JOURNAL OF MECHANICAL AND TRANSPORT ENGINEERING
Vol. 70, No. 2 2018
DOI 10.21008/j.2449-920X.2018.70.2.03

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(Received 21 Dec 2017, Received in revised form 25 Sep 2018, Accepted 5 Nov 2018)

MODERN COMBAT AIRCRAFT DATA ACQUISITION SYSTEMS

The article presents systems which record parameters of flight in modern aircraft F-16, which was delivered to Polish Airforce in 2006. These systems are responsible for the flight safety. Systems records basics parameters of plane and engine, as specific fuel consumption or height of flight, also provides video and audio recording, and aerial combat assistance. These systems record even failures of a braking system during landing. Thanks to modern technology, and devices like those described in this article, F-16 is one of the best fighters in the world.

Keywords: aircraft, data acquisition, jet engine, safety

1. INTRODUCTION

With the current level of technical development of the aviation industry, data acquisition systems are an important element of all aircrafts. These systems allows to read and storage the most important flight parameters, and combined with digital control and safety systems allow to counteract dangerous situations which especially can happen often in the case of military aircraft such as the F-16 (Fig. 1) due to their combat purpose. The amount of data provided by analogue and digital sensors is so large that it requires the partitioning of parameters and use of several basic recorders, which will be listed in chapter 1. Each of the recorders has a specific task, i.e. data processing or storage, and processes certain parameters, e.g. Engine Monitoring System is responsible for data obtained from a turbine jet engine. The

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Fig. 1. F-16 during take-off [31 BLT 2017]

heart of the entire system is the unit called DAU, or Data Acquisition Unit, which records the most important flight parameters, such as flight time, engine speed or altitude.

2. F-16 AIRCRAFTS DATA REGISTRATORS

2.1. DAS – Data Acquisition System

Data Acquisition System consists of two units that contains solid state non-volatile memory [3]:

- DAU (Data Acquisition Unit) (Fig. 2),
- Enhanced Crash Survivable Memory Unit.

Fig. 2. Data Acquisition Unit [GE Aviation]

The DAU use the following interfaces to acquire date [31 BLT]:
- Aircraft analog and discrete sensors connected to DAU;
- MIL-STD-1553B Avionics Multiplex Bus (AMUX) data (BMUX, Left CMUX, Right CMUX and DMUX are connected to the DAU but currently not used);
- Two serial channels from Digital Flight Control Computer (DFLCC);
- One RS-422 serial communication channel for the Digital Electronic Engine Control (DEEC);
- One audio channel connected to the aircraft intercommunication system.

2.2. DAU

The DAU contains data Types 2, 3 and 4 for service life monitoring and engine usage data and also Type 5 data for avionics health diagnostics data. The DAU's memory capacity is such that time history data of data types 3 and 4 from at least 30 hours is stored. Approximately 20 hours of Type 5 data is stored in DAU memory. The DAU is not crash hardened.

Type 2 data contains individual aircraft tracking data in terms of normal acceleration, gross weight, number of landing gear extensions and retractions, number of landings, number of flights, total flight time and number of flights with conformal fuel tanks. This data is generally not useful for mishap investigations.

Type 3 data consists of continuous measured parameters:
- Engine RPM;
- Longitudinal Stick Force;
- Leading Edge flap position.

Type 3 data consists also discrete measured parameters, mux parameters and calculated parameters:
- Landing Gear Down Command (discreate parameter),
- Valid Weapons Release (discreate parameter),
- Main Landing Gear Weight on Wheels (discreate parameter),
- Mach Number (MUX),
- Aircraft Gross Weight (MUX),
- Dynamic Pressure (calculated parameter)

Type 3 data is primarily used for the collection of structural loads data. In the event that any of the parameters from AMUX massages are identified as being invalid, unlike Type 1 data, the last valid values of those parameters shall be used for continued Type 3 data processing until next valid value is recived. Data is recorded based on peak/valley search algorithms and on the occurrence of specific events:
- Take-off;
- Landing;
- Peak/valley of longitudinal acceleration;

- Landing Gear Down Command.

The last 30 seconds of time history data for parameters recorded after touching the ground (WOW – weight on wheels) are recorded in separate block of Type 3 data. Parameters recorded by device are as follow:

- Engine PLA (throttle),
- Normal Acceleration;
- Radar Altitude.

Type 4 data consists of measured analog and calculated parameters that are important for monitoring engine usage, for e.g.:

- Throttle position;
- Fuel flow;
- Mach number;
- Angle of attack.

Type 5 data is a copy of Type 1 flight data recorded internal to the DAU. Only parametric data is recorded in Type 5; audio data is not stored in Type 5. All of the Type 1 detailed recording requirments for parametric data are applicable to Type 5 data, except that the data is stored in the DAU.

DAS memory contents are processed for investigative use by a decompression softwere program. The Viper MLV or the Integrated Ground Softwere (IGS) program can be used to decompess and view DAS data.While Viper MLV can be used to download all data recorded by DAS, only Types 1 and 5 data can be decompressed and displayed using Viper MLV. IGS can be used to decompress and view all DAS data types.

2.3. ECSMU

The Enhanced Crash Survivable Memory Unit (Fig. 3) houses non-volatile memory that contains what is called Type 1 data. This data consists of discrete event, analog parameters and audio that have been recorded for the primary purpose of mishap investigation. Recording normally starts when the main generator comes on line after ground eninge start. Recording normally stops on engine shutdown after flight. The crash protected memory is sized to record approximately 30 hours of parametric data and approximately six hours of audio data.

Fig. 3. Enhanced Crash Survivable Memory Unit [GE Aviation]

Due to the time required for signal transmissions and processing, the DAS cannot store data up to the very instant of impact or power loss. Approximately ½ second of data is in the accumulation and processing phase and will not be obtainable.

In the case of data stored in ESCMU, there is protected data. Data recorded for 30 seconds following takeoff (WOW) are protected from overwrite until the protected memory space is full. The takeoff event is called the baseline event. Some other selected events are protected from overwrite, these event are called special events. Protected memory space is available for approximately five baseline events. The oldest one will be overwritten by the latest event data.

The DAU samples data for recording at a specific rate for each parameter. Parameters that can change rapidly, such as Nz (normal G's) or Angle of Attack (AOA), are recorded at a higher rate than signal that do not normally change rapidly, such as fuel quantity. The value recorded is a truncated value determined by the resolution associated with the parameter. E.g. continous parameters are presented in Table 1 and dicrete parameters are presented in Table 2.

Discrete signals recorded in Type 1 data are listed in Table 2, signals are recorded with frequency equal to 16 [Hz]. All signals except FLCS RESET and VALID WEAPONS RELEASE have a two-sample filter applied (filtered discretes) before the change of state is recorded in crash protected memory. A filtered discrete signal must maintain its new state for two consecutive samples before the new state is recorded. Valid state changes for the discrete signals FLCS RESET and VALID WEAPON RELEASE are recorded in crash protected memory upon detection of the new change of state.

2.4. AMUX

MIL-STD-1553B Multiplexed (MUX) Data Buses (AMUX) parameters listed in Table 3 are recorded at the rates shown in the table. These data is also displayed in the ground suport software.

Table 1. Continuous parameters recorded by ECSMU [31 BLT]

Label [Unit label]	**Parameter**	**Frequency [Hz]**	**Resolution**
TIME [hh:mm:ss.sss]	Time	8	-
Eng N1 Fan [%RPM]	N1 RPM	2	0,5% RPM
Flt NormG Nz [G]	Normal Accel (Nz)	8	0,1 G
Eng N2 Core [%RPM]	N2 RPM	2	0,5% RPM
Thrott Angle [(EPLA) deg]	Engine power lever angle (EPLA)	4	1,5˚
Nav Gnd Spd [ft/sec]	Ground Speed (GS)	2	0,5 ft/sec
Eng Nozzle [% Open]	Nozzle Position	2	1%

Table 2. Discrete paramters recorded by ECSMU [31 BLT]

Label	**Parameter**	**Display/Scale**
TF Fail LT	TF FAIL LIGHT	0=NOT FAIL 1=FAIL
ADV OHEAT LT	OVERHEAT CAUTION	0=OFF 1=ON
AP ENABLE	AUTOPILOT ENABLE	0=OFF 1=ON
ENG OIL LOW	ENGINE OIL LOW	0=NOT LOW 1=LOW

Table 3. Parameters recorded by MUX [31 BLT]

Label	**Parameter**	**Frequency [Hz]**	**Display**
DTS OBS CTR1	OBSTACLE CENTER	4	0=NO 1=YES
DTS BLW SAF1	BELOW SAFE CLEARANCE	4	0=NO 1=YES
TGP MASK ST	MASK STATUS	1	0=CLEAR 1=SPARE 2=WARNING 3=MASKED
NVP TURNACEL	TURN ACCELERATION LIMIT EXCEEDED	4	0=NOT EXCEEDED 1=EXCEEDED

2.5. DFLCC i EDU

Serial data from the Engine Diagnostic Unit (EDU) recived by the DAU and recorded in Type 1 data on an interrupt basis. Table 4 shown examples of parameters recorded by DAU from EDU. The DAU recives on an interrupt basis the same serial data from Digital Flight Control Computer that is recorded in the Flight Control System Seat Data Recorder. Periodic records are made every 15 seconds beginning with weight off either main landing gear on takeoff and continuing until 7 seconds after weight on both main landing gear on landing. Untimed recordings can be triggered by events such us flight control systems failures or change in state of the landing gear handle, weight on wheels switches, air refueling door. The data is recorded in Type 1 data. Examples of the data recorded from DFLCC is shown in Table 5, and list of special event is shown in Table 6.

Table 4. Parameters from EDU [31 BLT]

Label	Scale	Unit	Description
AJ	130	%	Exhaust Nozzle Position
MOP	256	Psid	Oil pressure
N1	18000	RPM	Low rotor speed
N2	18000	RPM	High rotor speed
TAS	2048	Knots (węzły)	True airspeed
PB	650	PSIA	Burner pressure
ALPHA	180	Degrees	Angle of Attack
MACH	3	-	Mach number

Table 5. Parameters send by DFLCC [31 BLT]

Label	Scale	Unit	Description
Obs Warn	0=OFF 1=ON	-	Obstacle warning
Rudder Pos	0.2555	Degrees	Surface position RUDPOS (+=Left)
Pitch Att	1.40625	Degrees	Pitch attitude (+=Nose up)

Table 6. Special events [31 BLT]

Number	Event Description
SE #1	Main generator goes off line
SE #3	Normal acceleration (Nz) less than 3,5g
SE #4	Leading Edge flap asymmetry lock-up
SE #14	AOA > 29˚for 3 [sec] or AOA < 5˚
SE #15	Ovearheat Caution Light

In the Data Acquisition System there i salso Active Maintenance Fault List (MFL) Data. DAS records at last 16 active MFLs in Type 1 data. The listing of active MFLs from the Modular Mission Computer (MMC) is sampled twice per second and is recorded at lest every ten minutes and also when a Baseline Event occurs. New unique MFLs that occur between the ten-minute minimum update intervals are recorded as soos as the DAU recives information from MMC. The time of first occurance is DAS time not MMC time.

Audio data is recorded in ECSMU by DAS, in Type 1 data onlu. The audio records consist of radio and interphone communications and also tones and voice messages generated by aircraft systems.

ECSMU is equiped with an emergency beacon, which automatically actuivates upon immersion in water. When activated, the unit produces a 35,7 [kHz]; 160,5 [db] acoustical signal for a minimum of 30 days. The output of the beacon is detectable by passive receivers and directional hydrophones. The beacon is sealed unit, powered by a lithium battery. The battery has a six year life date of manufacture.

2.6. DVR – Digital Video Recorder

The Digital Video Recording System provides recording capability of one audio and three video sources as well as one MIL-STD-1553B MUX source to a solid state memory cartridge (Removable Memory Module – RMM).

The DVRS provides the pilot with the ablitity to make video recordings of both Multifunction Displays (MFDs), the combined Head-Up Display (HUD)/aircraft flightpath and Helmet Mounted Display (HMD) video. The system is also records simultaneous audio from the F-16 Intercommunications System. The information can be used for troubleshooting, training, mission anlysis, or help in crash investigation if the DVRS memory cartridge survives.

2.7. EMS – Engine Monitoring System

System is made by some cooperating devices [31 BLT]:

- Built-on engine:
  a) DEEC (ang. Digital Electronic Engine Control)
  b) EDU (Engine Diagnostic Unit)
- Assistance devices for engine monitoring system:
  a) EMMS, Engine Monitoring and Management System
  b) EMATS, Engine Monitoring and Tracking System

EDU stores data from engine and sensors built on aircraft in six categories:

- Documentary Data,
- Time Cycle Data (e.g. Engine Operating Time)
- kody błędów,
- Event Data/Maintenance Data (recording starts in the case of engine failure, e.g. angle of attack at event, core speed at event) with three groups of data:

a) Error Code
b) Time from EDU power on to event
c) Crytical parameters
- Performance data (recorded during takeoff and landing),
- Transient data (recorded with 8 [s] before and 2 [s] after event or after pilot demand)

2.8. Main landing gear breaking system memory

This memory is used only in the event of improper system operation, data readout from this block is implemented and evaluated by maintenance personnel. This data is stored with last 31 anomalies in the system, when the memory is full, the next data is overwritten.

3. CONCLUSION

With the development of aviation, it has become evident to use high reliable safety monitoring systems. Such systems can be found today in almost every aircraft, no matter whether it is a glider or a large airliner. In the case of combat aircraft such as F-16 or MiG-29, which can carry weapons, it is important that there are no adverse events that can lead to disaster and losses. Particularly dangerous situations that are prevented by data recording systems are: blocking of the weaponry, too little or no fuel flow or activation of hydrazine fueled backup installation [Janeba-Bartoszewicz 2017, Satkowski 2016], which is particularly dangerous for the civilian population if such a failure occurred over the city. These systems detect failures before they lead to dangerous situations [Trelka 2016], thus reducing losses to a minimum and often allowing the pilot to make an emergency landing that can take place without loss.

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ACKNOWLEDGEMENTS

The research work financed with the means of statutory activities of Faculty of Machines and Transport Poznan University of Technology No 5/56/DSPB/4967

SYSTEMY PRZECHOWYWANIA DANYCH WSPÓŁCZESNEGO SAMOLOTU BOJOWEGO

Streszczenie

W artykule przedstawiono systemy rejestrujące parametry lotu w nowoczesnych samolotach F-16, które zostały dostarczone do polskich Sił Powietrznych w 2006 roku. Systemy te są odpowiedzialne za bezpieczeństwo lotów. System rejestruje podstawowe parametry samolotu i silnika, są to np. zużycie paliwa lub wysokość lotu. Systemy te zapewniają również nagrywanie wideo i dźwięku oraz zapewniają pilotowi wsparcie podczas walki powietrznej. Użyte w F-16 systemy rejestracji i przechowania danych są zdolne rejestrować nawet awarie układu hamulcowego podczas lądowania. Dzięki nowoczesnej technologii i urządzeniom opisanym w niniejszym artykule, F-16 jest jednym z najlepszych najlepszych samolotów bojowych na świecie.

Keywords: samolot, przechowywanie danych, silnik odrzutowy, bezpieczeństwo