type/ID attributes. The Length specifies the total size of the frame and can be up to 2,048 bytes (including header and trailer). The time stamp is a "c time" field of 32 bits, and the 8-bit Frame Type can either be used for separate classifications or combined with the 1-byte Frame ID for identification purposes.

For a given Frame ID, the Parameters are recorded, and the necessary bits for each are used. If certain parameter rates result in the Frame Length to be exceeded, a second frame at the same rate is used (multiple frames are expected for the most common recording rate of 1 Hz).

The Frame Trailer again contains Header Frame Type/ID fields, and is used if difficulties existed in recording the frame; if a problem transpired in recording the Frame Header, the Trailer can be used to process the parameters.

The biggest 767 Frame difference versus ARINC 573/717 subframes is that any desired rate is used for a Frame versus the unique utilization of the four subframes for recording various parameter rates. Therefore the tedious process of scheduling and "fitting" parameters into a subframe is moot with 767 frames. This easier 767 method is underscored using Figure 5 parameters and straight-forward collection with five Frames. E1 BP, EGT, pos sel a, ofctr / SW sel, and superframe data can be captured using four periodic Frames at 2, 1, ½, ¼ Hz, and an event-triggered frame (e.g., at power-on), respectively. The ARINC 767 frames do require scheduling[22], but this is much easier versus "scheduling" all of the 573/717 parameters.

Similarities between ARINC 573/717 and 767 recording center on parameter collection for these "designed for bulk-recording" standards. "Packing" for 573/717 QAR Words and 767 Frames is used to record an even number of bytes: a QAR Word is recorded "packed" if only 1.5 Bytes are used when written to media, or four bits can be added so two bytes are used, and, 767 Frames expect added bits so a byte boundary is utilized. Additionally, both standards use synchronization words, have specific frame lengths[23], and can be defined using FRED.

5 FRED SUBFRAME/FRAME DEFINITIONS

Flight Recorder Electronic Documentation (FRED[24]) was developed to save time and effort associated with data frame determination in support of incident investigators[25]. FRED defines the content of 573/717 subframes or 767 frames; ARINC 647A specifies subframe or frame sizes and content for ARINC Standard recorded data (reference Figure 6).

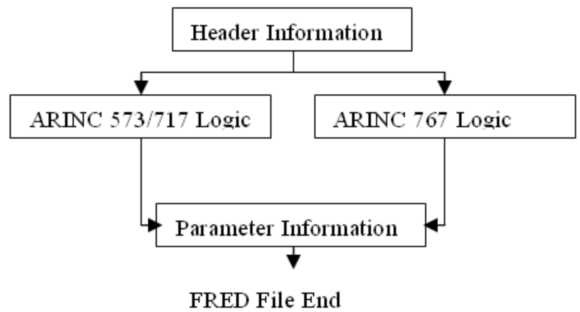

Figure 6: FRED Logic Overview

Important FRED terminology includes four following element types. Mandatory fields must be used (requires a non-zero value). A Necessary element is Mandatory when one of a possible group must be used (e.g., it is Necessary to have either a Subframe or Frame section in a FRED file). Optional fields indicate that the information is analytical, and could be used by more advanced data replay systems. Discretionary fields are documentary in nature and usually not processed by the analysis system. It is strongly suggested that Optional and Discretionary fields be used as often as possible.

Header Information

The FRED Header contains the same type of Mandatory and Discretionary information for both standards. There are six Mandatory items: ARINC spec version # (e.g., 647A-1), Revision number (for configuration management control), Date/Time of the FRED revision, Aircraft Manufacturer & Model, Source Documents, and Default Sign Convention[26].

[21] Hexadecimal EB90 = 1110101110010000 binary or 60,304 decimal.

[22] For three frames at 4, 2, and 1 Hz recording rates, using an 8 Hz schedule: tick #1 can be used for the 1 Hz frame, the even ticks for each of the 4 Hz frames, and tick #3 & #7 for 2 Hz frame (tick #5 unused).

[23] One ARINC 573/717 Frame size is equal to the subframe data rate multiplied by four.

[24] Smiths Aerospace is supplying a FRED based FDR for the 787 airplane.

[25] Reference http://www.arinc.com/aeec/projects/fred/ .

[26] "CRT+" for "Climbing Right Turns are Positive" is an example (each parameter can have a different sign convention versus the default).

The Discretionary or optional entries include Aircraft, Recorder & FDAU descriptive material, and, File Comments.

ARINC 573/717 Logic

FRED Subframe Information covers Figure 6 ARINC 573/717 Logic to create "x.5" to "x16" maps as discussed earlier. Five mandatory fields exist: Bits per word (usually equals 12 for 573/717), Data Rate (e.g., 32, 64, 128 or 1,024 wps), seconds per subframe (usually = 1), Subframes per Frame (4 for 573/717), and used Sync Pattern Sequence. If Subframe Information is not used ARINC 767 Logic must be.

ARINC 767 Logic

File/Frame Descriptions are used for describing the Figure 6 ARINC 767 Logic as described in the next two paragraphs.

Recorder File Description material contains three fields. One mandatory value is a listing of all the Frame Titles to identify each of the used ARINC 767 data frames. Recorder file name and fie size are optional fields within the File Description.

One Frame Description exists for each 767 data frame and it contains four mandatory fields: Frame ID, Title, Recording Type (scheduled or event-triggered) and Parameter List (name of each used parameter). A Necessary field exists for either scheduled or event-triggered frames and defines its steadily recorded rate or the condition that triggers the frame, respectively. Two Discretionary fields exist: Recording Phase (or "tick scheduling information"), and Comments.

Parameter Information

The final Figure 6 item before the end of the FRED file consists of "seven initial", Component or "Number of bits", Range, and "ten ending" values subsections as overviewed in the following four paragraphs.

There are two Mandatory fields within the seven initial Parameter Information elements: a unique name and modification date. Two optional items exists for parameter mnemonic and additional ID (e.g., manufacturer number). Necessary elements exist for sign convention (if different versus the default) and Units (while analog parameters like EGT always have units such as Degrees Centigrade "DegC", "off" / "on" discretes usually do not).

The next parameter subsection has Component Items or Number of Bits for subframe or frames, respectively. The Component Items define what QAR subframe, word number and bit numbers are used for recording the parameter. Besides these three mandatory component fields is an optional element covering acquisition time offset. Three necessary Component Item fields exist: Overlap Bits (used for a parameter within multiple QAR words and/or subframes) and two elements for superframe identification (if superframes are used). For ARINC 767 Frames there are no component items, and Number of Bits is used to define the amount of parameter bits utilized for frame recording.

Range Items start with a mandatory Raw Data Range field. Most often, this displays the "min/max" values for a parameter, but if more then one range is used then a discretionary Correlation Coefficient[27] is utilized. The next step for Range Item processing is to apply a data type (mandatory element specifying unsigned or signed binary, Binary Coded Decimal (BCD), IEEE Float or ASCII ISO #5). Then conversion items provide all the documentation necessary for converting raw data to Engineering Unit (EU) values. If BCD is used then a necessary definition element exists. Next, for linear conversions the necessary Polynomial Coefficient element is used and only the A0 and A1 terms are defined (specifying A2 or more terms results in higher order polynomial or non-linear conversions). Then necessary Table items exist for Integer-Real and Real-Real EU conversion. Necessary Predefined (e.g., Teledyne or Fairchild-F1000 Synchro equations) and Free-Text (if prior EU methods can not be utilized) fields complete the EU FRED options. The final Range Item is a Conversion to Text field, for example: weight-on-wheels discrete logic 0 and 1 values can be interpreted to "air" and "ground" textual representations, respectively.

There are no mandatory fields within the ten ending parameter elements. The first field is an optional Operating Range (often lower then the parameter range per physical and/or operational limits). Three more optional fields follow: accuracy (can differ per parameter ranges), Resolution (for linear parameters is the Least Significant Bit), and Transport Delay (or signal propagation delay, if known). Three discretionary fields follow: Sensor Type (e.g., synchro or strain gauge), Signal Type (such as AC volt ratio or shunt discrete), and Signal/Data Source (e.g., Flight Control Computer #1 or FCC#1). The final three elements are used for mapping parameters to various data busses (i.e., ARINC 429, AFDX network, or Multi-Transmitter Data).

The FRED file is read at run-time and defines the recorded data content – this introduces many IVHM opportunities as described next.

[27] Reference FAA Advisory Circular AC 20-141.

6 ENHANCED STANDARD USAGE FOR IVHM

Enhancements to the Standards covered in Sections 3 through 5 support dramatically improved IVHM operations, discussed using the following four subsections: ACMS/ACMF (ACMS/F) Recording & Reporting Overview, ACMS/F Recording FRED Updates, BOLDR® IVHM Interfaces and Life Cycle Advantages.

ACMS/F Recording & Reporting Overview

Figure 7 depicts ACMS Recorded data and associated FRED being either obtained using wireless techniques such as a WGL-QAR, or manually removed via PCMCIA Card or Optical media. After FRED is read by the Flight Operations Computer, it then performs ACMS/F recorded data processing. (Note: FRED file existence mitigates "configuration control risk" incumbent with ACMS updates of the following subsection.) Upon the completion of data processing by the Flight Operations Computer teammate reports are generated, and the displayed graph will be analyzed.

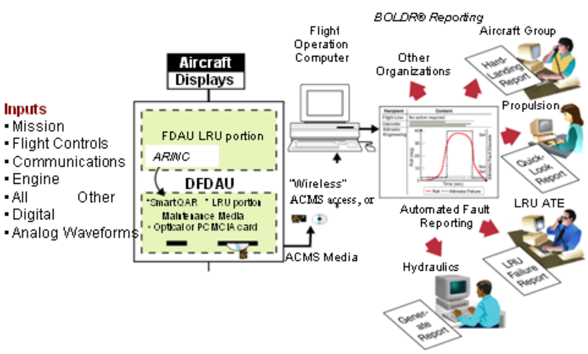

Figure 7: DFDAU ACMS Media & Reporting

The graph is expanded in Figure 8 and illustrates an altimeter fault discrete (black dashes versus right Y-axis) being set as the airplanes roll (red trace using left Y-axis) exceeds approximately 25 degrees. As the intensity of the altimeter radio waves reflected off the earth diminishes, eventual "height above terrain" information is lost and results in the altimeter fault setting.

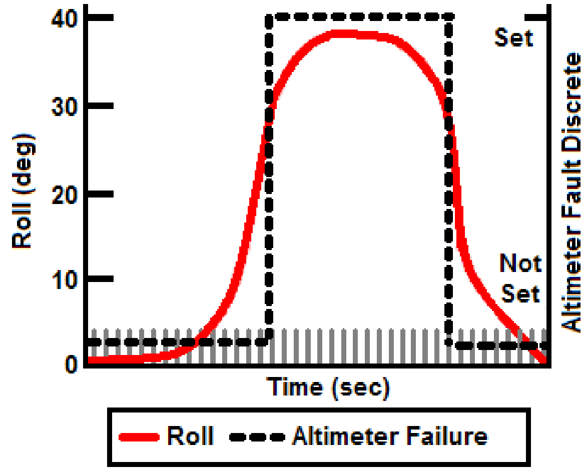

Figure 8: Graph of Roll versus Fault Discrete

Additional data such as location ("lat/long") or internal system parameters may also be desired for reporting. The following two subsections discuss recording additional parameters that are already available to the ACMS/F, and then extending the update technique to every system, respectively.

ACMS/F Recording FRED Updates

Following the review of recorded data as shown in Figures 7 and 8, teammates can stop performing chart analysis and "turn around in their seat[28]" to accomplish FRED Updates to ACMS Recording as illustrated in Figure 9. This update technique to ACMS Recording can be considered "Smart QAR" for its ability to adapt as circumstances require. Following paragraphs provide an example change, Figure insight including pertinent steps for implementing the ACMS update, and a FRED tool discussion.

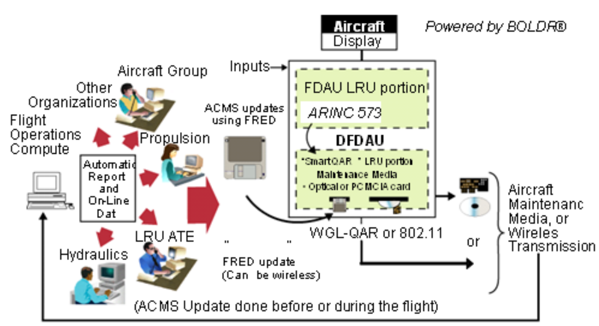

Figure 9: ACMS Recording Updates

28 In Figure 7 they are looking to the left for reporting analysis and now focused "in the opposite direction" for ACMS updates of Figure 9.

ACMS data reporting can always be improved, and to cite an example: the flight operations PC illustrated in Fig. 7 can report that two LRUs be removed, while only one has failed. This can result from an insufficient number of fault data parameters for an unexpected, or rare, failure condition. Thus, the lack of a recorded parameter at a sufficient rate[viii] can result in this dual LRU ambiguity, and yet, if this ambiguity is reported more frequently then expected, maintenance personnel can adapt to this challenge using Fig. 9 ACMS updates. The personnel are updating the ACMS/F using a FRED update to subsequent flight recording, supporting fault isolation of the prior two LRU ambiguities, and solving the challenge. For this model the maintenance recorder map would be updated to record the necessary data field at the higher rate, and the ACMS report improved by necessary reasoning modifications[ix]. Seven pertinent steps are used to accomplish this change:

1) A Teammate from the left side of Figure 9 is editing FRED Header, ARINC Logic and Parameter information for necessary comments, subframe or frame and parameter updates, respectively.
2) There are manual and wireless methods for transferring FRED from the organizational PC to airplane. The same ACMS Media that will be used for recording has the updated FRED (legacy applications required a separate drive for reading as shown in the figure). Since the update to the FRED file is a small size, Data Link[29], or, aforementioned Gatelink[30] or WGL-QAR can be used[31].
3) For manual media or wireless techniques performed on the ground: following ACMS/F initialization the change takes effect (the FRED file is read at "run-time" by the ACMS of the figure's DFDAU at power-on). An uplink can also be used[32].
4) The flight is performed (or continued, for Uplink use).
5) ACMS Recorded Data and FRED accessed (discussed in prior subsection).
6) FRED is utilized for data processing and reporting (reference section 5).
7) Prior steps repeated for another future change.

As mentioned earlier, the first Boeing airplane utilizing FRED is the 787 airplane. Since it is a new ARINC standard, equivalent ACMS/F updates are performed using tools supplied by ACMS suppliers or with the Ground Based Software Tool (GBST[33]) for ACMF. The use of these ACMS/F update tools result in functionally similar updates, while no FRED file exists (the tools can create specification files that define the recording, similar to FRED).

This subsection discussion assumed that the needed parameters were available to the ACMS/F, however, there are abundant signals within the Figure 7 input Systems / LRUs that are not available for making the "seven step update" since a costly and time intensive operational software change is usually required. (This is a significant problem and precludes ACMS/F update use for LRU troubleshooting.) The next subsection addresses this, extending ACMS/F updates to these input systems.

BOLDR® IVHM Interfaces

BOLDR® supports systematic acquisition of data that is often deemed "too voluminous" to record[x]. The data bus required for LRU operational communication often does not support the transmission of all internal (IVHM self-test) data. The addition of another data bus solely for this purpose is often deemed impractical (per cost, weight and other issues), and, BOLDR® provides operational data bus "optimization" (e.g., overlay use designating subassembly failure conditions coincident with the units summary failure annunciation).

A simplified BOLDR® example will utilize an electronic unit with summary failure conditions for Power Supply Voltages, Processor Task Rates and other self-test functions. The available unused/spare[34] bus bandwidth supports transmitting a coded overlay with the results of one self-test function (i.e., each function will utilize available "spare" communication bus bandwidth, thus, all self-test function data can not be transmitted at the same time). As shown italicized within Figure 10, when the BOLDR® control word is equal to 1 or 2, Voltage Values or Task Rate data are transmitted, respectively. FRED would utilize an event-triggered frame for ARINC 767 recording of either condition, and for ARINC 573/717 the figure's Control Words overlay bits dictate what the Word 300 to 340 parameters are (the other shown words utilize recording rate techniques discussed earlier). Additional event-triggered frames or overlay values can be used for exciting diagnostic strategies including boundary scan, ground readiness testing, and structural assessment "very high rate data" results.

---

[29] Using an ACARS Uplink, for example.

[30] Can be used in conjunction with Airborne Data Loader.

[31] When ACMS/F updates are used in conjunction with active troubleshooting, the Data Link and WGL-QAR implementations are expected.

[32] ACMS/F recording update via uplink is being researched by Boeing.

[33] GBST updates used for Boeing's 777 and 747-400 ACMF.

[34] Spare requirements often dictate approximately 30% bus bandwidth allocation for future growth – this can be utilized until such future time.

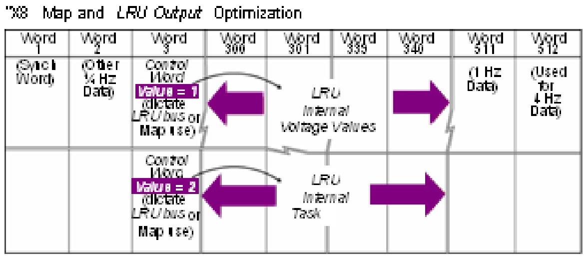

Figure 10: BOLDR® Data Acquisition

These BOLDR® techniques can also aid ACARS "Fault Forwarding"[xi]; Data Link reporting inclusion of integral LRU internal parametric or (reasoned) structural data can greatly aid integrated diagnostics.

Several aspects related to ACMS/F updates and BOLDR® interfaces support continual IVHM improvement as discussed next.

ACMS/F Life-Cycle Advantages

Many program phases are improved with ACMS/F maturation or IVHM interface utilization throughout the life-cycle of a Weapon System or Commercial vehicle. This can't be underestimated as IVHM involves cost avoidance that is frequently difficult to fund, and addressing as many program efforts as possible will aid health management implementations.

Early in the program, when Concept of Operations[xii] and Affordability[xiii] based design trade-offs are made, considerations reflecting ACMS/F IVHM interface technique utilization are important. For example, if initial lab development and integration testing utilized unique recording frames for verification/quality assurance purposes, outstanding leverage of standard hardware results (e.g., unique "lab test only" parameters are now available for operational use later in the program). This also applies to production type testing. An ACMS/F map can be used for on-board production test verification (especially important when considering that results can be reported on-board using airplane displays).

Integrated Diagnostic Models[xiv] is one critical item that is utilized for system development, and includes important testability design influence. IVHM Interface and BOLDR® techniques allow for capturing necessary failure data to both aid in LRU troubleshooting/repairs, and continual model improvement, enabling full association from any changes into the diagnostic/prognostic construct of the integrated system.

Flight testing can also be enhanced using ACMS/F for reporting "test point" completions and storing "FOQA event" results. FAA certification requires thorough verification/validation testing, and use of the same ACMS/F hardware for event recording aids validation and follow-on FOQA by using standard tools and setting "exceedance levels", respectively.

Additionally, class II changes are regularly performed to mitigate LRU part obsolescence (e.g., a given Integrated Circuit is not manufactured anymore and a "form/fit/function" equivalent part is utilized). While the Supplier performs testing to "ensure equivalence", unexpected problems still transpire (e.g., a timing issue associated with certain system operational modes), and updated Diagnostic Models and IVHM interface use can significantly aid new part maturation (using associated operational data for the new part to quantify equivalence, or mitigate risk if otherwise).

These examples aid nearly all of the product cycles, and since the same standard equipment can now be used without requiring special equipment, tools or associated skills "full-scale" IVHM implementation should be assured. One significant item supports active IVHM Interface utilization: ACMS/F maintenance data does not affect in-flight airplane performance, thus flight-test and other associated quality control functions are not required (thus avoiding costly operational software changes as described earlier). Thus, these FRED and BOLDR® IVHM interfaces support a continual improvement method that can be used to rapidly address high cannot-duplicate, no-fault-found, removal or test-time rates.

7 HRS SPECIFICATION ENHANCEMENT USAGE

The HRS documentation was developed by Boeing Research and Technology's Support and Services IVHM Team to aid in receipt of "health ready" systems from suppliers. Boilerplate SOW, PS and SDRL requirements are utilized for "requirements flow down" to suppliers, and tailored as necessary by the individual program. There are two primary set of HRS Best Practices. One practice covers important BIT and Integrated Diagnostics testability requirements (includes ample lesson's learned to minimize false-alarms or improve self-test features). The other set of Best Practices involves IVHM Interface or system data availability, and includes the previously overviewed ARINC Standard enhancements (HRS data availability covers additional topics such as integration with all maintenance levels, updates to system ACMS/F-like parameters, and automated serial number data collection).

The HRS PS, SOW & SDRL and associated ARINC Standard enhancements are key constituents of the lower OSA CBM[35] data interface levels, and form important IVHM framework elements being prototyped in the Boeing IVHM Operational Environment.

8 IVHM PROTOTYPING

The Boeing IVHM Operational Environment[xv] is operated by Boeing Research & Technology (BR&T) and was created to aid business unit IVHM deployments and mitigate health management project risks for Boeing Commercial Aircraft (BCA) and Integrated Defense Systems (IDS). Two key goals are to leverage COTS IVHM solutions for multiple customers and lab capability dissemination at multiple sites. Prototyping of ACMS recording features supports these goals.

Initial Operational Environment use commenced in the end of 2006 with a loaner DFDAU[36] used in the Digital Equipment Technology Analysis Center (DETAC) Lab in Long Beach, CA. MD-11 and MD-10 DETAC configurations were used for ACMS recording[37] of tri-jet subframe data, and updates were performed using “FRED equivalent” tools[38]. Before completing a year of activity, demonstrations were performed to BCA and IDS IVHM lead personnel supporting “technical transitions” and COTS IVHM solution leveraging achievement.

BR&T Support & Services and Teledyne Controls IVHM Teammates then addressed DFDAU capability utilization at St. Louis Electronics Prototyping and Integration Center (EPIC) facility. With the need to perform 767 and 737 ACMS recording and updates ARINC 429 simulation capability was needed. After complying with EPIC power & environmental requirements, the simulation capability was developed, supporting additional technical transitions to BCA and IDS customers in 2008.

Since the same ACMS capability also supports display generation (e.g., Mission Computer Display Unit (MC DU) parametric displays in support of troubleshooting), MC DU utilization is planned in 2009 at the EPIC. The team also expects additional ACMS update/HRS enhancements, continuing goal achievements.

Longer-term, all of the aforementioned IVHM Interface and other features are being considered for lab prototyping, and business unit needs will greatly influence associated efforts.

9 SUMMARY

ARINC 573/717, 767 and 647A have greatly aided FDR development and deployment, including important unit interchangeability requirements / supplier product availability. Since these ARINC Standards are applicable to ACMS Recording, several important IVHM operational aspects are supported, including ample data processing and reporting tool availability, the ability to rapidly update what is recorded using FRED tools, and, numerous techniques to optimize what is collected including BOLDR® IVHM system interfaces. Additionally, the continued demonstration of these techniques in the Boeing IVHM Operational Environment is aiding business unit deployments, to the delight of our Commercial and Military customers.

---

[35] http://www.mimosa.org/downloads/39/index.aspx

[36] Courtesy of Teledyne Controls (http://www.teledynecontrols.com/).

[37] ACMS reporting also performed (not applicable to this paper).

[38] Teledyne Controls Application Generation Station (AGS) http://www.teledynecontrols.com/productsolution/ags/overview.asp .

REFERENCES

[i] (Baldwin, 2008) A. Baldwin, "Boeing IVHM", white paper provided to the University of MD over viewing Boeing IVHM activities, 2006.

[ii] (Li, 2008) W. Li, "Standards Delivery", IEEE NANO Technology Magazine, 2008.

[iii] (Sudolsky, 2007) M. Sudolsky, "IVHM Solutions using commercially-available Aircraft Condition Monitoring Systems", IEEE Aerospace Conference, 2007.

[iv] (Withers, 2006) A. Withers, "Introduction to Data Frames and Flight Recording", Boeing IVHM Strategic Forum, 2006.

[v] (Cranfield, 2009) Cranfield University Short Course, Flight Data Monitoring (FDM) & Flight Operational Quality Assurance (FOQA) In Commercial Aviation.

[vi] (Sudolsky, 1997) M. Sudolsky, "Enhanced C-17 O-Level QAR Data Processing and Reporting", AUTOTESTCON, 1997.

[vii] (Clark et al., 2007) G. Clark, "Multi-platform Airplane Health Management", IEEE Aerospace Conference, 2007.

[viii] (Keller et al., 1998) K. Keller, J. Holland, D. Bartz, K. Swearingen, "An Advanced Onboard Diagnostic System for Vehicle Management", First IEEE International Workshop on System Testing and Diagnostics, 1998.

[ix] (Chidambaram et al., 2006) B. Chidambaram, "Recorders, Reasoners and Artificial Intelligence – Integrated Diagnostics on the C-17 Aircraft", IEEE Aerospace Conference, 2006.

[x] (Sudolsky, 1998) M. Sudolsky, "The Fault Recording and reporting Method", MDC 98K0007, AUTOTESTCON, 1998.

[xi] (Maggiore, 2003) J. Maggiore, "Always Fit to Fly", http://www.boeing.com/commercial/news/feature/ahm.html, 2003.

[xii] (Williams, 2006) Z. Williams, "Benefits of IVHM: An Analytical Approach", IEEE Aerospace Conference, 2006.

[xiii] (Andresen, 2006) G. Andresen, "Providing Best-Value IVHM Solutions for Aging Aircraft", Joint FAA/DoD/NASA Conference on Aging Aircraft, 2006.

[xiv] (DSI, 2004) DSI International, "Modeling it Both Ways – Hybrid Diagnostic Modeling and its Application to Hierarchical Systems Designs", AUTOTESTCON, 2004.

[xv] (Keller et al., 2007) K. Keller, "An Open Platform for Health Management Integration and Experimentation", IEEE Aerospace Conference, 2007.

Mike Sudolsky is an Associate Technical Fellow, and the first Boeing member inducted for ACMS/F expertise. After obtaining an Associate's degree from NYC Technical College, Mike's experience as a copy machine repair technician led to professional interests that remain today (e.g., no-fault-found, cannot-duplicate or retest-ok event solutions). Following Bachelor's degree receipt from Pratt Institute the subsequent 26 years have included accomplishments covering a diverse range of disciplines such as Aerospace Testing (Test Program Set's and Flight Testing) and System Design (ACMS/F and other subsystems) that have enabled his current IVHM work. This work includes Mike's Fault Recording and Reporting Method invention (US Patent #6,115,656) that forms the basis of BOLDR®.

Mike has been happily married for twenty-three years and has two son's attending College, and they enjoy living along the Southern California coast.