Flight Test News

http://www.sfte.org/

Spotlight on the Tech Council

According the SFTE Technical Council webpage, the "TC promotes Flight Test Engineer professionalism, improves technical communications among members in all related FTE fields, and provide forums for discussing flight test technology issues." The Tech Council advances these objectives multiple ways, including the technical paper and tech expert databases, but perhaps none is more obvious than the brightly colored SFTE Reference Handbook. In fact, many members have suggested that we should highlight Handbook content and use *Flight Test News (FTN)* as a laboratory to test material for future updates. Relevant, timely technical material is a priority shared by both the TC and *FTN*, so in this issue we beta test this idea.

Al Lawless, chair of the Tech Council and Honda Aircraft Company corporate member representative, also wants to use FTN to update members on the actions of the TC and draw attention to website resources and reports that the TC already maintains and updates regularly, like their forum posts and technical papers database.

Al stepped into the member spotlight to answer some silly and some serious questions for *FTN* readers.

FTN: If you had to eat only one food for the rest of your life, what would it be?
AL: Quizno's Italian BMT

FTN: If money was no object, where would you travel to?
AL: Exotic South Pacific islands

FTN: If you could spend one hour with any Flight Test person past or present, who would it be?
AL: Fred Weick, NACA engineer

FTN: List the 3 most important things in your life right now.
AL: Family, fun, learning

FTN: What is the walk-out song for your life?
AL: Bright Side of the Road (Van Morrison)

FTN: If you could work on any flight test project regardless of time, money, or difficulty, what would it be?
AL: Light Aircraft program such as Extra, Vans

FTN: If you could ask 80 year old Al for flight test related advice for your life right now, what would it be?
AL: I would ask him how to improve the profession.

FTN: If you could tell younger Al advice based on what you know right now (that you wish you knew) what would it be?
AL: "Luck" is being prepared when opportunity knocks.

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Navigating Uncertainty – Arriving at the Signal in the Noise

What is a Markov chain Monte Carlo model, and why does it matter? What is the difference between RNAV and RNP? What is a data band? How is it different than tolerance? Why do we use them?

These are all *significant* questions, and their answer hides like a valley masked by the long shadows of towering mountains. These peaks grab our attention. They are a more familiar sight like the primary disciplines of flight test engineering—performance, flying qualities, test conduct, and systems evaluations. But in the misty fog-filled valleys below, data flow like a mountain brook. Downstream we are drowning in data.

The challenge for flight test in the twenty-first century is to build a dam to control the flow of data, like we control the flow of water—transform the flow of data into insight and information, just as we transform the flow of water into hydroelectric power. As flight test professionals, we must adapt to the evolving nature and quantity of flight test data. We must begin to familiarize ourselves with a more diverse array of *applied tools of mathematics and statistics*, building blocks to understanding data and using it to make decisions. Expert application of these tools is critical if we will successfully navigate the uncertainty and find the signal in the noise. *Noise* – this is the most common statistical phenomena in flight test, and understanding it better is the goal of the second half of this discussion, an objective to which we will return. This discussion, though, is just part of a larger strategic discussion—one that has been conducted rigorously, among other places, in the break room and cubicles of the flight test department at Honda Aircraft Company. It includes the following points:

1. Probability is as important as airmanship;
2. The important thing is not (necessarily) the formula for standard deviation or any probability distribution but the big ideas, the fundamental principles and the way our knowledge of them guides our thinking; and
3. We need to communicate a clear and convincing explanation for flight test professionals in some format less than dissertation length.

Would you mind reading the following anecdote and letting me know if a light bulb comes on for you? Does this story motivate and correlate to these fundamental points?

I want you to recall an elementary idea, a cross-country flight. Do you remember back to the days when you were learning how to fly? For me, the plane was a Cessna 152, tail number four-hotel-bravo, and the place was Cook County Airport (15J) in southern Georgia. My instructor's name was Ian. He flew seaplanes somewhere in the South Pacific for many years before teaching private pilot students.

When I walked into the flight school one day, Ian told me something I would never forget. In fact, he predicted I would never forget it before he even told me: "Can ducks make vertical turns with turbulence." That mnemonic helps me remember the steps needed to plan a cross-country flight. The fact is, a pilot's head is full of crazy sayings and silly words that mean something when translated into aviation jargon. Remembering a wacky sentence about ducks is easier than remembering Compass heading, Deviation, Magnetic heading, Variance, True heading, Wind correction, and True course. Back at Cook County Airport, I opened up the sectional charts and sat down to figure out where I wanted to go. Once I did, I could draw a single straight line on my chart and jot down a heading. Those two things would get me pretty close: 255° magnetic for 25 minutes. After five minutes on a 255° heading, I should cross over a major highway with an overpass to my left. I look outside to see where it is. It's not as far south as I thought it would be. At seven-and-a-half minutes, I should pass over the southern tip of a large pond. The pond is just north of my position. Apparently, the winds are drifting me south of my intended course. I correct my heading to 260°. At 15 minutes, I should overfly an intersection in a small town. I am just north of the intersection. A heading of 260° corrected me back to course and then a bit right. Two-five-seven is right in between. That should keep me on course.

Three steps—clock to map to ground—are the process we follow when navigating in an aircraft. There is this notion, "the pond is just north of my position." Being able to recognize that and make that judgment call is a critical element of airmanship. It's also a fundamental principle of applied tools of mathematics and statistics. Sometimes, "just north of my position," is close enough. In this case, we don't need to quantify what "just north of" means.

In summary, I want to explicitly state three fundamental facts.
1. We are going to encounter uncertainty—uncertainty means we won't hit every waypoint.
2. Predict-test-evaluate is the process for navigating uncertainty. In aviation, this means plan the flight— fly the plan using the "Clock-map-ground" technique—and evaluate, using your "engineering judgment," when that's close enough.
3. *Applied tools of mathematics and statistics* help us evaluate when "that's close enough" (as in the case of navigation above) or when more quantitative rigor is needed.

The Rest of the Story
At the beginning of this column, I promised to return to the subject of noise, the most common statistical phenomena in flight test. Henceforth, this is the subject of our discussion and a beta test of what I hope will be an evolution in the math section of the SFTE Reference Handbook.

Introduction to Measurement Error
In flight test as in other disciplines, measurement and calculation result in different types of errors. Some of these errors are not systematic but are random. Often we call these measurement errors noise, and it is these errors that are the focus of this section. Furthermore, it is a commonly accepted practice that the normal distribution is a suitable model for noise and measurement errors. It is imperative to emphasize that the normal distribution is just a model, a simplification of the physical world. The purpose of this next section is to demonstrate why this is a suitable model and a very relevant one.

Suppose that we are going to measure airspeed, x, with some transducer. Suppose further that at each step in the measurement process we have one of two hypothetical outcomes:
1. We measure airspeed correctly; that is, the error is zero: $\varepsilon = 0$.
2. Or there is some error in our measurement of airspeed, which we model as follows: $\varepsilon = 1$.
In other words, we have a model that returns 0 when there is no error and 1 when there is.

We can show this in tabular form as follows:

Measurement process	After a single step or factor in measurement process: *x + ε*
Possible outcomes	*x*
	x + 1

Suppose that there are two steps that affect the given measurement. For example, measurement of airspeed requires both static and dynamic pressure. The error term propagates at each step. So we have the following:

Measurement process	After a single step or factor: *x + ε*	After a second step or factor: *x + ε*
Possible outcomes	*x*	*x*
		x + 1
	x + 1	*x + 1*
		x + 2

After two steps, we can any of three possible outcomes, *x, x + 1,* or *x + 2*. But the middle outcome occurred twice. Imploring upon your patience, consider outcomes after three steps.

Measurement process	After a single step: *x + ε*	After second step: *x + ε*	After third step: *x + ε*
Possible outcomes	*x*	*x*	*x*
			x + 1
		x + 1	*x + 1*
			x + 2
	x + 1	*x + 1*	*x + 1*
			x + 2
		x + 2	*x + 2*
			x + 3

Another way to see how these tables propagate is in the tree of figure 1. At each node of the tree, the value in the node represents the cumulative error, and the two branches indicate that there are two possible outcomes either *+0* or *+1*.

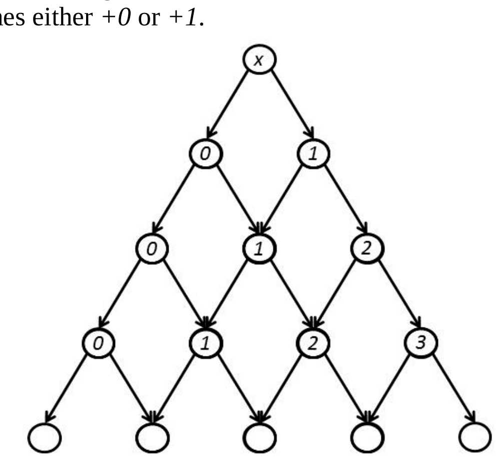

Figure 1 – Propagation of error term in a measurement

Thus after three steps or factors in the measurement process, there are four possible unique outcomes, *x, x+1, x+2, x+3*, but two of these outcomes occur more than once. In other words, there is more than one possible path through the tree to certain nodes. We can record the different outcomes and the frequency with which they occur in a rudimentary table as follows:

Number of occurrences	l	l l l	l l l	l
Outcome, *x+ ε*	*x + 0*	*x + 1*	*x + 2*	*x + 3*

This table allows us to picture qualitatively, based on the height of the tallies, the relative frequency of each particular outcome. It also allows us to quantitatively compute the probabilities of a given outcome. Thus, *P(x+0)* is the probability of no error in the measurement, and it is a ratio given by (number of times *given outcome* occurs) / (number of total possible outcomes) = 1 / 8; in other words, the number of tallies in a given column / total number of tallies.

The reader may continue this exercise for several more iterations and see two important principles:
1. Simple probabilities like the toss of a coin (a fifty-fifty chance) can quickly compound and propagate into more complex distributions.
2. There is a formula with which we can compute the number of occurrences in this discrete model, the binomial distribution.

Definition: Binomial Distribution
The *binomial distribution* is the probability of obtaining exactly *n* outcomes in *N* trials.

$$P(n) = \binom{N}{n} p^n (1-p)^{N-n}$$

From our example above, we could compute the probability of obtaining *n* errors in *N* stages or factors of the measurement process, that is, *P*(obtaining *x + ε* as the outcome) for *ε=0, 1, 2,* or *3*. However, we must define a few more terms in the formula above. In this case *N = 3* when we examine the outcome after *3* stages or factors in our measurement process.

Number of occurrences	l	l l l	l l l	l
Outcome, *x+ ε*	*x + 0*	*x + 1*	*x + 2*	*x + 3*
P(x + ε)	*P(ε=0)=1/8*	*P(ε=1)=3/8*	*P(ε=2)=3/8*	*P(ε=3)=1/8*

We let *n = 0, 1, 2, or 3*, based on whether we want to know the probability of the outcome *x+0, x+1, x+2,* or *x+3*, respectively. Additionally, *p* is the probability of the error at each stage. For the purpose of our example, we can say that *ε = 0* or *1* are equally likely, and thus we assign *p = 1/2*. We leave it to the reader to understand the formula$\binom{N}{n}$, but suffice it to say that this term allows us to compute the number of different ways a given outcome may occur. In this example there were three possible ways to arrive at *x + 1*, something we can see in both the tree and the tabular depiction above—the $\binom{N}{n}$ term allows us to compute it rigorously in any situation. Microsoft Excel or Google spreadsheets, MATLAB or python, and many other tools have functions that allow us to compute these probabilities.

Modeling Error with the Normal Distribution
Up to this point, our example has highlighted use of the binomial distribution, a model capable of handling discrete cases. In other words, we can compute the probability for any *N = 1, 2, 3…* including any whole number value. However, this model cannot accept continuous or fractional values, and it is cumbersome for even nominally large values of *N*—it becomes an unnecessary burden on memory and computational resources. There is a natural relationship between the binomial distribution and the normal distribution, and the bell curve is an excellent model for continuous and fractional measurement errors.
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