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Mahler to Mach 1

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As a classically trained musician who studied with the Boston Symphony and worked for the Opera Company of Boston, the author was able to directly apply the skills used in the high pressure world of professional music performance to become a Navy fighter pilot with 10 years of service and 321 carrier landings. Later, after flying for a major airline and completing his certificate in Aviation Safety at USC, the author worked with the NTSB on major accident investigations and started to observe the link between aviation human factors, safety analysis, and the similarities between accident investigation skills and the skill needed for professional musicians. This presentation will discuss topics including how data in both music and in safety management systems can be heavily influenced by training and talent, and the striking similarities in the skills used. Other topics include human performance and how music auditions and carrier landings share identical mental modeling, how error management and non normal operations are treated in both fields and how the functioning of a chamber orchestra can serve as a model for cockpit situational awareness and CRM. The presentation shows how classical music and aviation safety relate in unique and fascinating ways.

When the World Changes

The Apollo I fire was a tragedy so unexpected and the consequences so unimaginable that it shook the country to its core. Three national heroes were killed in a matter of seconds, only feet away from a crew helpless to do anything. The exercise itself was no more than a dress rehearsal meant to have about as much risk as an evening in front of the television. The political aftermath was equally brutal. The year was 1968 and in front of the US Senate Apollo astronaut Frank Borman was trying to keep the effort to go to the moon alive.

Amazingly the best and brightest minds of the day couldn't foresee what would have been obvious to any high school physics teacher: placing three men in a metal container, clamped shut and filled with 100% pressurized oxygen while throwing hundreds of electrical switches and packed full of flammable plastic was a sure recipe for disaster. The consequences of just one small spark would be catastrophic. And yet that disaster occurred. When asked why this was allowed to happen, the answer was straightforward and eloquent, Borman replied: "a failure of imagination." Even though safety", he said, "was never intentionally compromised …no one ever imagined [a fire] could have happened on the ground. If anyone would have thought of it the test would have been classified as hazardous…but it wasn't, we just didn't think of it."

You don't need to be in NASA to have decisions about risk affect you. We live in a world defined by risk and the rewards that taking them bring to us. We call it a business approach for preventing unnecessary cost and everyone from your local school to airline pilots try to imagine the best way to keep all of us free from the kinds of consequences we feel unable to afford. Why then do failures occur? In recent years we’ve had professional pilots crash airplanes, one of the largest and most advanced oil platforms blow up, and see established financial institutions fail and threaten to take the entire country down with them, just to name a few. In each case we ask the same questions as the Senate Panel for Apollo 1; why someone, anyone, didn’t see it coming? We ponder this despite the fact that the data available to us has increased exponentially. The problem is obviously not our lack of data.

Analyzing the present flood of information and imagining the risks it represents in our complex world takes as much training and skill as it does the Boston Symphony when they look at the data (musical notes) given to them. The only difference is that the symphony is composed of people highly trained, mentally disciplined, possessing the background knowledge, analysis techniques, and communication skills necessary to pull immense meaning from raw notes and present them in the most effective way possible. The people responsible for safety most likely are not so prepared. For both the musician and the airline pilot the question is fundamentally the same: “what turns information into knowledge and knowledge into relevance?”

This question started to appear when I was part of a lengthy investigation with the NTSB. The data was there in black and white and yet two extremely smart people looked at the same information and came to completely different conclusions. In this case it was the Joint Winter Runway Friction Program conducted in collaboration by NASA, the FAA, and Transport Canada. Coming out of this research the US and Canada developed two different guidelines concerning what the hazards were and how best to effectively deal with them. The Canadian’s used a friction index that managed both uncertainty and measurable components. The US relied on pilot reports alone. Both were correct from the standpoint of their respective reasoning, so how could one have contributed to the accident but still be viewed as a valid conclusion contributing to safety? Could a risk lay not in what was answered but in the question?

When looked at in hindsight it became clear that there were two visions of “risk” being used. One was engineering and legal risk, the other was an operational risk. The engineering approach sought to eliminate randomness in favor of the most direct path towards what could be considered a consistent correlation between observations and performance. The operational approach sought to minimize engineering variables through equipment standardization and embrace the possibility of corrupt data (randomness) as a variable that itself had to be identified. The data itself didn’t point to one approach over the other. Instead it was the interpretation of the individuals themselves that played such a large part in defining hazards and mitigations. This was not the first time a scenario like this has been played out.

One of the more famous quotes came from the Space Shuttle Challenger accident when a Morton Thiokol manager pointedly told someone to “take their engineers hat off and put their manager’s hat on.” It’s not that people were intending to cut corners on safety; they just couldn’t imagine what was around those corners. And even if they did, can a hazard reside not only in a potential event but also in someone’s ability to communicate risk effectively?

In the Senate Panel on Apollo I, Frank Borman was saying that at the time the people involved in the process didn’t have the skills to see how much meaning lay embedded in what was before them. What was put down on paper as a testing protocol was actually a treasure map for the many interconnected perspectives that a story about risk could possibly contain. It was if the people involved were reading a book called “Moby Dick” purely for guidance on how to look for whales with no expectations that it could be talking about anything else. Borman was an engineer and pilot, but his observations were in fact more a reference to art.

You see what your knowledge tells you and when that knowledge changes, what you see changes. When looking at the dawn it makes just as much sense to think that the sun goes around the Earth as it does the other way around. We only see that it that way because over time we've asked the kind of questions that changed our knowledge in the first place. As for the orbit of the sun, the question that first leads to the theory of planetary motion was: "On what day should we celebrate our religious holidays?" Knowing what day it was and how to accurately predict what planet will appear in the sky then lead to Copernicus and a major re-shuffling of our view of the sky. To the church, the question of risk was a political one. How can you run a religion without having some concrete direction on when to do things? Of course what they got in the end was more of a headache than they bargained for.

Today we look at risk from perspectives we chose and sometimes end up with unintended results just like the church did. They come from different viewpoints on what is important such as from lawyers worried about legal risk, from elected officials worried about political risk, from managers worried about financial risk, and from almost everybody worried about social risk. Will any of those people, the lawyers, accountants, bosses, or politicians be worried about the risk of someone's "failure of imagination?" To them there is scant room for imagination because their world is carefully defined by variables that set the boundaries of what is acceptable and not.

Let us now look at how musicians ask questions and about how not only their perspective changes but how they *expect* and want their perspective to change. In fact, if a musician looks at a series of notes and doesn't find some change in perspective it is deemed downright unprofessional!

Anyone with a child in a school band knows what an 8th grade concert sounds like. Now take that same piece of music and give it to the Boston Symphony and it'll probably sound a lot different. You pay good money to go to the movies where they employ a top orchestra to play a soundtrack, whereas you'd feel much differently if some high school band gave the score their best shot. In my experience, company safety briefs and professional safety conferences are a lot like 8th grade concerts. The people who attend are there because they should be there, whether they get anything out of it is up for debate.

To understand how meaning is extracted out of data and presented in a way that is both science and art we first look at the Navy Pilot out at sea.

Music and the Pilot

The carrier landing and the concert stage have many facets in common. First, they are both very much dependant on the mental state of the performer to bring his skills to bear. Unlike the landing on normal runway, the carrier landing is always performed in front of a knowledgeable and critical audience. Every landing on the carrier is graded, de-briefed in person, and posted for all to see. Every landing is also broadcast over TV through the entire ship as one of the channels available for general viewing. The landing requires an ability to repeat a skill that has been practiced beforehand and to do so under stressful conditions for not only he being watched but there is a very real possibility that if done incorrectly, he may not survive.

While for the musician physical survival is rarely at stake, the mental demands are almost exactly similar. For such an event the preparation is accomplished using a multi-step process. First, a large amount of repetition is employed to create a subconscious relationship between mind and body coordination for the skills required. This is first and foremost a physical learning process. Then the musician will employ what is known as technical rehearsals. This is where a the music is played up to the point where a difficulty arises whereupon that particular part is again broken down into component parts, repeated, and strung together again until it flows. Last is the performance rehearsal. This is similar to a LOFT event in that the entire piece of music is played, mistakes and all, in its entirety and examined later.

Aviation's success lies in the fact that many of the tasks and skills required are broken down and institutionalized in procedures. For the carrier pilot this takes place during the approximately 150 landings made in a dedicated training syllabus before the first carrier landing. The technique is similar to the technical rehearsal in that only a few skills are concentrated on during any particular event. Some skills such as flying the aircraft in reference to a specific angle of attack are similar to musician's scales. Steady deliberate repetition is the order of the day. More complex skills are then added as the landing pattern altitudes are refined. Finally the subtleties of optics, flight physics, engine design, glide slope geometry, and wind are introduced to form a broad picture of the event that goes well beyond mere stick and rudder technique.

In the case of both carrier flying and music, we can see that technical correctness alone is not enough, a broader context must also come into play. For the pilot flying onboard ship, for the safety analyst investigating an accident, and for the musician approaching a piece of music, technical skills are merely one set of tools for interpreting a larger canvas of relationships. For this the musician enters a deep well of human factors and physics.

If we are to consider human factors as anything that affects human performance, then music is the study of performance that affects humans. In both music and aviation, human factors strive to produce an intended result and both use known tendencies of cognitive psychology in the process. We start with the basics of breathing and discomfort. When two jet engines are not operating at near similar speeds the result is a kind of audio interference pattern. Most people would rather not have the oscillating noise drumming against their ears for extended periods of time. Increase the frequency of that same audible pattern and speed and you have what is known in music as a dissident chord, equally tough to listen to, and either a compositional effect, or an indication that something's not right.

All sounds produce pitches that can be both heard and unheard. The unheard sounds are what are known as "overtones" in music and represent harmonic frequencies, much the same as they do in mechanics. There's one catch however: the harmonics aren't integers or perfect fractions. In fact if you take a frequency, say the 440 cycles per second of the concert note "A" and double it, you will indeed get an "A" an octave higher (this was a major discovery of Pythagoras). If, however, you wish to create a pitch that will correspond to an appropriate dissonance with relation to that "A", say a minor 7^{th}, it will require a slightly different pitch than if you were simply to mathematically calculate where such a frequency should populate the spectrum of sound. Thus, if you are a professional concert pianist and you are to play Rachmaninoff's concerto in C you would have your piano specifically tuned for that key. If, however, you want to tune your home piano once and be done with it, you would want to consider Bach's "Well

Tempered Clavier," a set of music specifically designed for evenly tuned pianos that cleverly avoids chord combinations that highlight such a discrepancy.

Fine you say, but Bruce Springsteen doesn't care about this and what has all this to do with aviation anyway? The answer is Crew Resource Management. Before we get to that point let us look at one more aspect of music, phrasing.

No matter how simple or complicated the music, it all has to do one thing and that's to tell a story. Garth Brooks and Igor Stravinsky both have one thing in common: their music has the same basic phrase length of a human sentence. Perceptually we are so used to it we don't even notice, but the affect on the mechanics of timekeeping are profound. The data in audio notation is similar to the data in an Flight Data Recorder plot in that it is all relative to a mathematical notation of time. As with our discussion about pitch, however, knowing when to "break the rules" is the stock and trade of the performer. You see when we speak, we subtly alter our rhythm so as to allow us to breathe, place emphasis, create an effect and so on. This also happens when we dance. The most difficult music for an orchestra to play well is a waltz because it's lilting and slightly hesitating rhythm must be accomplished exactly by all members of an orchestra without specific, detailed direction from the conductor.

A true professional musician normally spends years, usually nine to twelve including summer education, full time college, and graduate or advanced studies before his "mental model" of pitch, phrasing, along with physical technique allows him to truly ply his trade for a living. Then he will most likely do what pilots do; attempt to join a group of likeminded folks in producing some sort of desired output. For the pilot this will mean a multi-crewed passenger airline jet. For the musician it means an orchestra or some form of ensemble. While most of us are familiar with the image of the conductor, there is a large area of music that is played without one. These ensembles are known as "chamber groups" and can range from small orchestras to groups of three. It is here we start to notice how situational awareness and leadership are built and enacted.

Situational awareness is the result of a shared mental model among groups of people. In a chamber group what is important is that such a model is expected to *change* and *so are its leaders.* Because how you perform depends on what your relationship is to a commonly shared awareness of pitch structure (B flat for instance), as well as whether or not you or someone else is controlling the phrasing, your role as leader, supporter, or vitally important facilitator is relative to the current situation. As a result the chamber orchestra becomes skilled at rotating the roles of leadership in quite a fluid fashion. This does not mean there is not a dedicated leader responsible for the overall coordination of the activity, merely that while it is taking place, there is a collective understanding that no single person can define all the requirements for a successful outcome.

From an error management point of view the ramifications are obvious. Error is a fact of human performance both on stage and in the cockpit. The chamber orchestra however is more resilient to unexpected slips in performance because changes in leadership are a desired outcome of the group mentality and the mission training is more robust in that there is a greater appreciation for the roles each person plays and a recognition that how an outcome relates to others is more important than the individual effort.

I want to stress again that this is no casual technique. All symphony orchestras are composed of "sections," the violin section, the trombone section, the bass viola section, and so on. Each section has a designated leader that coordinates how the section should phrase and each section performs according to how their pitch lies in relation to the other pitches, rhythms, or melodies that can be involved at the same time. It is similar to how an airport operator, ATC facility, and flight crew operate; the only difference is that the musicians have been heavily trained to understand each other's roles and how they relate to them.

Compare this to the many examples of CRM breakdown seen in the accident databases. Even when looking at a basic safety management issue such as the un-stabilized approach we see that a fluid transfer of leadership based on commonly understood conditions runs into challenges. The reasons for this are both simple and elusive. The first and most obvious is training. We don't train pilots in the underlying science of human cognition anywhere near to the extent that musicians do, but even if we did, the musician has one advantage we don't, positive feedback. Even without an audience a group of musicians can get satisfaction from an exercise where situational awareness has been proficiently maintained because their recognition of success or failure is immediate. For purposes of safety success or failure is often viewed as how well exposure to risk has been managed. But while exposure to risk may be important to those in the safety office, it rarely has any connection with the satisfaction of accomplishing a successful mission of delivering passengers to their destination. While an on time arrival at a destination is easy to comprehend as a successful outcome, how much exposure to risk was amplified in the process can require some imagination.

And so we find ourselves back to Apollo I and the question "what makes a hazard?" There are some things a musician doesn't need to know that professional risk management does. As the musician needs to know phrasing, the safety professional needs to know rhetoric. Both disciplines deal with communicating relevance. As the musician needs to know the physics of sound, the safety professional needs to know about probability from Gaussian to Bayesian to the concepts of the "Black Swan" and the effects of the highly improbable. Both music and probability teach how to relate information. As the musician needs to know music theory and the differences between Gregorian chant and Wagner's "Tristan chord" so the safety performer needs a thorough understanding of human factors. Both deal with how relationships between events can be viewed in different and unique ways.

A "hazard" is really no more than a story presented to an audience that places in their mind's eye a unique image of their world. Professionally trained and skilled musicians invest heavily in the many ways their world can present itself, how all those facets interrelate, and in how to effectively communicate that composition. Most important, however, is that music taps into our fundamental yearning to witness the economy of precision, that the image we are painting for others is exactly, to the finest subtlety, what we mean it to be.

We finish with the comments of astronaut Frank Borman about a failure of imagination. If we start by looking at our safety information; our reports, our data, our investigations, and believe that they hold the answers to *our* questions than we miss an opportunity. If instead we take that information and ponder what questions we can ask about the data itself, what questions we should ask, and what questions would most likely lead to a change in our perception then we start down the process of changing our view of the world in new and unique ways. If we are surprised by what we find then we can re-assure ourselves that it is a view that won't surprise us in the future.