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Simulator Motion…It Rocks! (Or Maybe Not)

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I want to briefly share some of our early work at the University of Illinois Aviation Research Laboratory relating to the nature and role of motion cueing and its relationship to pilot performance in flight training, skill evaluation, and flight instrument utilization. First, though, I'd like to offer some personal testimony about Stan Roscoe, the director of the Lab, so that you can appreciate the extraordinary environment we were provided in which to pursue our research and to learn.

Stan was one of a kind. As a scientist, as an educator, and as the leader of a research organization, Stan always set the bar at its highest limit. He insisted that we who worked for him, studied under him, and helped him to contribute to the understanding of how best to combine human beings and technology in systems reach well beyond "good enough". For Stan, whether the task at hand was human factors engineering support to a major aerospace program, the conduct of experimental studies in aviation psychology, or the sharing of our scientific activities with sponsors and peers, a clear focus, professional quality, and absolute integrity were required without compromise.

Like my colleague Larry Scanlan, I had the privilege of working for Stan at Hughes Aircraft for several years before following him back to the University for graduate studies. During that time, I was constantly amazed at Stan's incredible energy, his patience, and his persistence as he directed our work in the Display Systems and Human Factors Department. In most aerospace companies, human factors engineering was just one of the "illities" – a backwater discipline staffed by individuals of modest aspirations performing work that was required by the customer to check off the contractual "boxes", but in truth not of very high interest to company leadership. This because like training, logistics, or safety, human factors was regarded as an annoying constraint to main product line technical innovation and certainly not fertile ground for the growth of business and profits. Across the industry, the human factors organizations were on the lowest link of the food chain when it came to support for corporate sponsored independent research and development, capital investment, or other expenditures.

Stan made things very different for us at Hughes. First, he constantly reminded us and others up and down the chain of command how important our work was to producing systems that would deliver maximum man-machine system performance to our customers. He taught us to find out what was going on in every corner of the company and to aggressively market our technical knowledge and research capabilities to programs inside the company that could benefit. The result was that at Hughes, the human factors organization was, I believe, held in much higher regard for its contributions to program success than was common elsewhere.

Second, Stan early on recognized the importance of simulation as a tool for supporting system engineering, and developed a center of expertise focused primarily on man-in-the-loop simulation for research and concept demonstration. This was a unique resource within the company, and it became an important tool for the attraction of work both within the company and from customers outside. Although quite unusual for what would typically be regarded as a support service by other companies in the aerospace business, at Hughes, the human factors activity was a very successful direct support contractor to many DoD customers - system developers as well as research oriented agencies.

Third, Stan believed strongly in hiring strong people and developing the talents of those who worked for him. Stan must have been the record holder for securing a disproportionate share of Hughes' generous educational support for graduate studies for his people, and the department enjoyed one of the highest ratios of graduate degreed professionals in the company. Larry Scanlan and I were both to become beneficiaries of his efforts to secure graduate fellowships for us – in both cases unprecedented at Hughes because they provided full time study for an extended period at a University far away from southern California.

Lastly, Stan appreciated the importance of communication skills for his staff. Even those in very junior positions were put before customers to present their work, and given the opportunity to participate in the preparation of proposals and reports so that we could learn how to share our ideas verbally and in writing to his high professional standard. The fact, as we knew all too well, that he had been an undergraduate English major in college, was constantly on our minds as we prepared our materials.

I offer this description of how Stan ran his organization at Hughes because when he returned to the University of Illinois to reactivate the Aviation Research Laboratory, he brought these same values and beliefs to the directing of the Lab. Stan was able to create the Engineering Psychology program and establish parity for the discipline within the Psychology Department with the other more traditional pursuits there. He brought relationships with the government agencies that sponsor research in aviation psychology with him when he arrived, and quickly built up a portfolio of funded research contracts that made ARL a going concern. Stan's appreciation for the importance of simulation as a focal point and tool for the research program continued, and he developed a sponsorship relationship with a major manufacturer of general aviation simulation systems that resulted in the laboratory obtaining a state-of-the-art simulator for its work. He also succeeded in finding the resources to provide real-time computing capability and access to aircraft to support our experiments.

Stan's standards for high quality staff remained unchanged as well. The Psychology Department of the University of Illinois is held in very high regard and is very selective in its acceptance of graduate students. At the time of my admission, the acceptance ratio was around 5% of the applicants. Over and above this, Stan insisted that for a graduate student to become part of the research staff at the ARL, a minimum of a private pilot's license was a prerequisite, and more advanced certification was desired. Many of us were commercial pilots and flight instructors when we became part of the ARL research family.

Stan continued to insist upon high standards of communication skills for his people at the University as well. Unlike most research organizations on campus, Stan scheduled annual program reviews for our research sponsors and professional colleagues. Graduate students were expected to prepare professional conference/journal quality papers for presentation of their work to an audience that traveled to the University from all across the country. These were quite formal affairs, but Stan considered them to be learning experiences as significant as any of the academic work or research. The papers were published in a proceeding of the meeting, and often submitted for further publication in professional journals.

Student researchers were also required to write proposals and technical reports describing their proposed work and results to meet contractual requirements of our sponsors. These documents were also required to meet a high standard of quality. Stan considered them to be practice for our eventual professional counterpart activities.

In many respects, the laboratories operated as if it was a research and development enterprise, but with the overlay of University academics and periodic turnover of the staff researchers as new candidates were accepted and others completed their degrees and moved on.

Now in that time, high fidelity flight simulators were a very expensive commodity. High performance visual systems ran about $1M per channel, and synergistic 6 post motion systems were also significant cost drivers. Stan recognized and wrote that in the case of the motion systems, the cost impact arose from more than just the cost of the motion platform and its driving software. These systems were very maintenance intensive, but in addition required a large volume of space within which to operate –read bigger building, consumed a lot of power, and were thought to pose a safety risk and so required costly risk mitigation. Our research simulator had a simpler pitch/roll motion system, but even that device was significantly more expensive to purchase than a non-moving counterpart.

The prevailing wisdom among simulator manufacturers than was that the contribution of various aspects of simulator fidelity to the overall effectiveness of the systems for flight training or flight proficiency assessment was not known, so under the presumption that higher fidelity correlated with higher transfer effectiveness and/or higher predictive validity for flight checks, simulator users were advised to purchase as much fidelity as possible. One simulator manufacturer at the time marketed its products with the slogan “uncompromising realism”, as if that ensured the purchaser would realize maximum return on investment.

The problem with that theory, at least in the motion dimension of fidelity, is that even the best synergistic platforms are only capable of limited physical excursion on each axis; so sustained acceleration cannot be simulated. Instead, these systems can be used to cue supra-threshold linear and rotational acceleration over a very limited range, and then must be restored to a neutral state ideally subliminally so that the simulator occupant does not notice the transition. This is not the same as the set of motion cues experienced by the occupant of a maneuvering aircraft which can sustain accelerations through vast displacements – so even the best motion simulation does not produce “uncompromising realism”.

We began talking about an alternative design philosophy for simulation – one that we called “selective-fidelity”. The concept was to invest in cue realism in visual, audio, whole body motion, tactical feedback, etc. when the cues could be demonstrated to contribute to the transfer effectiveness or predictive validity of the simulator experience, but not to spend money on aspects of the simulator design where no relationship could be shown to its value as an environment for training or testing. Of course to put this strategy into practice, it became important to gain an understanding of the relationship between the nature and fidelity of these cues and the effectiveness of the simulator in its design mission. Understanding the role of motion cueing in this respect became a major research thrust for ARL during the early 1970’s.

A further question on the table had to do with the role that motion cues had to play in aircraft flight control related response. Was the perception of motion an alerting cue – one that merely triggered a process of interpretation of instrument indications leading to formulating a response? Or was the cue an essential input to the response formulation itself – were the magnitude and direction of the motion cue characteristics when processed in concert with some sort of operative dynamic model of the aircraft control loop, determinants of the characteristics of the response?

Recall that at that time, ARL was the beneficiary of substantial support from a major manufacturer of simulation systems, including the general aviation simulator that the lab intended to employ to address these questions. When it became known that it was our intention to try to quantify the role of motion cues in determining the effectiveness of simulators as training or testing environments, our benefactor, who realized a meaningful proportion of its revenue through the sale of motion systems, was none too happy. I recall that there were extensive discussions between Stan and our point of contact at the company in which it was suggested that:

1. Perhaps we ought not to be doing this research, or, alternatively,

2. Perhaps we ought to perform the study at their company facility or at an Air Force simulation facility that they operated, where they could provide "help".

To his great credit, and at some risk to the continuing support of the lab, Stan resisted both suggestions. I regard this episode as one of many instances of Stan putting scientific integrity before political considerations.

In the few years that followed, we conducted three sets of experiments that focused on the issue.

One of our graduate researchers, Fuat Ince, conducted a research application oriented study in which various formats of attitude indicators (moving horizon, moving airplane, frequency separated, kinalog) were tested in a disturbed roll-tracking task under various conditions of motion. Error in tracking and especially control reversals were measured. Ince found that there was a reliable interaction between the nature of the motion cueing and tracking performance, and that there was also a significant difference in the frequency of control reversals in recovery from unknown attitudes across motion conditions. Interestingly, the results showed that tracking performance most closely matched performance in an aircraft when the simulator was operating with washout motion, but that control reversals were minimized when the simulator was set to present sustained bank and pitch cues. This suggests that the role of motion cueing extends beyond the alerting role postulated earlier, and that to some degree at least the directionality of the motion in the roll axis helps to produce an initial roll control response in the right direction.

Lt. Col. Jeff Koonce, a graduate student at the lab with the Air Force Institute of Technology Ph.D. program, investigated the role of motion cueing with respect to a second domain of simulator application – predictive validity of ground based flight proficiency testing. In his experiment, experienced instrument rated pilots were given two flight proficiency checks in the simulator on successive days, followed by an check flight in an aircraft. Simulator check rides were conducted under three motion conditions (no motion, sustained motion, and washout motion). Jeff found that, as would be expected, performance improved with each succeeding check ride. Test subjects made more errors in the simulator without motion, made fewer with sustained motion, and performed best with washout motion. The order of results was consistent from day one to day two in the simulator. But when the check ride was conducted in the aircraft, the no-motion group performed reliably better than the other two indicating a differential impact of motion condition on any learning that may have been taking place over the three sets of trials. Flying the simulator without motion is harder – pilots have to concentrate more intensely on the instruments without motion cues to aid them. The suggestion here is that perhaps that greater effort resulted in measurably different skill gain in transfer to the aircraft.

To test whether this might have been the case, in my own dissertation study, I examined the role of motion cues as a factor in the transfer effectiveness of the simulator in an abbreviated primary flight-training curriculum. I will not detail the procedures for establishing control of such variables as instructional technique or subject aptitude; only reassure that these were accounted for. Four groups of subjects, none of whom had any previous flight experience as either pilot or passenger and thus had no expectations for the motion cues in an aircraft or simulator, were trained to private pilot proficiency standards on a series of maneuvers under instrument conditions. To make the task more challenging, a complex airplane with retractable landing gear and a controllable pitch propeller was used. A control group received all of its training in the aircraft, repeating each of a series of successively difficult maneuvers that involved at first simple maneuvers such as maintaining heading and altitude, and progressing to more complicated "Charlie" patterns in which the subject had to calculate headings, climb and descend then maintain target altitudes, make standard rate turns alternating left and right through 90 or 270 degrees, adjust power, retrim the aircraft, etc. All of this was performed under an instrument hood which would pose a significant challenge to even a certified private pilot. Subjects repeated each maneuver task until two successive trials were performed to exit criterion (private pilot) standards.

The experimental groups went through the same training sequence, but received instruction in the simulator first under one of three conditions of motion then were tested in the same way in the aircraft. One group trained without motion, while the other two groups experienced washout motion or a special hybrid condition in which the simulator provided washout motion but with a random directionality. The latter condition was introduced because it provided an alerting cue, but not a dependable polarity and so could not be relied upon as a parameter from which to formulate a directional response.

I found that when comparing the performance of the various experimental groups to the control group performance, that motion produced higher transfer effectiveness in the simulator and that washout motion was best in terms of skill gain rate. However, an examination of the uptake rate resulting under the various conditions of motion and no motion, when adjusted for the respective costs of motion and non-moving simulators produced a surprising conclusion. For this particular set of flight skills, the most cost effective strategy for training is to utilize the non-moving simulator for a longer period of time to reach exit criteria rather than to achieve it faster in the washout motion condition.

The comparison of the washout motion to the random washout condition was not definitive for every dimension of performance measured, but generally it indicated that motion cues provide a reliable alert to a need to take a control action, but that the students cannot utilize the magnitude or direction of the motion perception to decide what should be done. This is consistent with what every flight instructor attempts to teach – trust the instruments, not you own senses.

These motion studies had an impact in the simulation industry – some of us became rather widely known – or perhaps infamous would be a better choice of words – because of them. Today, many general aviation training devices do not move but deliver cost effective flight skills as compared with training exclusively in the aircraft. Further, they enable the practice of certain types of tasks that would be too risky or expensive for initial training in flight.

Motion has a place in flight simulation, but it is application specific and the design of a simulator must take into account for what it will be used to develop the best cueing environment for the device. Since leaving the University, I have gone on to develop many hundreds of simulators, some with motion systems, some without. For those in which motion is the right choice, I say "Simulator Motion Rocks!" In other cases, we don't need it.

Thank you for listening, and thank you Stan.