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Flight Test Instrumentation System for a Typical Prototype Civil Aircraft

Satyajeet Sahoo, L. Priyadarshini and G.Shekhar*

Abstract: When an aircraft is manufactured based on a new design, it needs to undergo a series of flight tests before it's allowed for commercial flight operations. This is done in accordance with the procedures laid by the government airworthiness certifying agency whose aim is to make sure that the aircraft adheres to minimum safety criteria, meets aerodynamic performances etc. It is then that the aircraft project is given a go-ahead for mass commercial production.

During flight testing, various system designers need to check and validate performance of their respective subsystems installed on the aircraft. Based on the designer requirements, different subsystems of the aircraft are instrumented with a variety of sensors and appropriate data acquisition system to capture a number of aircraft health parameters. The data thus generated is stored onboard for post-flight analysis as well as transmitted in real-time through a wireless telemetry link to a ground monitoring station.

The presented paper elaborates on a typical instrumentation strategy for flight test purpose and discusses various practical issues encountered while designing and implementing such a strategy. It's the gist of the relevant work carried out for over a decade.

***Keywords**:* Flight Test Instrumentation; Data Acquisition System; Solid State Recorder; Transducer; Signal Conditioning; Telemetry.

1. INTRODUCTION

The field of Flight Test Instrumentation (henceforth to be termed 'FTI') is very widespread and varies considerably based on the category of the aircraft viz. military/ civilian, light aircraft/ heavy aircraft, rotary wing/ fixed wing aircraft, low-flying/ high–flying aircrafts etc. The job of FTI is to pick up various parameters such as temperature, pressure, vibration, strain, linear speed, rotational speed etc., from different aircraft subsystems and store them in suitable media for further analysis. The FTI strategy is made based on the types of subsystems available on the particular aircraft e.g., fast-moving aircrafts specifically need more vibration, temperature parameters than a slow-moving aircraft. A rotary-wing aircraft (helicopter) needs completely different set of parameters in comparison with a fixed-wing aircraft. Similarly, aircraft structures fabricated from different materials (metal/composite etc.) require different FTI strategy compared to each other. Some low-flying aircrafts do not have the air-conditioning system in comparison to the high-altitude aircraft where air-conditioning and cabin pressurization is a must. Here also the FTI strategy has to be different.

In the past, the FTI was carried out by manually recording data from instrument panels. This method was not only tedious but also could not provide accurate data especially in dynamic flight conditions. Lags and inaccuracies in the cockpit instruments could affect the phase and quality of the data. These

CSIR-National Aerospace Laboratories, Bangalore, Karnataka, India
* e-mail: sahoo@nal.res.in, priyadarshini.l@nal.res.in, gshekhar_cad@nal.res.in

factors were involved in the decision to develop a more automated flight test data acquisition system of the present day.

We present before you the strategy of a typical FTI system successfully implemented on a light transport aircraft powered by a pair of 1200 SHP turbo-prop engines.

2. DESIGN CONSIDERATIONS

Several factors have influenced design of the FTI system for the said aircraft. If we take a look at the aircraft from system point of view, it comprises of the following major subsystems: Power plant (engine), Flight Control System (FCS), Environmental Control System (ECS), Cabin Pressure Control System (CPCS), Electrical subsystem, Avionics suite, Hydraulics etc.

The parameters of interest from the Power plant include engine RPMs, temperatures/pressures at various locations of the nacelle, fuel system parameters, engine vibration, pilot control-lever angles etc. The parameters from FCS include aileron, rudder, and elevator surface angles and control column/wheel angles. Similarly, the ECS/CPCS system requires temperatures/ pressures inside cabin/cockpit etc. to be measured. Also an ECS system designer will be interested to check pressures/ temperatures at the source (pressure-controller) end. The electrical system has DC generators whose voltages and currents along with temperatures at various locations are to be measured. The main/auxiliary battery also generates a lot of parameters of interest.

The avionics suite of the aircraft includes LRUs which are useful for navigation and communication purposes. Also it has Air Data Processing Unit and Attitude and Heading Reference Unit which generate critical aerodynamic (pitch, roll, yaw angles) and air data parameters (speed, altitude etc.). In addition, the Structures engineer needs to measure dynamic load /strain at various locations of the airframe.

Taking into consideration all the inputs/requirements of the system designers, a list of parameters was finalized. It was decided that suitable transducers along with signal conditioning system and a data acquisition unit (DAU) need to be installed on the aircraft. The standard DAU is a digitizer-cum-multiplexer and generates multiplexed PCM serial data. A solid state recorder is used to store the data.

Another important consideration was that during flight testing, many parameters which are identified as critical from flight safety point of view must be monitored by a team of specialists available at the ground telemetry station. Hence the DAU output was to be transmitted to a ground monitoring station through a dedicated L-Band FM telemetry link. But since the number of parameters was more and it included dynamic parameters such as ‘vibration’ whose sampling rates used to be very high, the baseband data rate of the DAU was too high and it was causing the telemetry RF modulated carrier to consume a greater bandwidth. But since there is a restriction on the bandwidth, the data rate had to be reduced in order to contain it within the allotted limit. Thus, a separate multiplexed data stream was made containing only critical parameters and was fed to the telemetry link whereas all other data (whether critical or not) were recorded in the onboard Solid State Recorder.

3. DATA ACQUISITION SYSTEM

The aircraft is 15m in length having 14m wingspan. The avionics suite and cockpit systems are in the front while the engines, ECS, and Electrical systems are in the aft. This is the reason why two DAUs were selected one installed in the front fuselage and the other in the rear. Sensors close to the individual DAUs were terminated to the respective ones so that the sensor analog output is not required to travel longer distance in which case it would have picked up more noise. The two DAUs would work in synch with each other (i.e., both the units work according to the same clock cycle) with one working as the Master Controller and the other the Slave unit. Both these units were from the same vendor (KAM-500).

The DAUs work on the principle of TDM/PCM. All parameters captured by the DAU input channels are first given suitable signal-conditioning followed by 16-bit digitization. All these 16-bit parameter samples are arranged in a user-defined PCM frame structure (one followed by the other) on a time-sharing basis by the KAM-500 Controller module. The job of the slave KAM is to prepare such a PCM encoded data and send it through a serial data link to the master KAM. The master KAM decodes this, extracts all parameters samples. The master also generates its own parameter samples. The total list of samples is again arranged in a final PCM format and is sent to outside world for data recording as well as for telemetry transmission.

Apart from this arrangement, there is a third-party DAU (NANO S2) meant only to pick up and process structural load testing parameters (strain gages) and vibration (accelerometers). Usually, these parameters are sampled at a very high rate and are not meant for telemetry transmission. They are stored locally on a compact flash card.

At a critical time of the flight testing, it was required to telemeter some parameters from the third DAU in addition to those from the first two DAUs. This was a difficult task as all the three DAUs won't work in synchronism with each other because they belong to different vendors. This situation was overcome by the use of asynchronous connection in which the final PCM stream from Master KAM-500 was fed to the NANO S2 PCM Merger module asynchronously. The latter could decode/extract all parameter samples from the incoming data. Along with these data, it added its own data required for telemetry and prepared a fresh PCM frame. This PCM encoded serial data was forwarded to the telemetry transmitter as well as the solid state recorder. This was done in addition to its duty of storing dynamic data in the Compact Flash card.

The KAM-500 is a high performance modular data acquisition system with a maximum of 13 user slots designed for harsh aerospace application and supports PCM Encoding and integrated data logging.

Two such KAM-500s are connected with each other by using a merger module in one of the KAM-500 chassis which is called the MASTER and the other SLAVE. Both chassis operate synchronously with appropriate interconnections.

KSM software is used to configure the hardware modules for acquiring sensor data at the required sampling rate, sequence and scale by generating suitable frame and defining word locations for parameters. A Quicklook display facility is also provided for the ease of monitoring parameters onboard in real-time. The encoder of MASTER KAM generates an IRIG-106 Ch.4 PCM stream which is sent to a third DAU which is described in detail in the next section

The ETEP NanoS2 acquisition system is an efficient and modular flight test data acquisition-cum-recording unit, with an ultra-compact design, and an ease of changing acquisition modules. This unit is similar to the KAM-500 unit from functionality point of view. The controller module of the unit is equipped with a reliable internal time code source/IRIG B or it can be coupled in option with GPS time code. It generates IRIG 106 chapter 4 telemetry output. This encoded PCM stream carries all parameters data except for vibration and strain data, and transmits them in real time to a ground station. A PCM merger module accepts and decommutates the PCM stream from the Master KAM 500 DAU via an asynchronous connection (Fig. 1). The final PCM stream is subsequently transmitted in Bi-phase TTL protocol to Ground Telemetry station and in parallel to this, same PCM data in RS-422 protocol is recorded in an onboard recorder for post-trial analysis also. The NanoS2 DAU has an inbuilt recorder thus providing a compact and modular solution. The vibration and strain gage data with high sampling rate are recorded on a flash card in the memory module of DAU. Data logging is controlled by the Cockpit Display Unit (CDU). This data is however available only for offline analysis.

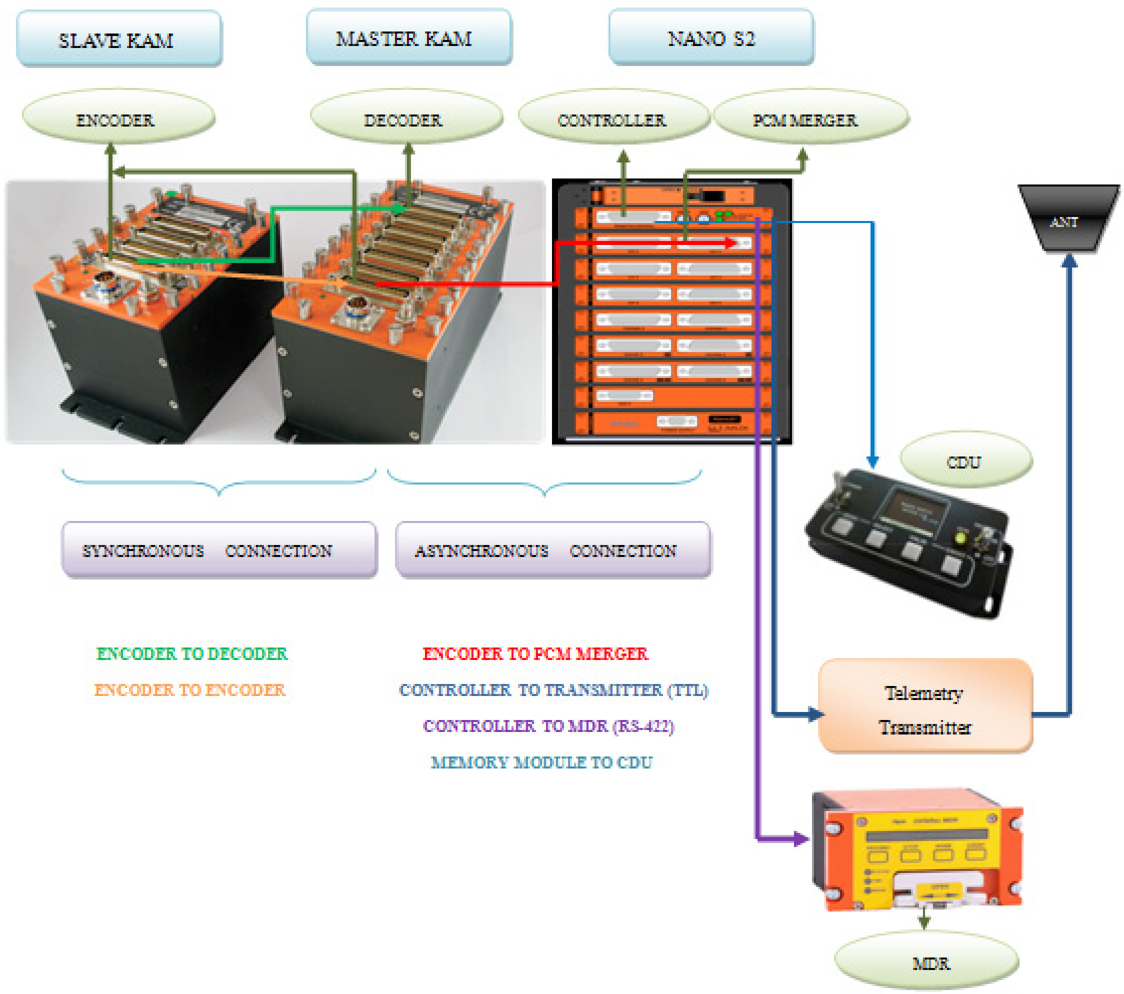


Figure 1: Interconnection between Master-Slave KAM and NanoS2 DAUs

4. SENSORS AND SIGNAL CONDITIONING

FTI involves several environmental and structural measurements on the aircraft using variety of sensors. These sensor outputs, in turn, require signal conditioning before a data acquisition device can effectively and precisely measure the signal. Signal conditioning is one of the most important components of a data acquisition system as it bridges the gap between sensor and the digitizer.

About 72 discrete warning signals are tapped from across 20 different avionics LRUs and other primary systems of the aircraft. Opto-coupler circuits are designed in order to provide electrical isolation between the measurement system and the signal source in order to avoid any sort of loading effect. Further, a frequency-to-voltage converter board with amplifier circuit has been developed to process tachogenerator installed in engine to sense engine rotational speed. The tacho's pulse output is converted to proportional voltage using the circuit which is further fed to the DAU. Sensors such as strain gages/ RTDs, are part of Wheatstone bridge configuration. Regulated DC power supplies and instrumentation amplifiers have been designed in-house to process those signals to make them compatible to the DAU modules. Sensors such as pressure transducers viz., absolute, gauge and differential, K-type thermocouples, IEPE accelerometers, bidirectional current sensors and linear precision potentiometers are used widely in the aircraft to examine and validate functionality of different systems.

5. CABLE ROUTING

A well-planned structured cabling system facilitates the continuous flow of information between the sensors and DAU, enables the sharing of resources and promotes smooth operations. Further, good quality airworthy cables are to be used to keep cable losses to a minimum, to make sure they are heat resistant, which in turn enhances data integrity. With these in mind, a combination of cables are used which are certified with air-worthiness standard IPC/WHMA-A-620 and can support variety of data signals.

Cables are chosen depending on the applications, architecture, environment and sensor output viz., single core insulated cables for single-ended sensor outputs; 2-core shielded and twisted cables for differential-ended outputs and audio signals; 3-core shielded untwisted cables for potentiometers and Chromel-Alumel 2-core shielded twisted cables for K-type thermocouples. The main purpose of considering twisted/shielded cabling is to provide protection against electromagnetic interference (EMI). The 22 awg cables carry analog signal whereas 16-22 awg cables are meant for power supply depending on the ampere/wattage requirement. An RG393 coaxial cable connects telemetry transmitter to antenna for effective RF power transfer over long distances without attenuation. ARINC 429 data from avionics LRUs is transmitted to FTI DAU using twisted pairs carrying balanced differential signaling.

All the wirings and routings are well planned with proper AutoCAD drawing, color coding and documentation. With these in place, the looming is carried out and is validated with rigorous continuity checks and megger checks for testing cable insulation.

6. DATA STORAGE

A total of 400 parameters generated by FTI system are recorded at two places, the MDR and the CF card during each flight trial for post-flight analysis. This recording is different from the Flight Data Recorder (Black Box) recording which stores all critical parameters of aircraft and is meant for accident investigation purpose.

The Modular Data Recorder (abbreviated MDR; Make:HEIM DATaRec) is a highly qualified onboard recorder installed in the cabin and is easily accessible to the flight test engineer to start/stop recording and identing test points during flight trials. It can support high bit rate of 240Mbps with expandable storage capacity of 64GB. Using proprietary software, the system can be configured to store incoming PCM data in IRIG 106 chapter 10 format. This file is processed further using software developed in-house to obtain the raw data which is in ASCII decimal format and then will subsequently be converted to obtain relevant engineering unit data. The MDR records data from the NANO S2 which also sends the same PCM stream to telemetry.

There are a number of high-sampling rate dynamic parameters which could not be transmitted to telemetry because of bandwidth issues, are stored locally on a compact flash card placed in the memory module of the third DAU i.e. NanoS2.

7. DATA CONVERSION/ANALYSIS

The raw binary data of 400 parameters logged in the MDR in IRIG Chapter10 format is converted to *.pcm format using OEM supplied D4 Converter application software. Consequently, data is converted from binary form to engineering unit form using appropriate conversion factors for plotting and analysis.

Table 1

Sample raw data of critical parameters of Electrical sub-system

MBatVol	*AuxBatVol*	*MBatChCu*	*ABatChCu*	*LC1*	*LC2*	*SSV1*	*SSV2*
41640	41101	32786	33231	32739	32860	41644	41692
41544	41107	32782	33231	32736	32862	41596	41664
41633	41092	32788	33223	32741	32860	41634	41692

Table 2

Sample EU converted data of critical parameters of Electrical sub-system

MBatVol	*AuxBatVol*	*MBatChCu*	*ABatChCu*	*LC1*	*LC2*	*SSV1*	*SSV2*
27.49	24.99	0.33	1.52	-3.64	-7.54	27.45	27.61
27.20	25.01	0.27	1.52	-3.92	-7.35	27.31	27.53
27.47	24.97	0.36	1.50	-3.45	-7.54	27.42	27.61

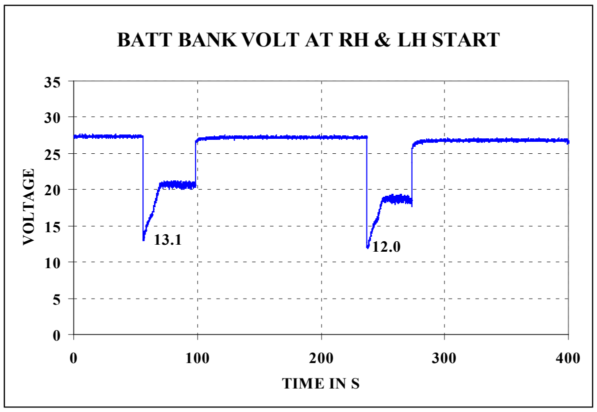
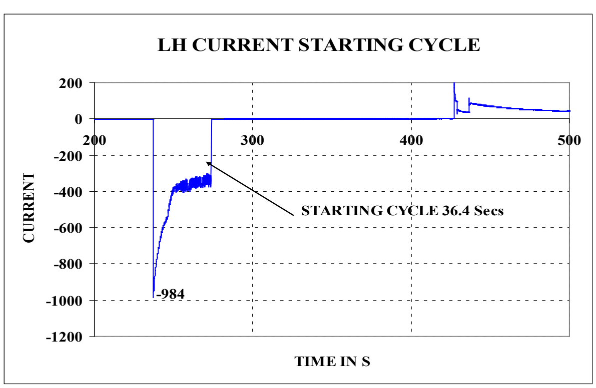


Figure 2: Aircraft battery voltage at engine start

Table 3

Electrical sub-system data at the start of LH & RH engine

Engine	*Starting Current (A)*		*Min Voltage at start(V)*		*Start Cycle Time(S)*		*Ng (%)*
	Exptd	*Actual*	*Exptd*	*Actual*	*Exptd*	*Actual*	
RH	<2000	1130	>12	13.1	<45	42.7	42.7
LH	<2000	984	>12	12	<45	36.4	47



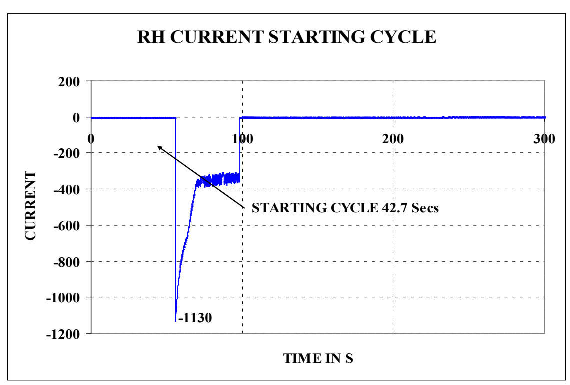


Figure 3: Initial current drawn at the start of LH & RH engine

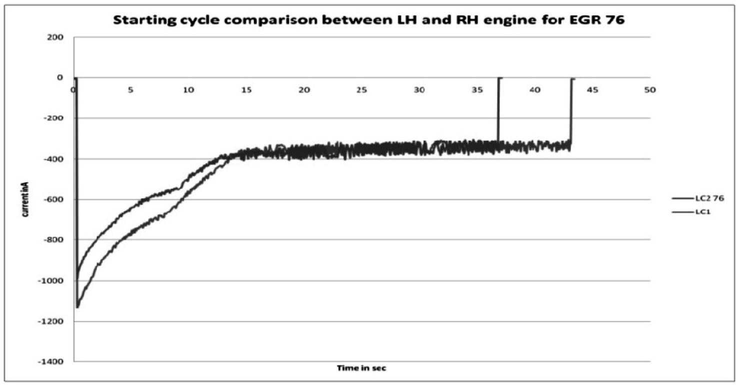


Figure 4: Comparison of initial current drawn from Ground Power unit by LH and RH engine

8. CONCLUSION

The FTI implementation has helped generate sufficient test data during routine engine ground runs, taxi trials and flights. Using this data, the system designers could validate performance of their respective systems. The entire setup has been validated and proven to serve the purpose of recording all users specified parameters very efficiently. The design is fully in accordance with Inter-Range Instrumentation Group (IRIG) norms. It may be noted that IRIG is an international body which formulates technical standards and protocols for aircraft and missile flight test instrumentation.

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