EDITORIAL

Acquiring Meaningful Test Data on Purpose

Patrick L. Walter, Contributing Editor

Large-scale, instrumented testing, such as crash, flight (see Figure 1), explosive, drop, and more, can be very expensive to perform and difficult to repeat. It is not uncommon that after test completion a group of stake holders (test engineers, test requesters, analysis personnel, calibration staff, and others) spend a lot of time "scratching their heads" trying to figure out what the resultant data are telling them.

As the data significance is being pondered, one hears questions being raised regarding sensor-mounting techniques, data-channel noise floor, data-channel bandwidth, extraneous environmental effects, and more. The fact that these questions are being asked after the test has been completed indicates that the pretest instrumentation planning was not performed in a methodical manner.

Figure 1. Typical commercial airliner outfitted for flight testing.

A requisite sequence of events to develop a successful instrumentation plan follows:

1. *Clearly identify why the test is being run.* What is its goal? Physics-based predictions or models must exist to justify the measurements requested. It is not unusual when discussing a test for someone to say as an afterthought, "let's add some instrumentation to the test." The instrumentation should be the first part of the test plan, *not* an afterthought.

2. *The physics-based analysis of item 1 should result in the specification of the specific measurands (strain, acceleration, pressure, force, angular rate, temperature, heat flux, flow, etc.) that need to be acquired.* It should also, as a minimum, provide guidance as to sensor types, sensor mounting densities, measurement directions, anticipated amplitudes, and required data bandwidth.

3. *All sensors respond to other measurands (environments) in addition to the one they are intended to measure.* The manufacturer's specification sheets clearly indicate this fact. Additional data channels should always be incorporated into the test planning to monitor the instrumentation system noise floor in application. If properly implemented, these additional channels will document system noise attributable to other inputs to the instrumentation system aside from the desired measurand(s). The sensors dedicated to this purpose are called "placebo" sensors. They should have signal conditioning identical to any similar channel, except that they are configured to not respond to the measurand of interest.

4. *The sensor must next be coupled or interfaced to the test item.* The goal is to acquire a measurement as if the sensor was not there to transfer energy from the process being measured. The mass loading and stiffening of a structure by accelerometers, the effects of cavities or voids in front of pressure transducers, and the mechanical compliance of load cells are but a few examples of undesired modification of the process being measured.

5. *The sensor's cable must be carefully selected.* The cable has resistance, capacitance, and inductance. If its influences are not understood and accounted for, it can attenuate signals and induce unwanted filtering. It can also be a signal source attributable to cable-induced triboelectric effects. In addition, if not properly shielded, it can also couple undesired electromagnetic and electrostatic fields into the signal. Wear, bend radius, and thermal capabilities are but a few additional cable selection considerations.

6. *The analog signal conditioning must be selected to be compatible with the sensor and its associated cable.* Over the bandwidth that the physics-based data are desired, not only should the bandwidth of the analog portion of the instrumentation system be flat (constant) but if data time histories are of interest, system phase response must also be linear.

7. *The instrumentation system must be verified to be linear in its input-output relationship; this differs from phase linearity.* Assuming dynamic measurements are being made, these input-output linearity checks must be performed to encompass the entirety of the data frequency range. If the instrumentation system becomes dynamically over-ranged in application (driven nonlinear), extraneous frequencies are generated within it, and these frequencies contaminate the data.

8. *The analog filter, when necessary, is typically the final modifier of the analog signal before digitization.* Terms such as filter type (Chebyshev, Bessel, Butterworth, etc.) must be understood as well as the degree of attenuation that the filter provides. The latter information is provided by the number of filter poles, filter order, attenuation in dB/octave, attenuation in dB/decade, or some analogous specification.

9. *In today's world, data are typically digitized for storage and analysis.* The data-sampling rate must be compatible with the analog portion of the system. This is typically controlled or constrained by the aforementioned analog filter, whose effect on the data must be understood. With modern technology, data are often acquired with sigma-delta type systems containing an integral digital filter whose characteristics must equally be understood. Digital system resolution (number of effective bits) must be considered relative to the subsequent data processing. For example, successful data integration is very dependent on the ability to define a true zero, which can only be quantified within the limits of ± one-half bit in a digital system.

10. *Before test, the sensor must be calibrated and perhaps have its response evaluated to anticipated extraneous measurands.* Then the entire measurement system must be calibrated end to end.

11. *Throughout this entire planning process, the end use of the data must be considered.* As noted previously, data integration requires an increased focus on bit resolution. Also of note, if the recorded data are to be integrated, less high-frequency response is required than if differentiation is to occur. If only data frequency content is of interest, theoretically we only need to sample to twice the highest frequency contained in it. If we want to visually see this highest frequency, we should sample to a minimum of 10× its value. For random

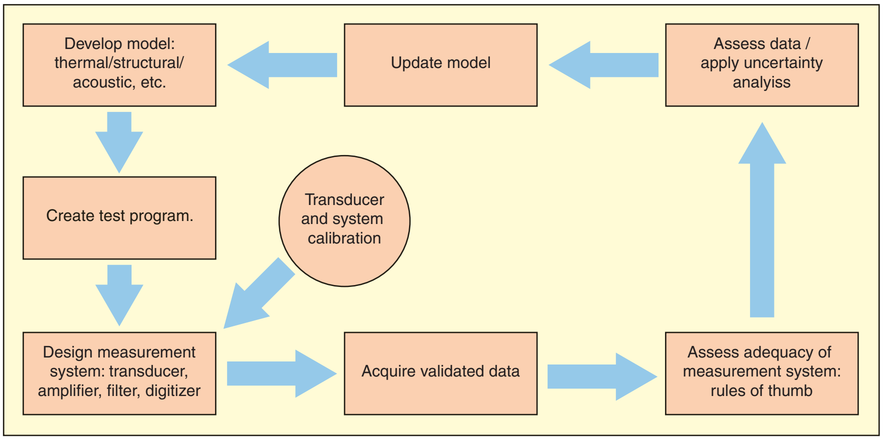

Figure 2. Schematic diagram of the dynamic data acquisition process.

signals to be subjected to power spectral density (PSD) analysis, maintaining instrumentation system phase response becomes less important. These are but a few examples of how the ultimate data usage should guide measurement system design.

12. *Finally, after comparison with pretest predictions, the data need to be carefully filed for future reference, and the instrumentation system that recorded them must be carefully documented.* The assessment of future test item improvements or the development of the next generation of test items depends on performance comparison to prior test results.

Now, having presented the sequence, it might seem overwhelming. However, it just requires a transformation in thinking. In our formal technical education process, we were typically presented with a system and asked how it would respond to a given input. That is called analysis, which can be summarized as follows:

$$\mathit{Input} \Rightarrow \mathit{System} = ?$$

Measurement is just the opposite. We typically measure an electrical parameter output (current, voltage) and try to infer the system input (temperature, pressure, acceleration, strain, angular rate, etc. as denoted before).

$$? \Rightarrow \mathit{System} = \mathit{Output}$$

Two things are obvious here:

- Unless the instrument system is appropriately designed and characterized, we cannot infer its input. Note that the instrumentation input is the object of the test. We measure its output. Grabbing components “off the shelf” and “sticking them together” rarely produces good test measurements.
- We all have the knowledge base to understand instrumentation. It just involves reorganizing lessons taught to us previously. *Independent of the amount of physics based analysis performed on a test item, if the item is properly instrumented, the truth is always in the data.*

Figure 2 illustrates a synopsis of the process just described. Without an orderly instrumentation system design process, the only guarantee that I can provide to you is that you will record something. It may be the cable breaking, a pressure transducer responding to dynamic strain or transient or steady-state temperature, a strain gage in a transient thermal environment behaving as a thermocouple, an accelerometer responding to base strain, etc. I can continue this list *ad infinitum*.

This takes us right back to where I started with the second sentence of this editorial: *It is not uncommon that after test completion a group of stake holders (test engineers, test requesters, analysis personnel, calibration staff, and others) spend a lot of time “scratching their heads” trying to figure out what the resultant data are telling them.*

We can do better than this!

The author can be contacted at: p.walter@tcu.edu.