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Implementation of Acquisition Data Recorder for an Aircraft

By

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Abstract:

Capturing and retrieving data from aircraft (A/C) for the sake of flight test recording, maintenance and crash recording or mission recording& analysis are crucial for fault diagnoses and pilots training. Acquired data from A/C are sorted into two categories; first one is analog/discrete data from analog systems, while the second concerns the MIL-STD 1553 serial data of all its connected remote terminals. UMA2000 is a state-of-art Flight Data Recorder (FDR) was used as a programmable Data Acquisition System for acquiring analog, digital signals and MIL-STD 1553 data acquisition channels, as a Bus Monitor to gather information of flight mission from several systems on the A/C. This paper introduces a way of interfacing UMA2000 on the aircraft platform, gathering, decompressing, decoding, analyzing and converting data to engineering units for retrieving the mission information about the status of the engine, avionics, mission computers ….etc.

Keywords:

Flight Data Recorders, MIL-STD 1553 data bus, Avionics.

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1. Introduction:

During the 1950s and 1960s, the electronics used on aircraft were fairly basic. Communication, navigation and weapon aiming systems were almost exclusively provided by analogue devices. Inter-system connections were kept to an absolute minimum because they were, in general, too difficult, complex and expensive to engineer [1, 2]. During the 1970s, the application of digital computers to avionics offered increased Computational capability and simplicity. As systems on aircraft became progressively more digitized in nature, it became apparent to avionics designers that a multiplexed bus system was required to enable all subsystems to be connected by only one set of wires [3].

To satisfy military avionics requirements for a Standard to cover the above, US MIL-STD-1553 was drafted as a Time Division Command/Response Multiplex Bus Standard in 1973. This was first published by the US Air Force and was quickly adopted for use as MIL-STD 1553A - an update of 1553 in 1975. In the mid 1970s the Standard was adopted for use by all the US services after comment by all concerned including UK Ministry of Defense Research Establishments. Finally the MIL-STD-1553B is developed as an enhancement in 1978.

The next section exhibits a background about the main key issues of the title of the study to give a light shed on the basics of this work. Experimental setup accomplished in that study followed the background to declare the preparation work of setting the system on the aircraft platform and to give a brief about the included devices. Practical work and data collection comes after the completion of the setup; the required data are collected from the connected system according to the pre-specified channels. The acquired and recorded data are processed and transferred to engineering units in the section of results and data analysis. Finally the conclusion of the work shows what are the benefits gained from this accomplished work beside an exhibition of a simulation for the recorded data.

2. Background (1553):

MIL-STD-1553 is simply a time multiplexed serial communication standard based on a multidrop linear data bus. 1553 network comprises a main transmission line ended at either side with the characteristic impedance (nominal Z is in the range of 70 to 85 ohms) [3]. Refer to Figure (1) for an illustrational example of a MIL-STD-1 553 bus.

Refer to Figure (2) Terminals are connected to the main transmission line through either a "transformer coupled" or a "direct coupled" connection. A transformer coupled connection utilizes an impedance matching transformer and a couple of isolation resistors in addition to an isolation transformer within each terminal. A direct coupled connection uses an isolation transformer and isolation resistors within the terminal and is directly connected by wire to the main bus [4].

Both direct and transformer coupled connections present unterminated stubs (or bridge taps) on the main transmission line. These stub connections will induce phase distortion in a transmitted signal. As the signal propagates through the main transmission line, the stub connection presents an impedance discontinuity. The mismatch in impedance will result in reflections. Part of the incident wave will be reflected back on the transmission line, part of the wave will be transmitted through the line and part will travel through the stub connection to the terminal.

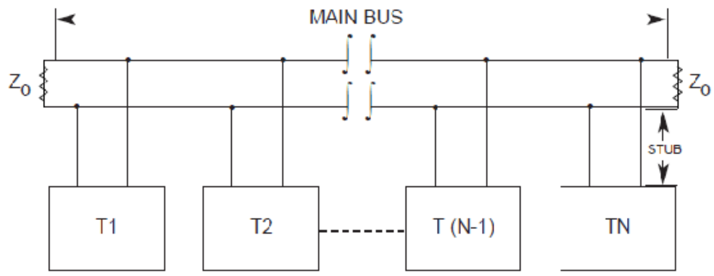

***Figure (1):** MIL-STD-1553 Transmit Data Path*

At the terminal the wave will again encounter an impedance mismatch. A transformer coupled terminal is required to have a minimum input impedance of 1000 ohms. This high input impedance will result in a large reflection coefficient and most of the incident wave will be reflected back onto the stub toward the main bus. This reflected wave will then be coupled back into the original wave on the main bus. The portion of the wave that traveled down the stub and back will introduce a time delay that creates a phase distortion in the transmitted waveform [5].

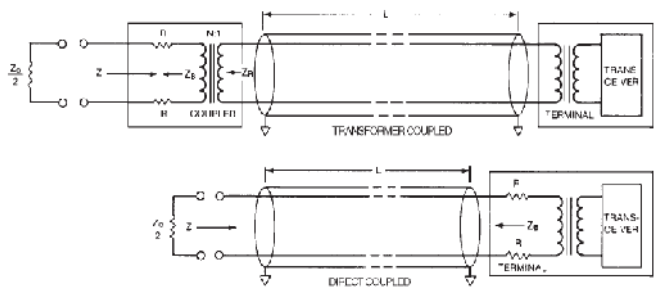

***Figure (2):** Transformer coupled and Direct coupled Stubs*

MIL-STD-1553 defines the maximum length of a stub connection (20 feet) such that the induced phase distortion is not significant within the frequency range of the baseband signal. The frequency of data flow for MIL-STD-1553 is low enough that the unterminated stubs do not cause a significant impediment. When a broadband system is considered which would utilize higher frequency bands then the unterminated stubs will become significant.

The stub connections are intentionally unterminated. If the stub connections were terminated at the terminals then a transmitted signal would be split at each stub connection which would result in significant signal attenuation. MIL-STD- 1553 allows for up to 32 terminals on a single bus. The analysis presented in this paper began with a specification of the main architectural elements of a MIL-STD-1553 bus. A transformer coupled connection utilizes a bus coupler. There are three distinct signal paths through a bus coupler as illustrated in Figure (1). Each of the transformer couplers shown in Figure (1) is identical but is labeled differently based on the direction of interest in terms of signal flow.

In Figure (1) the signal path is from the transmitting terminal to the receiving terminal. The “transmitting coupler” passes the signal from the stub connection to the bus. The signal passes though several “bus couplers” as it travels down the transmission line. Finally the signal passes through the “receiving coupler” from the bus onto the stub and down the terminal. Each of the three signal paths through the bus couplers will be characterized to understand the main sources of transmission impairment. After each of the individual elements has been characterized then several bus configurations will be measured to gain insight into the overall distortion introduced by the network. These measurements will be used in calculating the theoretical Signal to Noise Ratio (SNR) of the channel [6].

3. Experimental Setup:

The experimental setup was developed and implemented using data acquisition flight recorder UMA2000 7 slots, with 5 modules as shown in the following figure (3).. The harness was developed to collect data from aircraft gauges and indicators for the engine, hydraulic cycle, fuel cycle, and power supply to the UMA2000. Also a 1553 cable was designed by research team according to the MIL-STD-1553 bus and implemented in French company to collect data from 1553 data bus of aircraft to UMA2000. A very important study accomplished to choose the optimum position for UMA2000 to be placed on the aircraft platform also many studies have been accomplished related to the aerodynamic, heat treatment, shock absorber, and also vibration effect on UMA2000. Our experimental setup consists of:

1- Aircraft with 1553 Data bus.
2- UMA2000 Data acquisition recorder.
3- Analog interface.
4- Discrete interface.
5- MIL-STD-1553 interface.
6- Flash memory 4Gbyte.
7- Power supply.
8- Ground Station for analysis and simulation.

The first issue in this work is the existence of the Aircraft which is supplied with 1553 Data bus and studying the ability of adding the new system to its body without any side effects on its aerodynamic properties.

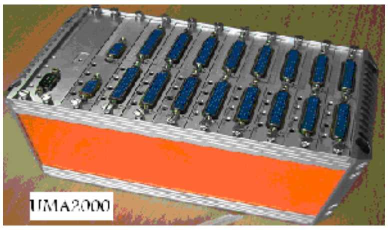

Figure (3): *UMA2000 Device*

UMA2000 is the data recorder device, which is supplied with Analog & Discrete interfaces to collect various (Analog& Discrete) data from different systems on the aircraft mount other than the ones connected to the 1553 bus as shown in the following figure (4).

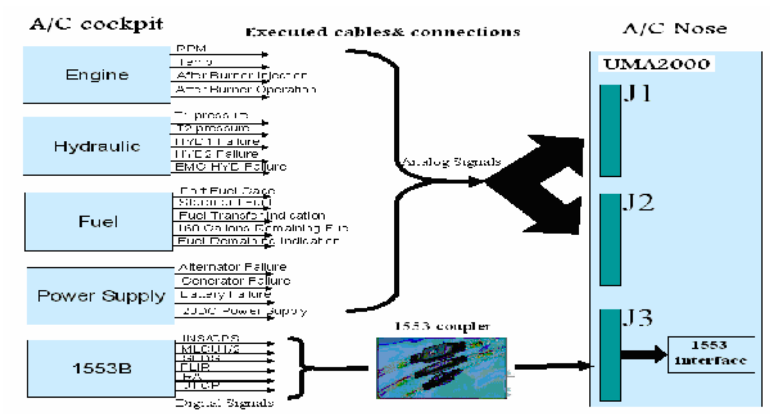

Figure (4): *UMA2000 Connection diagram with the airplane systems.*

MIL-STD-1553 defines three types of terminals; Bus Controller (overall control of the bus activity, all transmissions are initiated by a command from the bus controller), Remote Terminal (all other active terminals are designated as Remote Terminals (RT,s) each assigned a unique address, it waits for any message contains information which indicate to the RT the action required of it which may be receive or transmit), and finally Bus Monitor (it is a passive monitor for the bus, it does not normally transmit to the bus, its acquired data are mainly used for offline applications or to provide a back-up bus controller with what it would require).
UMA-2000 is interfaced with 1553 bus as a bus monitor (B.M.) device by transformer coupling connection. UMA-2000 interface with 1553 bus were accomplished with a developed cable with a pre-studied design for adaptation between the output interface of the 1553 bus and UMA-2000 as shown in the following figure (5).

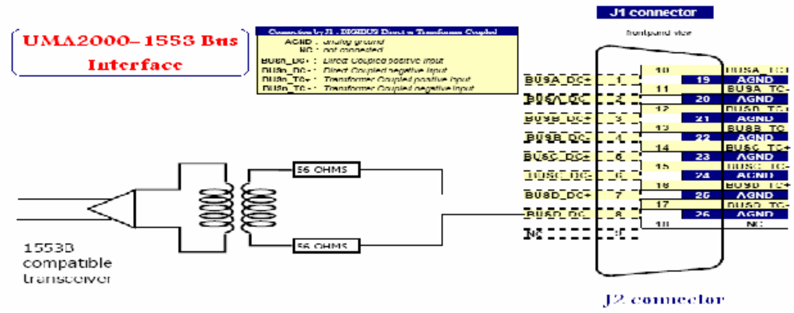

Figure (5): *Four Channels MIL-STD1553B (UMA2170)*

The main Remote terminals connected to the MIL-STD-1553 bus are:

- Air Data Unit (ADU)
- Up-Front Control Panel (UFCP)
- Radar Altimeter (RA)
- FLIR Camera (IRIS)
- Data Transfer Unit (DTU)
- Secondary Flight Display System (SFDS)
- Inertial Navigation system/GPS (INGPS)
- Mission Computer Unit ½ (MCU1/MCU2)

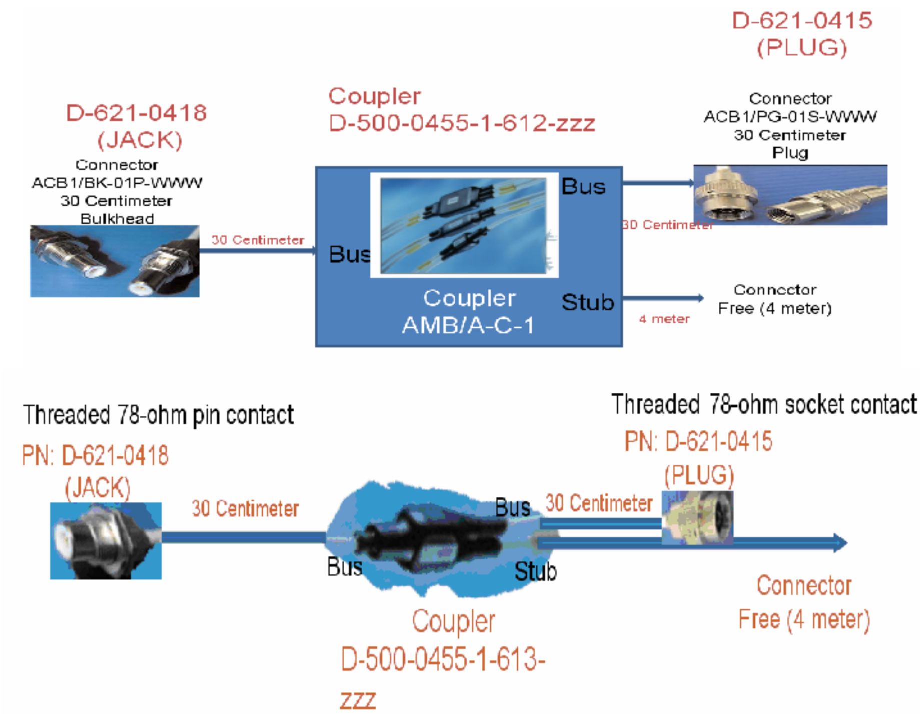

Figure (6): *Interface between UMA2000 and 1553 data bus.*

The cable of data transfer between UMA-2000 with the 1553-Bus interface cable was as shown in the following figure (6) designed to suit the word format of the data bus and the distance between the storage module (2310) of UMA-2000. The digital storage module is facilitated with 4 Gigabyte compact flash (CF) memory. The calculated time for full loaded data stored from the plane is around twelve hour flight mission. The record facility of the CF is supplied with:

1-Start / stop record / RAZ on external ON/OFF inputs

2-One external PCM storage in raw data files up to 20Mbit/s (with 45x CF) is in ONE CF.

The connection cable between the FDR unit (UMA2000) and the 1553 bus on the plane which carry the digital data from all bus connected devices. This cable is comprised of 46 pin to transfer 23 analog signals from all connected systems (Engine, Fuel Cycle, Hydraulic Cycle and Power supply) to the digital 1553 bus on the plane.

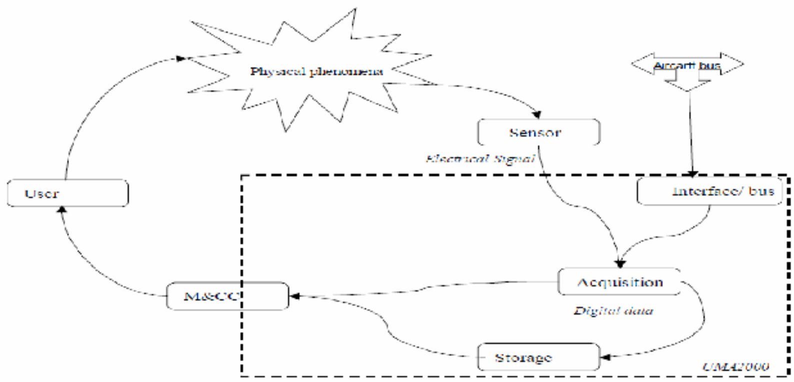

Figure (7): *Representation of data acquirement of one system on the aircraft mount.*

The UMA 2000 is a modular measurement acquisition system, offering two modes of data transmission, either by Ethernet or by PCM, together with a control and visualization interface by Ethernet link as shown in the following figure (7). It acquires Measurements from digital buses (1553, etc. …), Digital data flows of Video, Audio, and PCM etc. The measurement values are then presented on the output flow and/or stored on high capacity memory boards.

4. Practical work and data collection:

Finishing the installation of the flight data recorder UMA2000, harness of the AC, 1553 data bus cable, and the aircraft is the crucial step for being ready to examine the system. Programming UMA2000 various modules is accomplished by determining all the flight data parameters and its specifications required to start flight data recording. The main flight data parameters engine RPM, after burner, inlet temperature, hydraulic pressure, fuel consumption, power supply, 1553 data bus, navigation data, radio altimeter, mission computer, multi function display, armament ... etc.

Figure (8) Represents programming UMA2000-CPU module with enabling the digital and analog outputs and disabling the filtering stage to receive the whole raw data. The PCM used with flow name FLUX CE83 with protocol flow type CE83 and with bit-rate 210000 Bps.

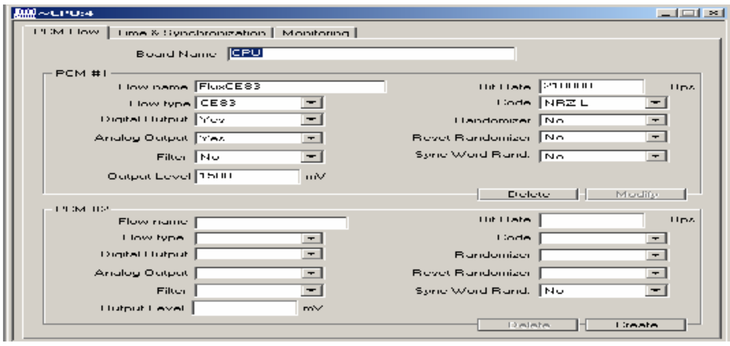

Figure (8): *setup of the CPU module of UMA2000*

The analog module (UMA2012 HV) has 24 separated channels. Each channel is facilitated to receive a signal from any of the subsystems on the aircraft mount. Each channel is settled according to the various characteristics (Voltage level, Bit rate, sampling rate, unit….).

Figure (9) represents the data flow distribution over the settled channel for recording process. The first channel is settles to receive the data over the 1553 data-bus with selected sampling rate 9581.5 Hz. The next three channels are standard for the UMA2000 device (Synchro, FFID and SFID). Starting from channel 5 up to channel 28 represents the analog channel of the analog module (UMA-2012 HV). Figure (10) represents the data flow grids preview which simulates the channels for recording data from the analog subsystems on the aircraft and the 1553 data-bus.

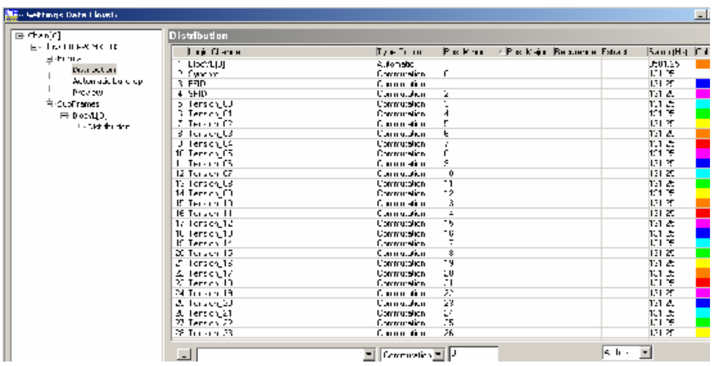

Figure (9): *Data flow distribution over the channels.*

Two types of operational modules are used: First the synchronous type produce messages periodically independently of the signals acquired. This is the case for acquisition boards of analog signals (UMA2012), The produced messages are intrinsically dated. The bandwidth used is deterministic and constant over a given period (in general 1 second). The parameters supplied by the module are ranked with a deterministic order.

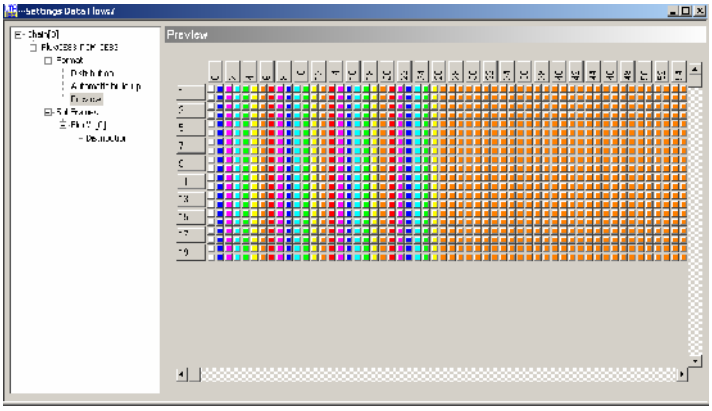

Figure (10): *Data flow grids preview.*

Second type is asynchronous one which produces messages nonperiodically on an EVENT depending on the signals or acquired data by the module. This is the case for most acquisition boards on the digital buses ARINC, 1553 etc. (UMA2170).

The dating of this data is explicit, carried out by the module at the time of acquisition of the event in question and supplied in the message transmitted to the CPU. The bandwidth used is NON-deterministic. The Flight Data Recorder UMA2000 data output is in a hexadecimal format frame of words. The output frame of the UMA2000 is a major frame which in turn includes minor frames inside it.

The major frame can have up to 20 minor frames. The minor frame consists of a hundred hexadecimal words as an example shown in figure (11).

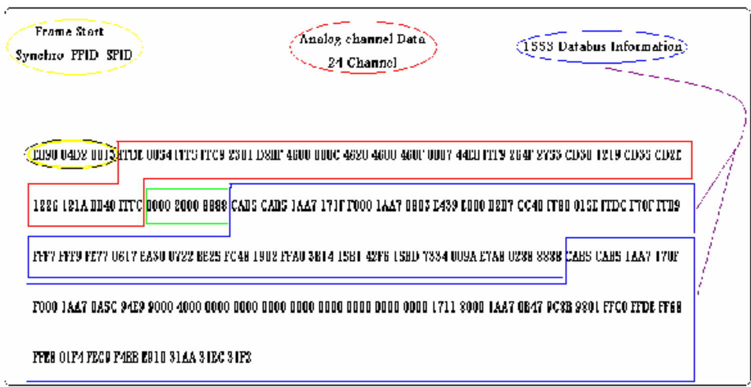

Figure (11): *UMA2000 output frame of data.*

The UMA2000 output minor frame starts with three reserved hexadecimal words as shown in the first ellipse in figure (11) for the three fields (Synch, FFID& SFID), the Synch word occupies the zero position in all minor frames, FFID is first frame identification, SFID is the sub frame identifier (which is minor frame counter) it occupies the same position in all minor frames, it is obligatory.

Follow the three identification words the twenty four hexadecimal words are the output of the analog channels as shown in figure (11). For example the first word

0xFFDE represents the engine RPM, second word 0x0054 represents the engine temperature which is equivalent after transferring it to engineering units to 528.125 Co degree. The following hexadecimal words represent the status of subsystems connected with hydraulic cycle, engine status, fuel cycle, power supply, etc…).
The rest of the UMA2000 output minor frame is for the 1553 data bus information. The identification (Id.) of the 1553 information is two reserved hexadecimal words (CAB5 CAB5) according to design procedure. The initiation is developed to distinguish between the 1553 data and any other data carried in the frame. Each complete message from the 1553 data bus including the Id. has a 35 hexadecimal word length. This message started with an Id. followed by a label and length for any useful data from the connected subsystems with the 1553 data bus. The label and the length are merged in one hexadecimal word, each occupies 8 bits.
The label (17) is a constant reserved 8 bits (half of a hexadecimal word); the second half of the same hexadecimal word represents the length of the message following (number of hexadecimal words in a hexadecimal display) the label and length word as shown in figure (11). The first three hexadecimal words after the label and length are reserved for the date according to the design of the frame divisions. The following rest of the message called the useful data of the 1553 data bus. For an example in figure (11), according to the command message of standard 1553 data bus, E439 is the command word which is followed by a status word then the data of the message.
E439 is a command word in a hexadecimal format which is represented in a binary format to 1110010000111001, the first five bits (11100) in the decimal format is equal to represents (28) which is the inertial navigation system (INS) address as a remote terminal (RT) connected to the data bus. The bit number six (1) may take the value "1" or "0". Bit "1" indicates the transmission command while the Bit "0" indicates the receive command. The next five bits (00001) is an indication for the sub-address of the message "INS01" required from the INS remote terminal, where outputs have more than one messages (INS01, INS02, INS03, INS13, INS30), each message has a specific data according to the design. The last five bits in the binary format of the command word (11001) represented in the decimal format as 25 in the decimal format which represents the word count of data words coming after the status word.
The status word in figure (11) is E000 in the hexadecimal format which is represented in the binary format to the following (1110000000000000), the first five bits is the terminal address of the (RT), where 11100 is equal to "28" in the decimal format which indicates the INS address. The data words are representing the information messages for INS01 message, for example the inertial latitude is represented in two words, the eighteenth, and the nineteenth words, and they are coded in binary coding "BC2". The latitude ranges from 90 to -90 with most significant bit (MSB) equal 90 degrees.
The first word is "15B1", and second word is "42F6". For longitude the first word is "15BD", and second word is "7343"as shown in figure (11).the latitude and longitude have been manipulated in engineering unit, the latitude is binary decoded as

following, the two words are concatenated to each others, 15B1 is transferred from hexadecimal to decimal format then it is multiplied by 90, and finally it is divided by 2-30 to give the real value; for example: the Latitude is (15B1 42F6) in hexadecimal changed to (363938550) in decimal format, after multiplication by 90 it becomes (3275449500) by multiplying with 2-30 it becomes (30.505) degrees and for the longitude is (15BD 7334) finally after processing became (30.5719) degrees.
The minor frame is restricted by its length which should be a hundred hexadecimal word, so if the 1553 data bus finished, a new 1553 message start to appear with its reserved word (CAB5 CAB 5) to complete the length of the minor frame. Inside the 1553 data if the length of the data is less than the length of the 35 hexadecimal words we assigned the hexadecimal word 8888 as a filler word. If a 1553 message started in a minor frame and it didn't finish while the minor frame length has reached its hundred word, it continues in the next minor frame after the analog channel data without any new identification word.

5. Results& Data Analysis:

In this section the results recorded for the planned mission will be introduced. These results are samples of the different aircraft subsystems data during flight. These subsystems include the analog ones and the various remote terminals (RT,s) connected to the 1553 data bus. The following figures record the variation of the output of the subsystems during special events such asthe landing time of the aircraft flight.

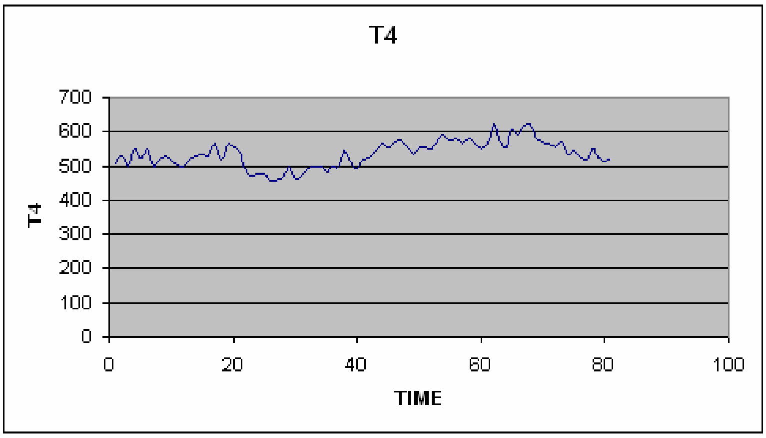

Figure (12): *the Engine temperature variation during landing.*

Figure (12) shows the variation in the engine temperature during the landing time which gives an indication about the status of the engine with time. Evaluation of the engine's temperature values variation during the flight mission aids in early detection of the engine malfunctions.

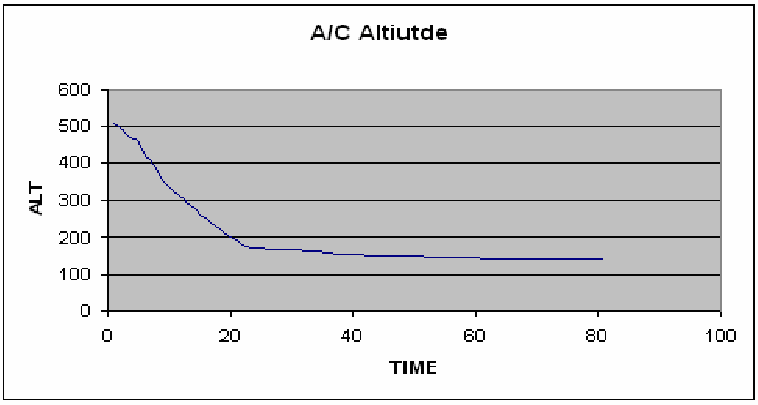

Figure (13): *the A/C altitude variation during landing.*

Figure (13) shows the relation between the A/C altitudes with time during landing. The illustrative figure gives an indication about the rate of loosing height with time from the 500 meter level till it reaches the runway of the airport which is at about 140 meter above the sea level.

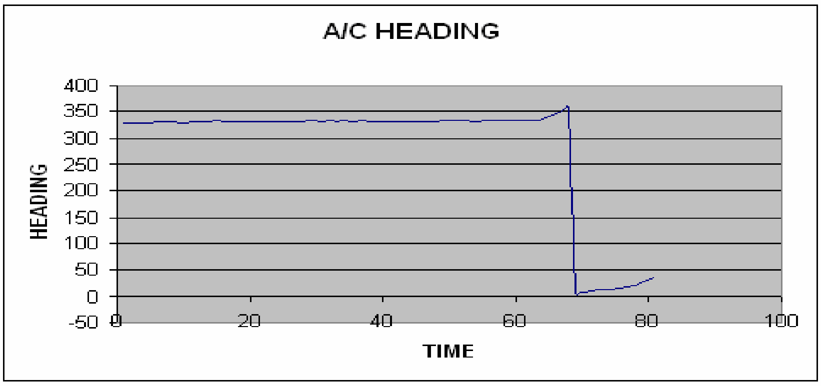

Figure (14): *the A/C Heading variation during landing.*

The A/C heading are almost constant for a long period of time during landing time because the A/C fixed its direction during this part of the flight. The heading ranges from 0 to 360 degree, so the abrupt change in the curve shown in figure (14) is fake, because the angle follows 360 is zero which explains the sharp change in the curve.

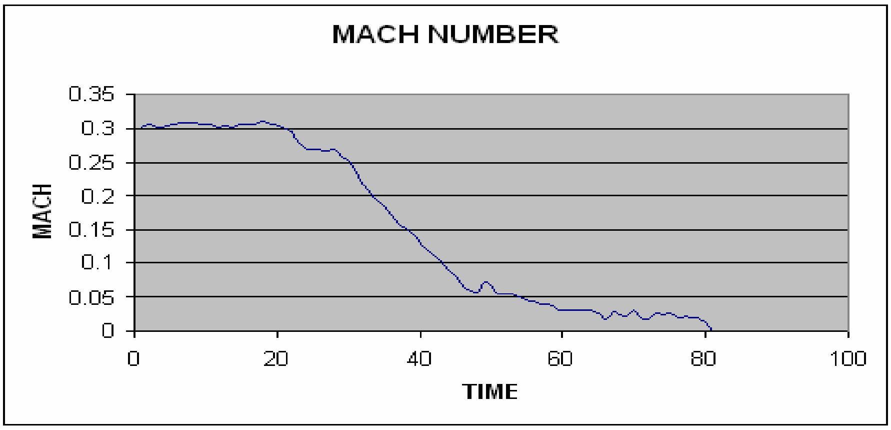

Figure (15): *Mach number variation during landing.*

Figure (15) shows The Mach number of the aircraft represents the speed of the air vehicle with respect to ground. During the landing stage of the flight the pilot is slowing down the speed gradually till it reaches the runway then uses the brakes to stop the aircraft at its place as shown in the above curve, where the speed decreased from around 0.3 Mach till it reaches the zero speed finally.

6. Conclusion:

The flight data recorder (FDR) is a crucial aspect in the air-vehicles space. The importance of this device comes from that it records and stores all data about the connected systems to support a complete vision for the technical & maintenance crew through the whole flight time. This development is applied on the air-vehicles, it supports the engineering crew in the accidental analysis with complete data to determine the real causes of the flight problem.

The contribution of this paper concern the recording process for a real mission of Air Craft for monitoring all flight parameters like: Engine RPM, Engine temperature, hydraulic pressure, Fuel Consumption, power supply, and all the messages from the systems connected to the 1553 data-bus such as the inertial navigation system (INS), global positioning system (GPS) and radio altimeter etc,.

All the recorded parameters have been analyzed and demonstrated especially the 1553 data which has been decoded and processed in engineering unit. The recoded data has been replayed after mission ended and displayed in a visual display as a simulated flight mission for training and technical analysis purposes as shown in figure (16).

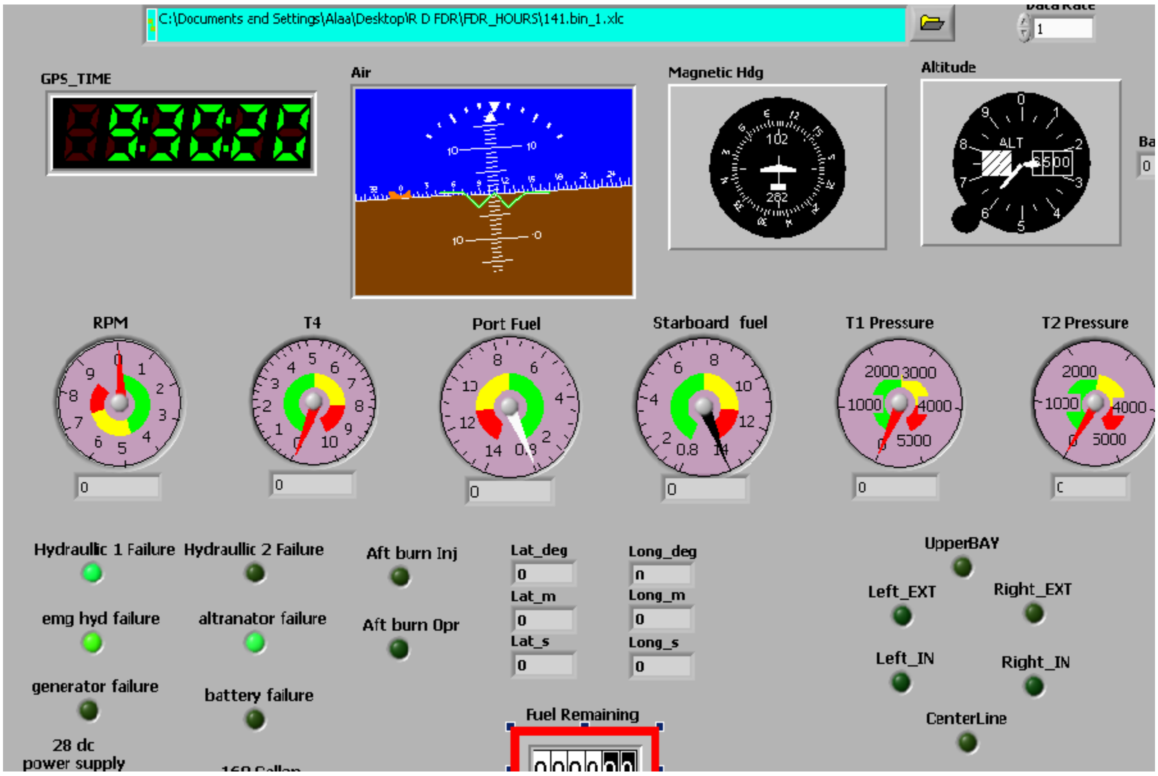

***Figure (16):** simulation the A/C mission according to the recorded data.*

This work clarify a lot of problems and malfunctions that may happen to the aircraft during flight, where the pilot may complain of things that didn't make sense with it on the ground. Finally any work or effort exerted in that aspect save a lot of money for maintenance besides saving pilot lives from sudden failures.

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