

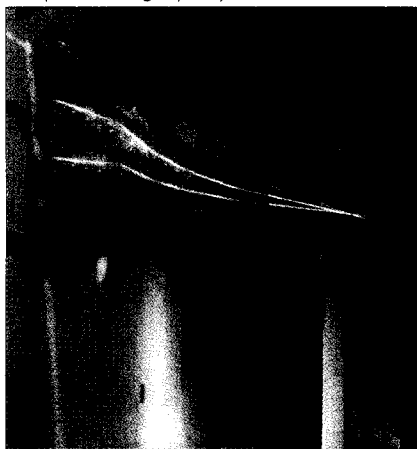
What every ground testing manager needs to know

Global competition in aerospace vehicle development has placed stringent demands on ground test facilities to continuously decrease test cycle times while increasing the quality of measured data. This demand for increased data quality is largely driven by customer test and/or design requirements and a facility's commitment to continuous quality improvement. Providing test data that meet customer requirements is essential to any test facility that strives for quality products.

Ground test facilities such as wind tunnels have always emphasized applying the proper testing and measurement techniques to obtain accurate, high-quality data. The best measure of this quality is the experimental uncertainty of the data produced. However, assessing the experimental uncertainty of these data has been a cumbersome, time-consuming task. Until recently, the lack of an accepted standard has caused uncertainty analysis and statistical process methodology to be regarded as "black arts."

An engineering approach to as-

U.S. test facilities such as wind tunnels face growing competition from overseas rivals that produce high-quality data.



sessing test facility data quality has recently been developed and accepted as standards by both NATO's Advisory Group for Aerospace Research and Development (now the Research and Technology Organization) and the American Institute of Aeronautics and Astronautics. These standards are becoming more widely known and accepted by both wind tunnel facility owners/operators and customers.

Issues and answers

Several fundamental questions must be addressed in order to provide the best possible product to the customer. The answers offered here are based on common logic and require little understanding of technical details on statistics and experimental uncertainty.

• **What is product quality?** In ground testing, we must assure that customers receive the high-quality products they expect. When customers perform testing in our facilities, the degree to which they perceive that we meet their expectations is the primary measure of quality. Ground testing is performed to answer specific R&D and design questions. High quality means that we provide the data needed to answer those questions with minimal ambiguity, which can only be achieved consistently through the practice of experimental uncertainty analysis and attainment of statistical quality control in testing processes.

• **Why do we need quality?** Sustained product quality is the only way to ensure viability. In the 1970s, the prevailing notion in the steel and auto industries was: "Customers are buying our products and not complaining; why do we need this quality stuff?" In the 1980s we learned the painful lesson that quality is the only sure way to keep customers. The U.S. might have

lost the steel and auto industries if it had not learned from its failings and staged a comeback.

In ground testing, especially wind tunnel testing, there are indications that the U.S. lead is eroding. Industry customers are increasingly relying on overseas facilities for critical product development testing because of the perceived high quality of their data.

Customers are interested in the value received for the cost of testing. As a result, they are paying more attention to the accuracy of the data acquired. Customers used to ask for "normal" wind tunnel accuracy, but as they begin to understand experimental uncertainty methodology, they are now specifying their accuracy requirements and are requesting a more thorough estimate of the experimental uncertainty of the data. They are also beginning to request preliminary uncertainty analyses.

In addition, testing personnel are beginning to work closely with customers to understand how the test data are used and how data uncertainty will affect the customers' perception of value. This will help facility personnel identify test techniques and instrumentation that will ensure the test goals are met—providing the highest quality data at the lowest cost.

• **How do you maintain the product quality edge?** Prior to the 1980s, when the concept of statistical quality control promoted by W. Edwards Deming in Japan was not well known, quality control in the industry relied on Quality Assurance and inspection programs. Products were produced according to established processes. They then were inspected for conformance with a set of inspection standards. Products were rejected or reworked if they failed to meet the standards.

We soon learned that this inspect-in-quality process put us behind our competitors who practiced Deming's method of statistical quality control of the processes and subprocesses that produced the products. The product quality edge is maintained by continuously improving these processes such

that the outcome is highly predictable and well within the tolerance required.

High-quality products from ground testing are no exception. They can only be produced by establishing statistical quality control of the processes, and the state of statistical control can only be attained by practicing experimental uncertainty analysis.

The specifications for instrumentation accuracy requirements have a direct bearing on product cost. In the past, customer data requirements were usually not well defined, and accuracy requirements were based on "what was done before," not on what was required to meet final data accuracy requirements. Not understanding how instrumentation error affects the final data often contributed to poorly defined requirements.

On the other hand, test data were sometimes produced with a quality far greater than that required to answer the development questions. For example, trend questions on stability and control were answered by data that could satisfy the requirement for high-accuracy cruise performance. The only time the requested accuracy was questioned was when it was felt that the level of accuracy could not be met.

Finally, a priori knowledge of data accuracy requirements can be used to determine if a required test can be successfully performed in a given facility with the existing instrument and test techniques. Large cost saving can result if it is known that the data produced would not be able to answer the design questions. Likewise, if test goals can be met with a lower accuracy requirement, cost savings may often be attained.

•*How do you sustain quality at low cost?* Many managers initially objected to the practice of experimental uncertainty analysis on the grounds that it is too expensive. But the best way to maintain a high-quality product at low cost is through statistical quality control. If you produce your product consistently to a predetermined quality through process control, rejection and

rework rates will be substantially reduced. This means "do the right things the first time," which leads to cost reduction. Repeat runs to provide better data will not be required, saving costs.

The difference is how we view the cost savings—long vs. short term. Establishing a state of statistical control through the practice of experimental uncertainty analysis will mean some up-front investment in training, documentation, calibration, and analysis. But the saving accrued from the avoidance of bad data and the need for repeated runs will far exceed the initial investment.

Uncertainty analysis can guide a decision as to whether testing should be done at a selected facility. It can also point the way for facility improvements, leading to world-class status. For example, a facility experimental uncertainty analysis will uncover areas where instrumentation is less than adequate to meet routine requirements. As a consequence, when upgrading or replacing capital equipment, it will be easier to identify and justify the allocation of funds to maximize benefits for the customer. Such analyses also lead to better trained workers as they gain greater understanding of facility capabilities and the data they produce.

•*How do you apply experimental uncertainty analysis?* Measurements are usually made by a physical device and translated into an electrical signal. For example, in a resistance pressure transducer, a diaphragm is deformed under pressure. The deformation alters the electrical resistance of a resistor network attached to the diaphragm and thus the output signal of the transducer. Each transducer is calibrated, which correlates the output signal to a pressure. The output signal can go through various types of signal conditioning to amplify and/or filter it. The signal may then be converted from analog to digital before it is recorded.

This process induces several errors into the measurement, stemming from: changes in temperature and humidity, resolution and instability of the device,

amount and type of use the device has seen since its last calibration, noise in the input electrical signal, amplification of the output signal, wire resistance, analog to digital conversion, and the original uncertainty of the calibration. The uncertainty of a measured value is dependent on the error sources, the process used to quantify the magnitude of the errors, and the techniques used to acquire the measured data.

As each parameter is used in engineering formulas called data reduction equations, the errors for each measurement propagate throughout the calculation. The final number should then be reported as its measured or calculated value plus or minus an uncertainty based on the statistical distribution of the propagated errors.

An uncertainty analysis is performed by estimating the errors associated with each measurement as it is converted into engineering units and propagating the uncertainty of each measurement through the data reduction equations to estimate the overall uncertainty of the results. The uncertainty analysis will also estimate the relative importance of each measured parameter. Doing this analysis in the planning stage of a test is extremely important. It will let you know if the proposed experimental setup will meet the test requirements or, if not, which measurements need to be improved.



High product quality is a primary goal for ground testing facilities. The ultimate objective is the ability to produce test data of predictable consistency in accuracy. The only way to achieve this is to rigorously establish statistical quality control on the test processes through the practice of experimental uncertainty analysis. The initial investment both culturally and fiscally may not be small, but the cost of not doing it can be very high.

James C. Yu
AIAA Ground Testing
Technical Committee