LOW COST VISUAL FLIGHT SIMULATOR TESTBED

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ABSTRACT

A testbed program for the evaluation of low cost flight simulator image generation systems is described, which employs a pragmatic approach based on simulator to aircraft transfer of training within the formal curricula for institutional flight instruction. The results of the first research study with this testbed, utilizing an image generation source which can reasonably be considered to represent a starting point along the low cost continuum, are presented. The results were encouraging with respect to positive transfer of training achievable with low cost technology.

INTRODUCTION

The technology for complex visual flight simulators has evolved rapidly during the past ten years, as has the acceptance of flight simulators by the aviation community for a wide variety of training and engineering applications. However, as the simulation industry has vigorously pursued the development of ever more "realistic" visual imagery, the cost of delivered systems has soared, in some instances exceeding the cost of the aircraft being simulated. This circumstance limits the capacity of the user community to acquire and implement such systems where they are needed. Although the U. S Army has made a very substantial investment in full mission simulators, for example, their expense places severe constraints on the number of such devices which can be afforded. Similarly, while large airlines are able to afford simulators having sufficient fidelity to support pilot certification, the expense of that approach may be beyond the reach of small regional airlines, though their need for such capability is proportionately just as great.

Within the past several years, however, dramatic strides have been made in the application of VLSIC for 3-D graphics, a development which has been most evident in the engineering CAD/CAM workstation arena. The computational and throughput capacity of these graphics engines, coupled to equally powerful microprocessor based host computers, is now approaching a level sufficient to permit their consideration as alternatives to the custom-designed computer image generation systems historically utilized on visual flight simulators. At the same time, the developments in this technology are having an impact on the design of traditional flight simulator specific architectures.

The availability of low cost computer image generators (CIG's) is rapidly increasing. In addition to CIG's developed specifically for the low cost market, the architectures for high end systems are clearly moving in the direction of modular packages, which will better permit the user to specify only such capability as he needs for the training tasks at hand, while allowing for subsequent modular expansion if his training requirements increase.

From a requirements perspective, a perennial issue with respect to CIG systems has been the question of - how much is enough? What level of scene detail, how many moving objects, what level of fidelity in the visual data base, and so on, have been traditional issues with which the requirements specifier has had to wrestle for every CIG procurement. Given the multimillion dollar costs of high end CIG's, these have been important issues that translate directly into payoff for investment. Unfortunately, the availability of hard data for use in the resolution of these issues has been piecemeal at best, because the complexity of the perceptual/human performance variables involved does not lend itself to quick answers. In the meantime, the technology in high end CIG's continues to push the limits of possibility, a circumstance which exacerbates the lag in the availability of behavioral research data which is in fact relevant to the procurement specification process.

In the low end CIG domain, the behavioral question has a somewhat different emphasis - how little is enough? The decision to procure a low end system to some extent entails up front acceptance of lower fidelity in visual imagery, although even here the limits of capability in available technology are rapidly changing. In general it would be naive to project that all the capabilities in high end technology will ultimately be available in low end systems. Though the gap between low and high end CIG technology may indeed narrow, it should not be expected to obviate the general proviso that you get what you pay for. High end systems will continue to evolve to meet advanced flight simulation training requirements, such as mission rehearsal. As always, the choice of the particular spectrum of technology needed by the user will remain principally a task specific function of what is to be trained.

For ARI's Low Cost Testbed Program, a pragmatic approach to the conduct of research on low end CIG technology is being taken. The emphasis is explicitly on the bottom line - what is the difference, if any, in aircraft flight time required to achieve a training standard by virtue of prior (or interpolated) training with a given low cost system? Low cost is operationally defined as under $200,000 per CIG channel, exclusive of installation, integration, and visual data base development. The goal of this program is to evaluate a family of representative low cost image generation systems within the specific bottomline context of measurable training performance differences in the aircraft. No attempt to empirically manipulate levels of scene content or other correlates of fidelity within a given CIG has been made to date. The intent is to employ each such system at its maximum capacity, and to compare the training payoff achievable between systems.

The U. S. Army Aviation Center environment in which this work is being conducted is well suited to the program's goals, since the resources of a highly centralized flight training program are available to support the research. A two phased approach has been established for program execution. Phase I focuses entirely on initial entry rotary wing (IERW) primary training. Experimental and control group participants are selected entirely from the population of students formally enrolled in the primary training Program of Instruction (POI) at Fort Rucker. Instructor pilots employed to administer instruction, or to evaluate performance, are also selected entirely from the IERW training program. In-aircraft training and evaluation for experimental and control subjects is conducted entirely within the normal curriculum for IERW training.

Phase II of this program, which will address the training effectiveness of low cost computer image generation technology for advanced aviation combat training tasks, will not be initiated until the completion of the Phase I research.

This paper reports the results of the first transfer of training study accomplished with the Low Cost Testbed. In selecting a CIG configuration for the first such study, a major goal was to employ a minimally feasible system, in order to establish a baseline data point which could reasonably be considered to represent the start of the low end continuum. Subsequent CIG's to be employed for this research will be selected to represent higher points along that continuum, and in fact the installation of a second such system is already underway.

METHOD

Equipment

This research employed a UH-1 Instrument Flight Simulator (Device 2B24) cockpit, selected from an existing complex of 32 such individual cockpits at the Army Aviation Center, as a platform for retrofit of the low cost image generator, host computer system, and displays/optics. The existing system software was entirely replaced with custom developed software tailored to the purposes of this research. A block diagram of the system architecture is presented in Figure 1. A detailed description of the experimental hardware/software configuration is available in References 1 through 4.

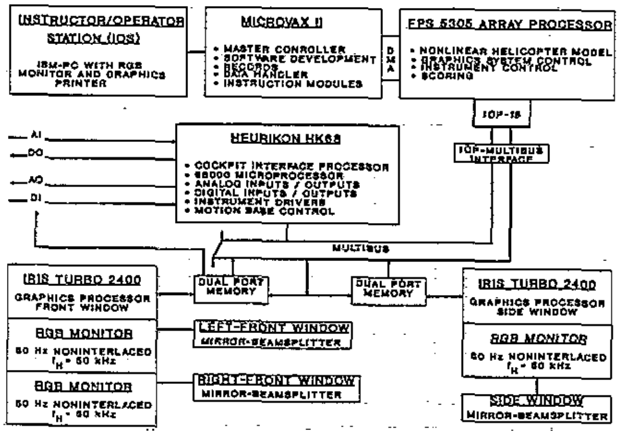

Figure 1. Low cost testbed architecture.

The 2B24 provides a high fidelity UH-1H cockpit with full instrumentation on a five degree of freedom motion platform. For this research all of the basic flight instruments were active. The aircraft systems instruments (fuel quantity, oil pressure, etc.) and radio navigation instruments were not functional.

Two Silicon Graphics Iris Turbo 2400 systems, equipped with 24 bit planes, 8 Mb of DRAM, and a 70 Mb hard disk, were employed as a two channel image generation source. Two independent channels of imagery were presented to the student pilot in the right seat, with perspectively and geometrically correct front and right side views. A 25 inch

Systems Research Laboratory 1024 line digital monitor was used for front view, while the standard Silicon Graphics 19 inch 1024 line monitor (Manufactured by Hitachi) displayed the right side view to the student. A 19 inch 1024 line Systems Research Laboratory monitor was used to repeat the front view to the instructor pilot sitting in the left seat. All displays were collimated to infinity, using Glass Mountain Optics mirror/beam splitters, all with 50 inch radius. From the design eyepoint the field-of-view in the right seat was 48H x 36 V front, and 36H x 27V right. Horizontal separation between the front and right displays amounted to approximately 20 degrees. Field-of-view for the left seat was 36H x 27V.

The Silicon Graphics Iris Turbo 2400 system has a maximum throughput capability of 300 polygons per frame, with asynchronous update. The system is not available with specific options for texturing, transparency, or most of the other features typically found in flight simulation image generators, as it was not designed for this purpose. The system will, however, support dusk simulation, and has an excellent symbology overlay capability. It is a full color system.

Because of its limited capacity for this application, special emphasis was placed on (a) refining the visual data base for optimum tradeoff between scene content and polygon throughput, and (b) the development of a customized pie sectoring priority processing algorithm to maximize the available detail in scene content. These efforts, which were highly successful, are described in References 2 and 4, respectively. The range in update rate during study execution varied between 12 and 40 Hz, depending on scene complexity, with an average update rate of approximately 17 Hz.

The visual data base represented 20 square miles of terrain and included a four lane heliport with control tower, landing crosses, a parked 3-D helicopter model, and adjacent 3-D parked trucks. A 2-D grid pattern representing 10 foot wide runway markings overlaid the runway. The visual environment also included nearby 3-D hills, multiple 3-D buildings, navigation reference towers, a river with 3-D bridge and 2-D bridge shadow, an approach to landing corridor with 2-D trees and radio towers, and 2-D mountains in the distance. In order to provide surface cues during the traffic pattern, a thin 2-D white grid, comprised of 20 x 20 grid squares 1000 feet long per side, was overlayed at ground level within five miles of the heliport. A 2-D grid pattern representing runway tire marks was overlaid on the runway below an altitude of 15 feet AGL.

Because during primary training the emphasis is appropriately on teaching handling characteristics and associated control strategies to novice aviators, particular emphasis was placed on aerodynamic modeling and refinements thereto during the development of this simulation. A single rotor helicopter aeromodel entitled <u>UNCLE</u>, obtained from the Nasa Ames Research Center, was implemented on a Floating Point Systems 5305 Array Processor, and iteratively refined to match the flight characteristics of the UH-1 aircraft over a six month period, with the assistance of helicopter engineering test pilots, who systematically performed comparisons (Cooper-Harper Ratings) between the aircraft and the simulator in the various flight regimes representative of the primary training flight curriculum. Based on feedback from instructor pilots employed during this study, this effort was successful.

A DEC Microvax II received the output of the FPS 5305 and functioned to pass the appropriate positional data by means of a parallel interface to the two image generators and a Heurikon HK68 Cockpit Interface Processor, which in turn communicated with the flight control loaders, cockpit instruments, the cockpit sound generation hardware, and the motion platform. The communications bus employed for this architecture was Multibus I.

The custom Experimenter/Operator Station (EOS) included an IBM PC with color monitor and graphics printer. A simple control panel was used to activate the motion system and raise the ladder to the cockpit/motion platform. A Silicon Graphics 1024 line display was employed as a visual repeater, which could be switched between either the front or right out-the-window view. The controlling keyboards for the Microvax II, the Heurikon HK86, and both Silicon Graphics CIG's were also located at the EOS. From the EOS the operator could change initial conditions (wind/turbulence, geographical coordinates, record/playback, etc.) in response to requests from the cockpit or as required by the research protocol. The IBM PC provided limited capability to analyze recorded flights, and create data plots or statistical summaries.

The simulator cockpit was equipped with function keys which the instructor could employ at his option to freeze, reset, replay the last 75 seconds of flight, or execute prerecorded demonstrations.

The cockpit was equipped for intercommunication with the EOS, using headset assemblies at pilot, copilot, and jump seat positions, and either an identical assembly at the EOS or a loudspeaker, selectable by the operator. The operator was provided with the option of deactivating his microphone while maintaining auditory communication with the cockpit, in order to prevent conversations at the EOS from interfering with instruction in the cockpit. The intercommunication system could be used for intracockpit communication, and also to simulate the UHF radio for air-to-ground communication.

Custom software to drive an existing cockpit analog sound assembly provided auditory cueing as appropriate for rotor, engine, and skid-runway contact.

Subjects

Ten officer student pilots, randomly selected from a single IERW primary training class, served as experimental subjects for this study. Ten student pilots, selected from the immediately succeeding class on the basis of primary phase grades, RFAST flight aptitude test scores, age, rank, and prior flight training experience, served as a matched control group, from which "stick buddies" were selected for pairing with the experimental subjects during aircraft training and evaluation. The rationale for the selection of such a control group was threefold: (a) to control for the effects of differences in individual instructor pilot evaluative biases, since for any given pair the effects of such bias would be more likely to be equal, b) a partial control for a possible Hawthorne effect associated with the special attention and scrutiny accorded the study participants, and (c) to permit some measure of whether non-simulator trained students benefitted in aircraft training by virtue of their pairing with simulator trained students. A second control group, comprised of the 16 remaining IERW trainees in the class who neither received simulator training nor were paired with experimentals, was employed as the principle comparison group for aircraft performance purposes.

All subjects selected had completed primary phase training in the TH-55 aircraft, and were at the point of initiating transition phase training to the UH-1 aircraft. No UH-1 training had yet been received by either group. To assure that experimental and control subjects would initiate their UH-1 aircraft phase training at exactly the same point in the IERW training curriculum, the experimental subjects were "set back" one class. This procedure provided time for two weeks of simulator training for the experimental subjects.

Procedure

Simulator Training. Five U S Army instructor pilots (IPs) provided all flight simulator training for this study. Each such pilot was provided with up to ten hours of flight simulator familiarization training under the supervision of a helicopter rated research scientist. To complete familiarization training, the instructors were required to execute the maneuvers they were to teach to a criterion of satisfactory performance based on IERW Flight Training Guide Standards.

Each IP was assigned two of the ten experimental students, at random, for flight simulator training. As is normally done in the UH-1 aircraft, the students received simulator training in pairs, with one student at the pilot's crewstation, and the other observing from the jump seat. A random selection procedure was employed to determine which student received pilot crew station training first on the first day. Thereafter, training order was rotated on a daily basis. The IP provided all instruction from the left crewstation position, as in the aircraft.

Eight representative standard primary training maneuvers were selected for simulator training. These maneuvers were:

(1) Takeoff to a Hover
(2) Hover Taxi
(3) Hovering Turns
(4) Hovering Autorotation
(5) Visual Meteorological Conditions (VMC) Takeoff
(6) Traffic Pattern
(7) VMC Approach
(8) Landing from Hover

Day one of student training in the simulator was devoted to one hour of general familiarization, off motion, without specific training or iteration on the target maneuvers, with the IP flying demonstrations of the eight target maneuvers. Training on the target maneuvers was initiated on day two with full platform motion, and continued, approximately one hour per day per student, until each student had demonstrated three consecutive iterations of each such target maneuver within standards. Once this criterion was achieved on a given maneuver, no further simulator training in that maneuver was provided. The instructor in the cockpit, and the research scientist at the EOS, both kept track of the number of iterations executed per maneuver, and which of those were completed successfully.

A custom designed paper-and-pencil scoring form was used for this purpose. The form was designed to allow the instructor to simply place a checkmark each time a maneuver was attempted, and a second checkmark for each maneuver attempted which in fact was executed within standards. When a maneuver was demonstrated by the IP, or any other time the IP took the aircraft controls, a "D" was written in the maneuver block to signify "demonstration". The scoring form was reviewed by the research scientist following each student's training session, as a check for discrepancies. None occurred.

The simulator was operated 12 hours per day, five days per week, during the two weeks of simulator training conducted for this study. This schedule permitted each student to receive 1.0 to 1.2 hours of training each day. The IP was provided with a twenty minute optional break between each pair of students.

Aircraft Training

A separate group of IP's was employed for UH-1 aircraft training and scoring. The aircraft IP's were provided with specific instructions on the execution of this study and the use of the scoring form, in dedicated meetings for purpose chaired by a research scientist prior to the initiation of aircraft training.

At the specific direction of the Commanding General, US Army Aviation Center, unusual measures were taken to prevent the aircraft IP's from obtaining specific knowledge of which student pilots (SP's) had received simulator training. SP's were under strict orders not to divulge this information. IP's were not permitted to review records which would have indicated who the experimental subjects were, nor were they permitted to ask the SP's themselves or the school staff questions in any way relating to this issue. These measures were taken in order to minimize the effects of either a pro or con simulator bias in evaluating student performance. Two research scientists on-site during the execution of all UH-1 aircraft training verified that this requirement was not violated.

Experimental subjects were paired with their matched controls for aircraft training. As required by the POI, day 1 of aircraft training was devoted to a familiarization flight for each SP, without structured feedback or instruction. Training on the target maneuvers began on day 2. The same scoring form as employed during simulator training was used in the aircraft. The same criterion of satisfactory maneuver performance was employed - three successive iterations of the maneuver within standards. One helicopter rated research scientist flew at least once with each experimental-control pair in the UH-1 aircraft during training on the target maneuvers, in order to maintain positive quality control over the execution of data collection procedures. A second research scientist debriefed IP's and SP's after each training flight, and reviewed the scoring forms for compliance with procedures.

RESULTS

Simulator Performance

All SP's completed training to criterion on all maneuvers in the simulator prior to the end of the two weeks scheduled for that purpose. The reliability of the low cost simulator configuration during its 12 hour per day, five day per week operation, was remarkable. Total down time due to system malfunction was 40 minutes.

Aircraft Training

Figure 2 presents the arithmetic mean iterations to criterion per maneuver in the aircraft for the simulator trained, matched control, and unmatched control groups, respectively.

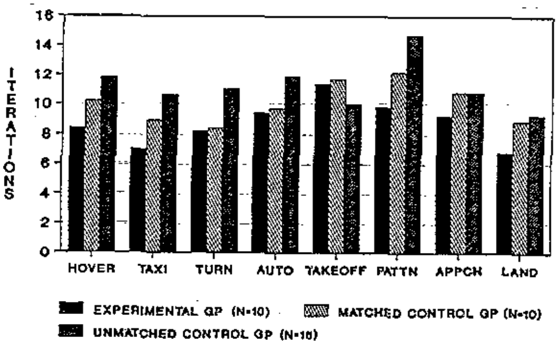

Figure 2. Maneuver Iterations in Aircraft

Figure 3 presents the Transfer Effectiveness Ratios (TER's) for the comparisons of the simulator trained SP's with the unmatched controls. The TER is an index of the savings in aircraft training maneuver iterations (or aircraft training time, etc.) achieved for a given number of simulator maneuver iterations (or simulator training time, etc.). A TER of

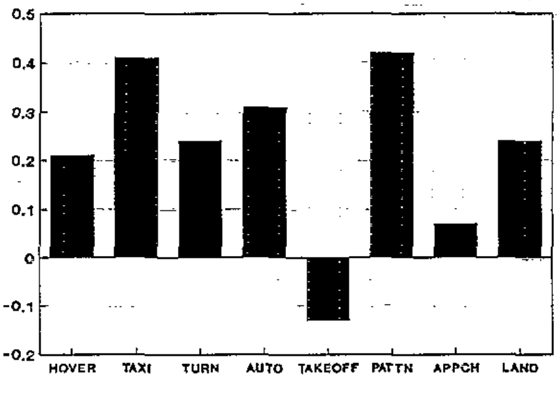

Figure 3. Transfer Effectiveness Ratios

1.0, for example, would indicate that one hour of aircraft training is saved for every hour of flight simulator training, or in the case of the metric employed in the present study, one aircraft maneuver iteration saved for every flight simulator maneuver iteration. Decimal values (the more typical result) reflect *fractions of time or iterations saved in* the aircraft. Negative values reflect increase in aircraft training time or iterations by virtue of negative transfer from the simulator.

In comparing the aircraft performance of the simulator trained SP's with the unmatched controls, two maneuvers *stood out* as *having benefitted* the most from simulator training - Hover Taxi (TER = .41) and Traffic Pattern (TER = .42). Respectable savings were also achieved, however, on four other maneuvers, Takeoff to Hover (TER = .21), Hovering Turn (TER = .24), Hovering Autorotation (TER = .31), and Landing from Hover (TER = .24). Negligible savings was observed on VMC Approach (TER = .07). Negative transfer appeared to occur on one maneuver - VMC Takeoff (TER = -.13). In terms of overall savings, collapsed across all maneuvers in this study, TER = .19.

The TER's with respect to the matched control group in all maneuvers were less than those obtained in comparing the performance of the simulator trained aviators with the unmatched controls. This result is consistent with the hypothesis that the pairing of these students with the simulator trained aviators did improve the performance of the matched controls in the aircraft, since the net savings was less than that observed with the unmatched control group. In comparing the simulator students and matched controls on a per maneuver basis, the largest savings were observed for Traffic Pattern (TER = .20) and Landing *from Hover* (TER = .20). *The savings for* the remaining maneuvers varied from small to negligible. In terms of overall savings collapsed across all maneuvers for this control condition, TER = .10.

In addition to measurement of aircraft iterations, IP's were asked to compare each SP pair (experimental and *matched control*) on a Post Contact Phase Questionnaire on every Contact Phase maneuver. The IP's task was to circle "SP1 Superior", "SP2 Superior" or SP1 and SP2 about the same" with the 2 SP's names presented alphabetically. The results of those comparisons are presented in Figure 4. The vertical bar labeled "other" presents the average superiority rating *summarized across* all *other* Contact Phase maneuvers, i.e., those maneuvers not specifically trained in the simulator. The post-questionnaire results indicate the aircraft performance of the simulator trained SP's was rated superior by fifty percent or more of the IP's on five of the eight maneuvers trained, relative to the matched controls. In general, the questionnaire results are consistent with the observed TER's, except for VMC takeoff, for which the simulator trained groups received the highest percentage of of post questionnaire superiority ratings *but failed to exhibit a positive* TER.

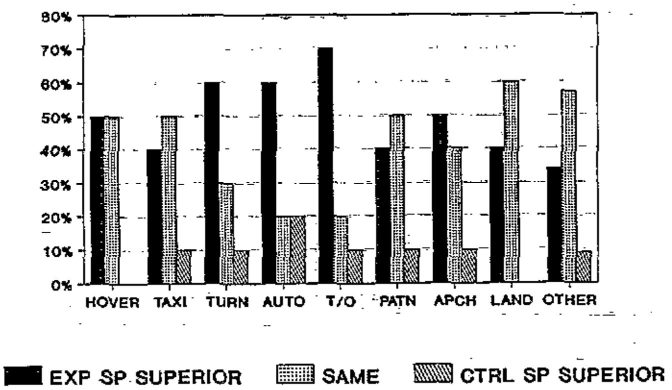

Figure 4. Percent of IPs Who Rated SPs Same or Superior On Each Maneuver

DISCUSSION AND CONCLUSIONS

Considering that the image generator *employed for this first study can* reasonably be described as the minimal feasible capability consistent with flight simulator application, the transfer-of-training results were encouraging. Relative to the performance of SP's who neither received simulator training nor were paired with those who had, positive transfer of training was clearly observed on *six* of the *eight maneuvers*. Substantial savings were observed on two maneuvers in particular, Hover Taxi and Traffic Pattern. Considering the low cost of replicating the simulator configuration utilized, these results suggest that significant savings in terms of total amortized training system cost over time would be achievable with this technology.

The results with respect to the matched controls may be variously interpreted, but in general are consistent with the original hypothesis that such students would benefit by virtue of observing the aircraft performance of simulator trained aviators. The fact that the aircraft performance of the matched controls was *observably* different from the unmatched controls, neither of whom had received simulator training, suggests that it would be prudent to maintain this control condition in future transfer studies.

It is important to note that with respect to the aircraft performance of the simulator trained group relative to the unmatched controls, negative transfer from the simulator to the aircraft was observed for one maneuver, VMC Takeoff, and negligible transfer occurred on one other maneuver, VMC approach. This result underscores the point that prior training to a criterion of proficiency in a simulator does not necessarily result in benefits to performance in the aircraft, and, more particularly, that the training effectiveness of the simulator is task specific.

Among the "lessons learned" in this experiment was a limitation in the data collection procedure which tended to mask group differences. IP's were asked to differentiate between a student's maneuver attempt and an IP guided maneuver attempt by writing "D" (for Demonstration) any time they manipulated the controls. Thus, a true maneuver demonstration and an IP assist were scored the same and SP's were not "charged with" a maneuver attempt when the IP touched the controls. Since the Matched Control SP's required more "Demo's" (mean = 24.7) than the Experimental SP's (mean = 20.4), the total training iterations to criterion differs more between groups than the iteration counts alone (and hence the TER's) would imply. This suggests that the mean iteration data in this experiment represent a conservative indicant of the transfer of training from the simulator. Future TOT studies, however, should control for this circumstance by defining and scoring IP Demo's differently from IP assists. In the present study, the scoring procedure used may account for the anomalous finding with respect to VMC takeoff, in which the simulator trained aviators received the highest percentage of aircraft post questionnaire superiority ratings, but failed to exhibit a positive TER.

This research design was not structured to test hypotheses concerning the effects of variations in simulator features on training transfer. It may be reasonably speculated, however, that the results observed with respect to VMC Takeoff and Approach could well be associated with the paucity of surface texture as the aircraft approached ground level, as anecdotal feedback received from IP's and students would suggest.

In Study 2 an image generator which more closely approximates the standard capabilities resident in a flight simulator visual system will be utilized. In contrast to that employed here, the Study 2 system will employ a synchronous 30 Hz update rate, with increased polygon throughput and significantly increased surface texturing capability, though still well within the criteria of low cost employed the present research. Of particular interest in Study 2 will be the question of whether a significant increase in TER's is observed as a function of these increased capabilities.

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