DOI 10.5162/ettc2020/2.1

Robust and Flexible Flight Test Instrumentation for Wireless and Wired Measurements

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Abstract:
This presentation will discuss the range of tasks in flight test instrumentation that can be solved with a modular and flexible flight test system. Examples include rotor tests, landing gear tests or complete certification tests, just to name a few. Often, a common challenge is to synchronize and combine the variety of data sources across the airplane or helicopter, like analog sensors, avionics or telemetry for rotating parts. In addition, modern possibilities for handling and processing the live data will be discussed. That includes self-explanatory visualization, real-time processing and if relevant transmission to ground.

Key words: data acquisition system, rotating telemetry, instrumentation, video, flight test

Basic Requirements for FTI

Flight test instrumentation nowadays needs to fulfil a variety of basic requirements. Many of these requirements are common throughout the variety of aircraft. For example, a certification test for a small airplane requires a similar variety of test parameters as one for a large aircraft. Of course there may be differences in the number of sensors, distance between them, available space and permissible weight. In addition, large aircraft allow test engineers to be onboard while small ones rely on telemetry.

Common requirements are such as:

- Acquisition of various sensor types like strain gauges, thermocouples, RTDs, LVDTs, RVDTs, voltages, pressures, vibrations or flow rates
- Integration of avionics or aircraft control systems, commonly via ARINC-429, MIL-STD-1553B or AFDX / ARINC-664
- Synchronization between all FTI subsystems and with absolute time, typically referencing GPS time
- Ruggedness in the mechanical sense as well as against moisture, low temperatures, low pressures and vibration
- Providing as much resolution as possible. Desirable and often possible is 24 bit. Then, saturation of A/D converters can be well avoided, as headroom on input ranges doesn't cost accuracy.
- Ability to handle thousands of parameters and channels

Potential of Flexibility

Flexibility can mean fundamentally different things to different people, especially depending on the industry they work in. Some of the concepts presented here actually do have their origin in automotive R&D or railway certification testing. There, some requirements are in line with flight testing, others are not important while again others are more crucial or simply more common.

All the presented concepts and possibilities have in common that they can make the testing more productive. May that be by providing more information to the engineers, reduce time or reduce the possibility of making mistakes.

Intuitive software GUI

Displayed data is most useful to a viewer if it is intuitive. Then it does not just show numbers or graphs, but it tells the viewer whether the test is going as expected, whether all subsystems are operating properly or to what extend something has improved compared to the previous test.

Everybody however has an own opinion of what is intuitive. One often-appreciated approach is to create a software GUI that looks similar to reality. That can mean that cockpit instruments are simulated with a realistic style and arrangement.

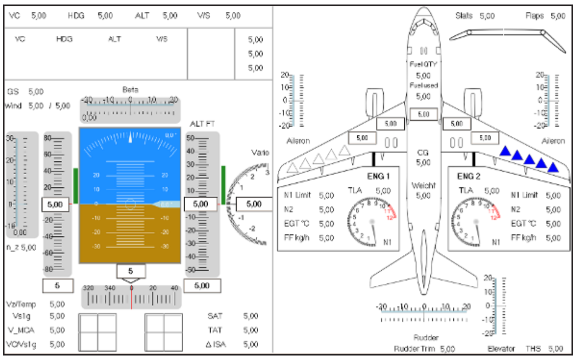

Figure 1 Example software interface designed based on customer ideas

On the other hand, many people appreciate a software GUI that looks similar to what they are used to, which is not necessarily from reality, but from an earlier generation data acquisition system (DAS).

Furthermore, sometimes the software instrument that perfectly illustrates a certain information is not available and difficult to build up by combining standard elements.

So to really achieve something most intuitive, following things have to be available:

- A useful set of combinable software instruments (widgets)
- A possibility to arrange and combine these quickly, i.e. without the need of software development
- A possibility to realize custom widgets for very specific subsystems

None of these points is a problem anymore in modern software. The third point can usually be realized by programming some C# addon or plugin to the test software, such as imc STUDIO. So a software developer is needed, however modern scripting interfaces reduce the needed development time to a few days only.

Multi-monitoring

During many tests, it is crucial that several engineers can access the live test data independently from each other. Then, an engineer might decide he only wants to see 100 out of 10,000 channels. This may not influence the overall acquisition nor what other engineers see.

This structure usually utilizes a central PC handling and storing all data, while offering live data streaming to further PCs. This can usually be scaled up to at least 15 PCs.

On each PC, selected data can be displayed with all the widgets mentioned earlier. Furthermore, engineers can decide to cut certain sections of data for themselves without influencing the overall data storage.

The number of PCs is flexible and can even change during the test. Usually, these monitoring PCs are unable to control the central data acquisition. They are purely for monitoring.

With such a structure, data is usually stored in parallel in

- the data acquisition systems,
- an on-board storage, e.g. NAS or PC and
- optionally and partly at each monitoring PC.

The concept can be used both with the PCs being in the aircraft or on the ground, receiving telemetry data.

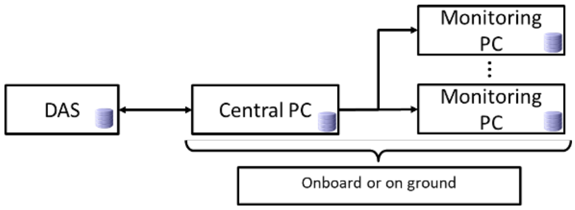

Figure 2 Structure of multi-monitoring PCs

Real-time data analysis

The purpose of data analysis is similar to the one of an intuitive software interface: to turn data and numbers into information and conclusions.

Simple examples are digital filters, slope calculations, integration or statistics. However, also advanced functions are useful like frequency-domain analysis, event detection or comparisons with reference data.

Nowadays all of these can be realized without programming. Instead, formulas are used which are commonly known from post-processing software like imc FAMOS. This enables the test engineers to implement the whole range of analysis themselves on-site without consulting external software experts.

Example formulas might look like:

- Power = Voltage * Current
- Velocity = Integral(Acceleration)
- Res = CrossCorrelation(Ref, In1, 512)
- Spectrum = FFT(Acceleration, 2, 1024)

Usually, in case of standalone applications, the data acquisition system is responsible for carrying out the calculations using FPGAs or DSPs, while any connected PCs or monitoring PCs can add further calculations, or handle those

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needing rather massive processing power. The PC-based calculations can also be modified or extended during flight, again without influencing or stopping data acquisition or interfering with other engineers monitoring the test.

3rd-Party Device Integration

Often, the central data acquisition system needs to be combined with further acquisition systems or data sources. Only this combination provides the needed data for complex applications such as certification tests.

Some technology originally developed for automotive R&D can be utilized here. There, it is very common to have various subsystems, controllers and data sources and have a data acquisition combine and synchronize all of these.

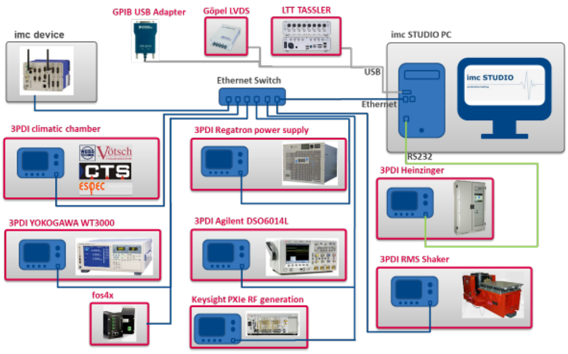

Figure 3 Example structure of combined subsystems in automotive industry

Data acquisition systems traditionally offer interfaces for field-busses like ARINC 429. A similar example is a maintenance port of a proprietary control unit. It can be seen as a non-standardized fieldbus. Such ports are often utilizing Ethernet or serial (RS232, RS422 or RS485) communication.

Figure 4 Example universal serial and Ethernet interface in a data acquisition system

To support such program-specific communication interfaces, modern data acquisition systems offer universal serial and Ethernet interface boards. They come with a basic framework for communication and can be equipped with custom firmware to support a specific protocol.

Nowadays, it is actually very common of electronic modules to fulfil completely different tasks just with different firmware. Modern universal fieldbus modules open these possibilities to flight testing, as their firmware framework is open source and can be adapted by any developer of embedded systems.

These programmable field-bus interfaces can handle rather simple data sources like readings of pressure sensors via a low-level RS485 port, but also several thousand channels originating from a control unit.

Rotating telemetry

The most typical requirements for rotating telemetry are to capture data from propellers, rotors, turbines or wheels during taxiing or landing.

Figure 5 Example KMT telemetry measuring strain on a helicopter main rotor

These telemetry systems are usually multi-channel and relatively high-speed. An important task of the central data acquisition system is to receive their data. It needs to be synchronized and made available in the same fashion as data from any other subsystem.

That includes giving the engineers all the ways of visualization, data analysis and monitoring that they are used to. Apart from this, a customized field-bus interface can be very helpful. For example, the telemetry system might output 16 channels of strain. Instead of needing 16 analog cables to transmit the data, a single Ethernet cable is sufficient. This reduces the number of cables, weight of cables as well as uncertainty of data by replacing an analog conversion stage with a digital transmission.

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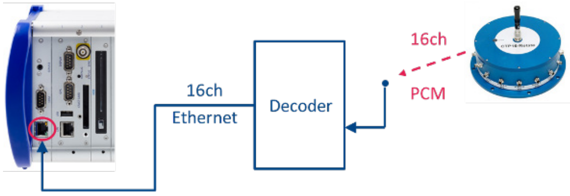

Figure 6 Digital communication between a 16 channel rotating telemetry system and the DAS

Video integration

Acquiring data in flight testing is more and more augmented by capturing videos. That can mean two different things:

- Video camera data
- Video signal data

The first point refers to cameras specifically installed on the aircraft to monitor a certain area. These cameras usually record throughout the complete test, which can create rather large files. It is however also possible to trigger video recording. The trigger can be based on some algorithm to detect meaningful events, or can be manually released. In any case, a pretrigger is also possible. For example, if an even occurs, the video starting 10 s before that can be recorded.

Video signal data in contrast is based on already existing video signals in the aircraft. That usually refers to cockpit displays. Using this approach, test engineers can understand what the pilot saw on his screen and utilize this during data evaluation.

Video signals from any of these sources are usually recorded in highly compressed format, e.g. H.265, sometimes accelerated by dedicated hardware boards.

Modularity and decentralization

Size and weight of FTI is something every flight test instrumentation engineer is interested to reduce as much as possible. In small aircraft, it can even pose serious problems as the tests gain complexity.

One recent helpful possibility to achieve this is to physically adapt the data acquisition system. A good first step is to vary the number of modules depending on the needed inputs. With slot-based devices, this only means weight saving, while there are also devices that reduce in size as modules are removed.

Figure 7 Modules with independent housings that form a variable-size DAS

A large portion of the FTI weight is the wiring. Even with full instrumentation, reducing weight can be achieved by reducing wiring. A typical way to do that is by decentralizing the data acquisition. Naturally, the location of several data acquisition systems can be varied to get closer to the sensor. However, it is also possible to distribute single modules around the aircraft.

Communication between the modules or to the main DAS is often using established field busses such as CAN bus (for low-speed signals like temperature) or EtherCAT bus (for high speed signals). Distances of 100m can easily be reached this way, combining potentially hundreds of signals in just a single cable.

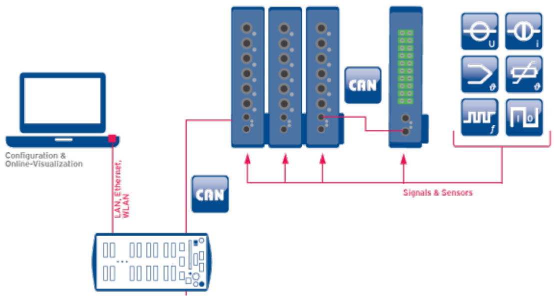

Figure 8 Example of distributed modules with CAN bus as inbetween communication

Conclusion

Flexibility of flight test instrumentation doesn't only mean being able to make changes quickly and easily. Fundamentally, it means that a data acquisition system's functionality can grow with the demands of the test engineers.

Many demands evolve after the first test flight and can actually still be implemented at that point without waiting for specialized software or hardware developers.

Utilizing such a level of flexibility, a data acquisition system cannot only cover a large variety of testing tasks, but can also provide some assurance to answer the unknown needs yet to come during a program.