EMBRY-RIDDLE Aeronautical University
SCHOLARLY COMMONS

Journal of Aviation/Aerospace Education & Research

Volume 30
Number 1 *JAAER 2021*

Article 7

2021

Can Backward-Chained, Ab-Initio Pilot Training Decrease Time to First Solo?

Samuel M. Vance Ph.D.
Oklahoma State University - Main Campus, matt.vance@okstate.edu

Kat Gardner-Vandy Ph.D.
Oklahoma State University - Main Campus, kat.gardner-vandy@okstate.edu

Jared Alan Freihoefer
Oklahoma State University, jared.freihoefer@okstate.edu

Scholarly Commons Citation

Vance, S. M., Gardner-Vandy, K., & Freihoefer, J. A. (2021). Can Backward-Chained, Ab-Initio Pilot Training Decrease Time to First Solo?. *Journal of Aviation/Aerospace Education & Research, 30*(1). https://doi.org/10.15394/jaaer.2021.1839

Introduction

Backward chaining is a learning strategy akin to Steven Covey's "Begin-with-the-End-in-Mind" philosophical approach to life's challenges (Covey, 1989). The term is well-defined by Rouse and Haugh (2018) as "the logical process of inferring unknown truths from known conclusions by moving backward from a solution to determine the initial conditions and rules." Parenthetically applying Rouse and Haugh's definition to solo flight, rather than teaching the student pilot (STD) from takeoff to fly an aircraft, a STD could be taught to land the aircraft first (*the solution*) from a very low altitude close to the intended-touchdown point. The position from the desired-touchdown point could then be methodically and progressively increased backwards through a standard Federal Aviation Administration (FAA) general aviation (GA) traffic pattern (*the series of rules*) to the point of takeoff (*initial condition*).

This exploratory study was undertaken to flesh out merit to a question – could backward chaining in a flight simulator accelerate a STD ability to solo by reducing the amount of dual-instruction time required prior to solo flight? The research was structured to explore a suggestive idea that appeared to have significant potential in accelerating a new pilot's ability to solo an aircraft. The research was not designed to critique the maturation of flight-training-instruction methods over the last 110 years, nor was the research proposed and executed to insinuate or recommend backward chaining should be a preferred/superior flight-training methodology to the competency-based training currently in emergence today across the aviation-training industry. Publishing this research at the exploratory stage will hopefully encourage other institutions/flight schools to initiate similar experimentation with the backward chaining approach to pre-solo-flight instruction and similarly report their findings.

At our collegiate institution, a records pull of 49 students over a three-year period (01 Aug 2017 - 01 Aug 2020) showed for our 12-lesson, pre-solo curricula, scheduled at 11.5 hours of dual instruction (one-hour dual instruction allocated per lessons 1-11, and 0.5 hours dual instruction allocated on lesson 12 immediately prior to solo), no student completed the pre-solo lessons within the scheduled 11.5 hours; rather, the average was 19.9 hours with a standard deviation of 4.7 hours. Our flight training records show immediately prior to solo, the consistent challenge was landing the aircraft; on average, each student required 7.2 hours of additional dual instruction, given in six or more lessons, dedicated to landings. Thus, the vast preponderance of the overage, while not unique to landings, was dedicated to landings practice. Could backward chaining landing exposure in a simulator prior to the start of flight training in the aircraft reduce this average closer to the allocated curriculum allocation of 12.0 hours?

Flight training history has been identified and presented for context in the Literature Review section of this paper to set the backward chaining methodology in perspective with other flight training methods. Historically, all initial flight training has ultimately relied on an "instructor demonstrates/student repeats" behavioral investment. Current U.S. methods (techniques) of flight instruction promulgated by the FAA in their FAA-H-8083-9B "Aviation Instructor's Handbook," all reduce to this basic "instructor demonstrates-prior-to-student-does" premise. The employed backward chaining simulation approach did not include "instructor demonstrate-prior-to-student-do"; rather, the STD was successively placed in a simulated landing scenario in which they had to land the plane based on a minimal set of received classroom instruction and then, with each successive iteration, build on their own previously demonstrated behavior to land the plane.

The desired outcome from this initial round of backward chaining experimentation was the STD solo manipulation of the controls of an actual aircraft, completing three circuits in an airport traffic pattern without the accompanying Certified Flight Instructor's (CFI) physical flight control intervention. Follow-on objectives could include curriculum modification to allow the STD to solo earlier than the current planned solo on lesson 12. The ultimate impact of this research could be a complete, curriculum flip in which the STD solos at the conclusion of their first, dual-instruction lesson.

The primary motivation for this research was to reduce our institution's FAR §141-syllabus-flow "bottleneck" common to pre-solo training. During this phase of STD training, landing repetition can become excessive as the STD tries to assimilate all the necessary skills for their first "test" initial solo.

Exposure to the backward chaining terminology and application to student flight training first occurred between the primary researcher and the CEO of an industry service provider during the fall 2017 University Aviation Association (UAA) annual meeting in Ontario, CA. This reference had reflected on the U.S. Air Force (USAF) in the early 1970s and recalled the Air Force Human Resources Laboratory (AFHRL) at Williams AFB, AZ had been involved with an experiment to apply backward chaining training for USAF undergraduate pilot students via the rudimentary, flight-simulation tools available at the time. Students were reportedly routinely soloing their primary T-41 (C-172) training aircraft at the conclusion of their first dual flight lesson (J. Stecklein, personal communication, September 15, 2017). This flight-training result was intriguing in both its novelty and its practical, present-day collegiate application.

In addition to encouraging other institutions/flight schools to initiate similar experimentation, further purposes of this paper are to report the experimental group of four pilots' results to date, the methodology used to elicit those results, and to propose modifications for further experimentation with a larger control/experimental group of STD.

The resulting research question (RQ1) is: If a STD, with no prior flight-training experience, is first taught to land the aircraft in a simulator, via a backward-chaining approach, will this reduce their dual instruction hours required to solo in actual aircraft?

Problem Statement

Flight training has always been expensive and time-consuming. Simulation has been successfully used for nearly 40 years to supplant flight time. A significant example is a new commercial copilot's acquisition of the sophisticated Type Rating qualifications needed to fly transport category, jet aircraft. The most recent update of the Federal Aviation Regulations (FAR §61.55(b)(2)) - Second-in-Command Qualifications on August 4, 2005 legally allows the first time an airline copilot flies the aircraft in which they were just Type-Certificated in a simulator will be in revenue service with passengers (Federal Register, 2005). This research was designed to explore the potential impacts and benefits of simulation at the beginning of a pilot's career, where simulation has historically not been widely employed. Of specific interest are pilots with no prior flight experience - ab-initio pilot training, starting with whether the initial solo experience (as the sole occupant and manipulator of the controls of an aircraft) in an actual aircraft could be accelerated with backward chaining simulation by teaching the STD to land the plane first? By mastering landings first, the positive motivation potentially derived by the new STD could provide him/her significant confidence to complete certification in less time as well as reducing the expenses involved.

Literature Review

The literature review sought to understand a) the historical use of simulation (either forward or backward chaining) in pre-solo flight instruction, b) the migration of flight training techniques over the last 110 years, and c) where backward chaining might complement other flight training techniques.

Historical Use of Simulation

Light aircraft flight instruction has historically been delivered in a forward chaining context where learning to fly is a sequential build of knowledge and demonstrated skill tasks, starting with taxi and takeoff. Learning to land has been typically one of the final tasks to be mastered prior to solo. Studies consistently have observed, "….the basic structure of the pilot training and licensing system has not changed considerably since World War II" (Barata & Neves, 2017; Todd & Thomas, 2013, p. 169). In the last 40 years, however, simulation has become progressively more capable and affordable for incorporation into GA flight training; but, significantly, is rarely used to teach pre-solo students (Ennis, 2009; Goetz, Harrison, & Robertson, 2012). A dedicated effort was made by Goetz et al. (2013) to explore the reduced-time-to-solo with forward chaining, pre-solo simulation; however, the experimental results, mean-time-to-solo of 17.1 hours and 77 days compared with the control group's mean-time-to-solo of 17.4 hours and 86 days, were not statistically significant.

The use of flight simulation in light aircraft was prophesized by Burt Rutan (Cox, 1990). In his article "On the Need for a Revolutionary Rather than an Evolutionary Approach to Solving Aviation's Problems," Cox explained Rutan's conceptualization of a single screen, "big picture" approach to projecting in front of the pilot's line-of-sight all the aircraft status, navigation, and flight profile information needed to safely execute a flight. Rutan's vision even included an ovoid HITS (Highway-In-the-Sky) and was thus 100% compatible with IMC (Instrument Meteorological Conditions). As prophetic as this vision was 30 years ago with HITS systems that have been available for nearly a decade in GA today, Rutan did not include application to the possibilities of pre-solo training or enhanced initial STD flight training.

With localized exceptions, simulation is generally not employed in pre-solo general aviation flight training (Brady, 2000; Page, 2000). Likewise, no USAF report was located which confirmed the usage of backward chaining in the USAF that was previously described (J. Stecklein, personal communication, September 2017). Currently, the USAF contracts pre-solo flight training to a local flight training school in the vicinity of the USAF Academy, and consultation of their website does not show they are employing pre-solo simulation. While anecdotal, a FAR Part 141 school, contacted in support of this research who desired to remain anonymous, is notable for its recently implemented, pre-solo, simulation curricula that is required for their ab-initio students. A transfer ratio of 1.0 is claimed because 8.0 hours of simulation has reduced the average time to solo from 18.0 hours dual instruction received in their aircraft to 10.0 hours. This pre-solo simulation work, however, is not backward chained.

Backward chaining is a training technique that, while it enjoyed popularity in the 1970s and 1980s, is no longer easily locatable in the literature. Mixed results comparing forward and backward chaining learning approaches, such as reported by Wightman and Sistrunk (1987), and Smith (1999), may have served to dampen enthusiasm for the backward chaining technique. Complications of methodological interactions and the sheer volume of evaluated tasks drove the mixed results, respectively.

No published flight training examples of backward chaining were located after 1996. Matheny, Gray, and Wates (1975) documented and explored AFHRL capabilities in

Undergraduate Pilot Training simulation research but did not expressly address either backward or forward chaining. Hughes (1979) offered a Williams AFB, AFHRL overview of advanced flight training features; however, no discussion of backward chaining applied to initial flight instruction was included in this report. Bailey, Hughes, and Jones (1980) presented a summary of backward chaining methodology applied to the overall, tactical application of air-to-surface weapons delivery. Goettl and Shute (1996) analyzed discrete flight-simulation tasks in two, separate but related, flight training experiments; however, they did not explore initial flight training, rather they explored specific abilities associated with spatial aptitude.

The historical research most relevant with the exploratory research desired to be explored in this study was published by Lintern, Roscoe, Koonze, and Segal (1990). Forty-two STD with no prior flight experience (experimental group) were placed in pairs with a CFI and tested for their ability to land via rudimentary, digital simulation from a distance of 10,100 ft and an altitude of 635 ft AGL (above ground level) with computational, vertical-flight-path-guidance augmentation. Each STD in the experimental group received two, one-hour sessions of instruction in the simulator and completed 26 simulated landings.

The STD start position was placed 0.5° below a desired 4° glide path. The vertical guidance comprised two components. The first component was a bilateral placement of “F-shaped” poles on either side of the approach corridor, in which the two horizontal members of the “F” flanked above and below the desired glide path; this presentation is another form of HITS. The second vertical guidance component was an iconified trajectory presentation of the aircraft’s future state with a simplified, single, cross-hatched bar in which the fuselage is represented by the small, vertical bar bisecting the longer, horizontal bar, depicting the wings. Figure 1 is an excerpt from their report illustrating the augmented F-pole vertical guidance and the iconified trajectory guidance. In this view, the pilot is slightly below the desired glide path and in a right bank, correcting to runway centerline. The inclined symbol (—+—) shown immediately to the left of the runway indicates the aircraft is in a right bank and, without further control inputs, will miss the runway to the left. Ideally, the STD would place this symbol on the runway centered, then level and immobilize the icon so the aircraft would arrive at the spot indicated on the runway. During the descent, the STD were instructed to maintain a constant airspeed of 70 KIAS without making any throttle or trim adjustments from the pre-set, optimized control positions.

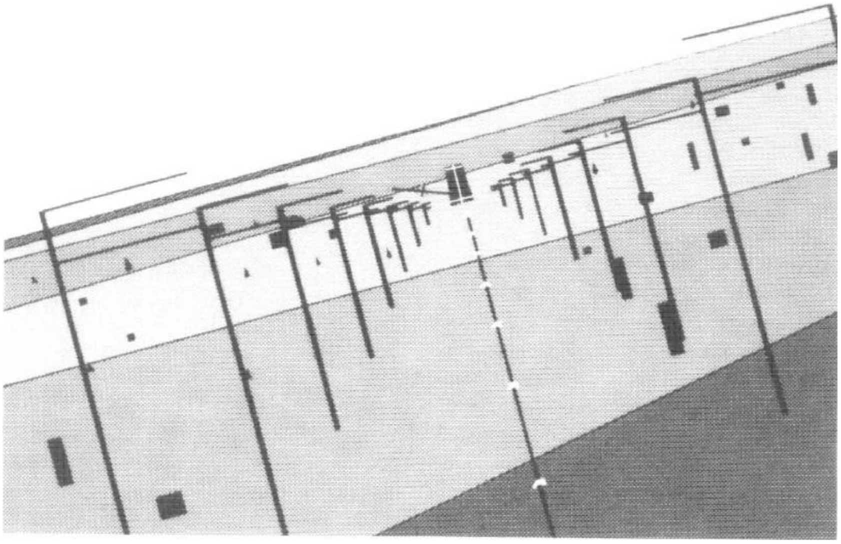


Figure 1. Lintern et al. (1990) digital simulation with "F-pole" vertical guidance bracketing the approach corridor and the iconified, instantaneous trajectory guidance.

After each STD was tested in the simulator, they began their dual-instruction flight training with the same CFI. Hours and numbers of landings attempted prior to solo were tallied. The specific results, compared to a control group, which did not receive simulation exposure, showed 66 landings and 17.6 hours of dual instruction received v. 76 landings and 18.6 hours of dual instruction received. These results were statistically significant and, assuming the 10 landings equated to 1.5 hrs flight time, showed a transfer ratio of 1.5/2.0 = 0.75; however, the researchers allowed a potentially significant limitation: "The saving was obtained despite the fact that the possible magnitude of the reduction was limited by the conservative (curriculum) practice of delaying first solo flights until after 17 hours of dual instruction. Thus, students were not sent out to solo as soon as it was reasonably safe to do so" (Lintern et al., 1990, p. 324). It certainly appears Lintern et al. (1990) felt their students *could* have soloed with less than 17 hours of instruction.

In summary, the literature review revealed only one, statistically significant forward chaining attempt at pre-solo simulation. No multi-step, backward chaining pre-solo simulation was identified; thus backward chaining appeared worthy of investigation.

Flight Training Instructional Methods

The remaining literature review question was how backwards chaining compares with currently employed flight instruction methods? For about the last 20 years, flight training has been transitioning from a historical task basis to a blend of task and competency basis (Fanjoy, 2000). This is an important development highlighted in adult-learning styles which focus on successful aviation outcomes by balancing mastery of sequential tasks with knowledge, assessment of risk, and demonstration of these skills in scenario-based settings (Brady, Stolzer, Muller, & Schaum, 2001; Watkins et al., 2016). This task and competency blend is commonly referred to as competency-based training (CBT). Kearns, Mavin, and Hodge (2016) details the concept of competency-based education in aviation, noting the importance of quality of training over quantity of training hours, and pushes for the standardization of knowledge, skills, and performance. Melvin (2018) offers a concise CBT definition, overview, and statement of benefit. In the late 1990s, CBT was first employed in Australian flight training (Franks, Hay, &

Mavin, 2014). CBT was institutionalized by ICAO in 2006 as the core of their Multicrew Pilot License (Todd & Thomas, 2013) and reinforced by Wong (2018) in an ICAO training package. CBT infusion followed in the U.S. with the FAA's migration, starting in 2011, from its Practical Test Standards (PTS) to Airmen Certification Standards (ACS) (Federal Aviation Administration [FAA], 2017). While the long-standing PTS had (and still has in the case of current PTS for CFI applicants) quantitative, defined outcomes to be demonstrated to specific standards, it lacked the overall risk assessment and application to real-life piloting in various scenarios the ACS now requires applicants to demonstrate as they seek certification. As a further endorsement, Boeing's chief test pilot has publicly endorsed CBT as a superior approach to training pilots on how to make decisions (Boeing, 2012).

Even though the approach of balancing tasks with competencies makes inherent sense, especially as automation is so prevalent in modern cockpits, the infusion of CBT into the flight training transition does not appear complete nor as widely implemented as might be expected (Burgess, 2016). Nonetheless, the transition is continuing. Bravenboer and Lester (2016) have promoted a work-based-degree program in which pilots add professional awareness competencies of Threat Error Management (TEM) and evaluating and managing risks. Keller, Mendonca, Cutter, Suckow, and Dillman (2020) have focused on and recommended six competencies necessary in pilots to achieve improved, pilot-training-program outcomes: teamwork, decision-making, communication, resilience, leadership, and technical excellence. Kearns et al. (2016) ends their text with a charge to academics to utilize multiple methods in studying CBT, recognizing the importance of small-scale qualitative studies.

Similar to CBT, backward chaining, as applied in this exploratory research, was also outcome-focused and required more than simple-skill repetition. Initially, the immediate outcome was landing the aircraft, but as the student was successively backed-up around a standard FAA traffic pattern, in addition to always concluding with a landing, the outcome shifted to the student's decision-making ability to balance pitch attitude, airspeed, and glide angle as they negotiated a standard FAA traffic pattern circuit. The student was, with each iteration, applying in a progressively more sophisticated manner their ability to sense what was required of them to maintain traffic-pattern integrity, proper flight path management, and to execute a landing. Endsley (1995) focused on methods of evaluation and measurement of situational awareness. It was easy to observe all STD in this research accept, grow, and execute with each successive, structured backward chained step, the additional responsibility for the motor skill manipulation of the air vehicle (throttle and flaps) and the cognitive skill responsibility for their traffic pattern position / glide path (pitch attitude, bank angle, and airspeed control). This showed an increasing ability to remain situationally aware of their need to both manipulate air vehicle controls, steer, and manage their overall energy to a successful landing. In a sense, each STD was teaching themselves how to competently fly in a repeatable manner.

Brandon (2003) applied backward chaining to baking a chocolate chip cookie in his instructional-techniques article. It was his overall advice which influenced our research methodology for this study, small steps in the beginning (the landing/final approach to the runway) were most appropriate; although, exactly what the incremental steps should be was not clear.

In our overall literature review of this topic, we found no consistent methodological approach for analyzing backward chaining. Critical to this study was the methodological set-up, i.e., exactly how far apart and at what frequency should the backward-chained incremental steps be set, and how many attempts should be offered to each student pilot at each step? The answers to these questions are essential for developing a useful methodical approach for backward chaining analysis in ab initio pilots.

Methodology

The steps taken in this exploratory study were accomplished in this order: a) construct a backward chaining FAA traffic pattern profile, b) program Redbird MCX with respective starting points, c) recruit and select non-flight experienced STD, d) orient selected STD to research objectives and basic aircraft control in a ground session (a one-hour session), e) fly STD in the simulator (two, ~ 1.5-hour sessions), and f) fly STD in an actual aircraft.

After discussing the completion of each step and the interim results to date, this paper will conclude with adjustments to these process steps to be implemented in the next installment of concept testing.

Profile

Not having located any examples of how backward chaining was applied beyond a single point in the approach corridor, with the singular exception of Lintern et al. (1990), the research team constructed their own set of points. We did not understand, nor was it explained in Lintern et al. (1990), why a non-standard, considerably steeper-than-normal, approach glide path of 4° was used. We elected to stay with the current FAA 3° glide path; which is, unless otherwise charted, the standard for all instrument (GPS [global positioning system] and ILS [instrument landing system]) and visual (PAPI [precision approach path indicator] and VASI [visual approach slope indicator]) approaches in the U.S.

A simple approach of doubling the altitude on the approach profile was taken. The first selected point, 4’ AGL, was actually the third doubling of 1’ altitude AGL. From 4’ AGL on a

3° glide path, the pilot would be 80’ from the glide path intercept with the runway, which is approximately one-second flight time from the theoretical touchdown point. Figure 2 shows the first, seven-selected points and the doubling of altitude (and distance from touchdown) through the fifth iteration. The AGL altitude (measured in feet) and the distance from the touchdown point (also measured in feet) are shown in parentheses. Note the touch-down point is the beginning of the standard Fixed Distance Markers, 1,000’ from the runway threshold. Each iterative point has also been given a name to help orient and qualify what the STD should be considering as he/she starts from the respective point and, on subsequent iterations, passes through that point on the approach profile. The points were successively doubled through the fifth iteration. All points after the fifth iteration were selected based on either the necessity to make an aircraft configuration change or a turn in the traffic pattern.

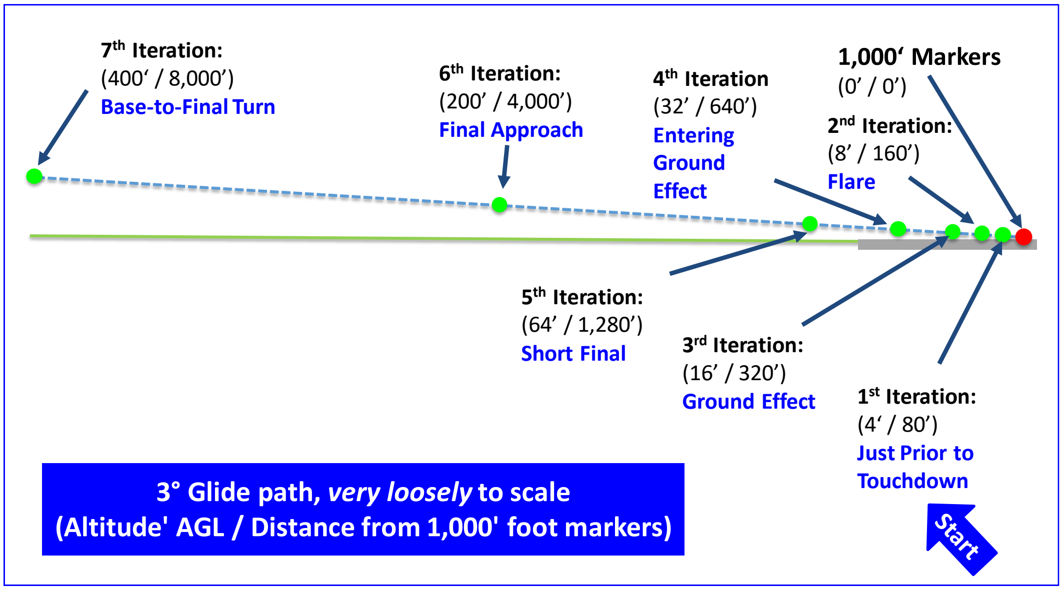


Figure 2. Profile view of the final approach corridor illustrates the first seven, backward chaining, iterative points.

The backward chaining approach starts with the first iteration where the aircraft is 4’ AGL, 80’ from the touchdown point and with ~ one-second of flight time remaining to touchdown. It is not until the fifth iteration that the STD sees the approach end of the runway. Iterations 1-4 are wholly contained by the runway environment. The 6th iteration is the first significant displacement of the aircraft from the landing environment and requires the STD to manage the aircraft energy and glide path, i.e., fly the aircraft.

Figure 3 shows the complete backward chaining approach as the STD was intended to experience in the simulation events. In addition to the iteration number and distance from the touchdown point, each iteration also includes a set of starting condition, aircraft parameters (Altitude [AGL], KIAS, Throttle, and Flap settings), which were communicated and displayed to the STD immediately prior to the start of the respective iteration. The red arrows show the successive progression backwards through the standard FAA traffic pattern. Starting with the 6th iteration, each data block also includes the standard FAA traffic pattern nomenclature (note the lateral separation of the downwind leg was specified as 1 NM from the runway). All other points were determined by the rectangular shape of a standard FAA traffic pattern, and/or the performance of the utilized C-172S aircraft.

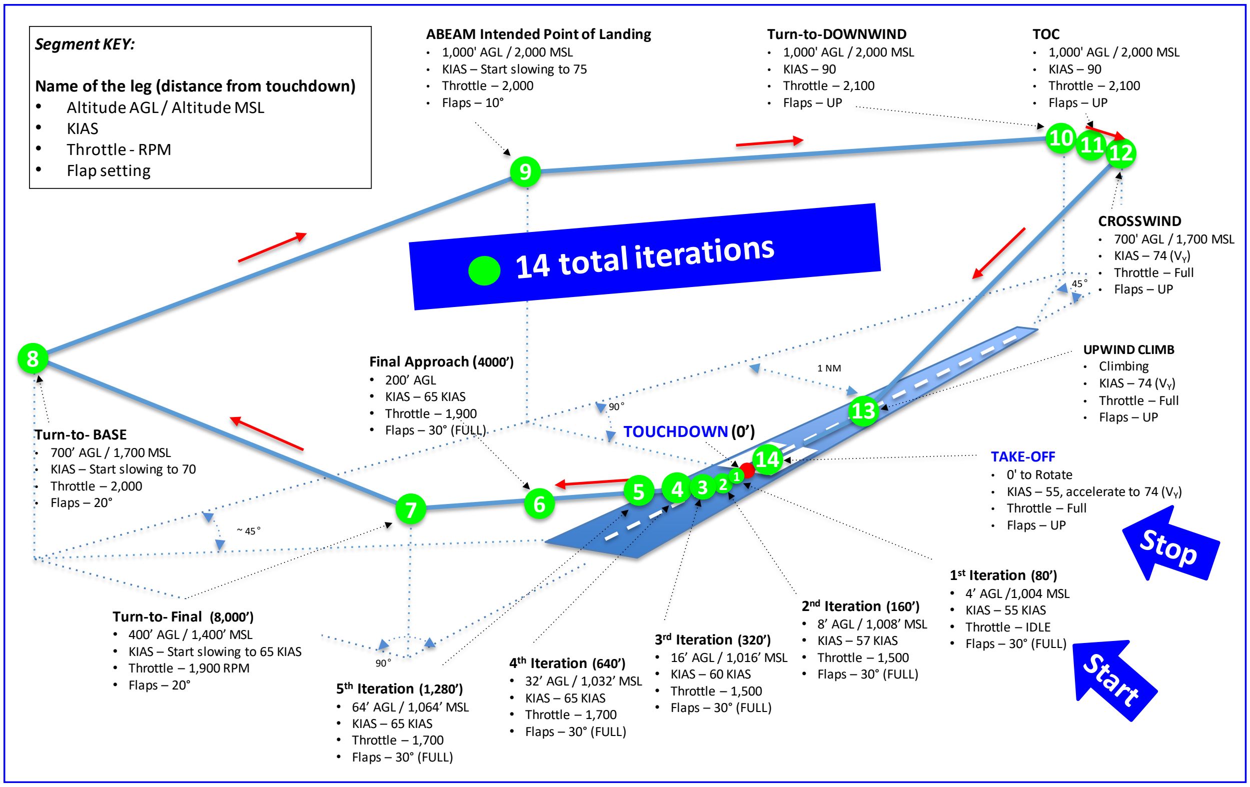


Figure 3. This isometric view was designed as a "big picture" orientation for the STD on the totality of what they would be accomplishing.

Redbird Start Points

Figure 4 shows a to-scale overhead view of the traffic pattern and the calculations necessary to support each of the 14-iterative, backward chaining start points. The leg length calculations were made assuming the segment airspeeds shown in Figure 3, a double standard rate turn (6°/sec v. the traditional 3°/sec), and with published Cessna 172S POH (Pilot's Operating Handbook) performance calculations for takeoff distance and rate-of-climb. The radial distance and angular orientation from the runway threshold were required to program the Redbird MCX starting conditions. The pattern is spaced 1 NM laterally from the active runway and assumes a no-wind condition.

The Redbird MCX was configured as a C-172S with G1000 avionics suite. Programming the Redbird MCX start points was not initially self-evident nor can the end user/customer set all the desired parameters. The lead researcher fortuitously personally met the lead Redbird simulation engineer at the 2019 National Intercollegiate Flying Association (NIFA) national competition in Janesville, WI. A generous offer was made by Redbird to supply an executable file with all the desired start parameters. Each of the 14 iteration points included the following parameters and this information was supplied to Redbird: a) iteration step number and name, b) aircraft pitch attitude in degrees above or below horizon, c) airspeed (KIAS), d) altitude (MSL), e) heading (° Magnetic), f) RPM (throttle setting), and g) flap setting (either 0°, 10°, 20°, or 30°).

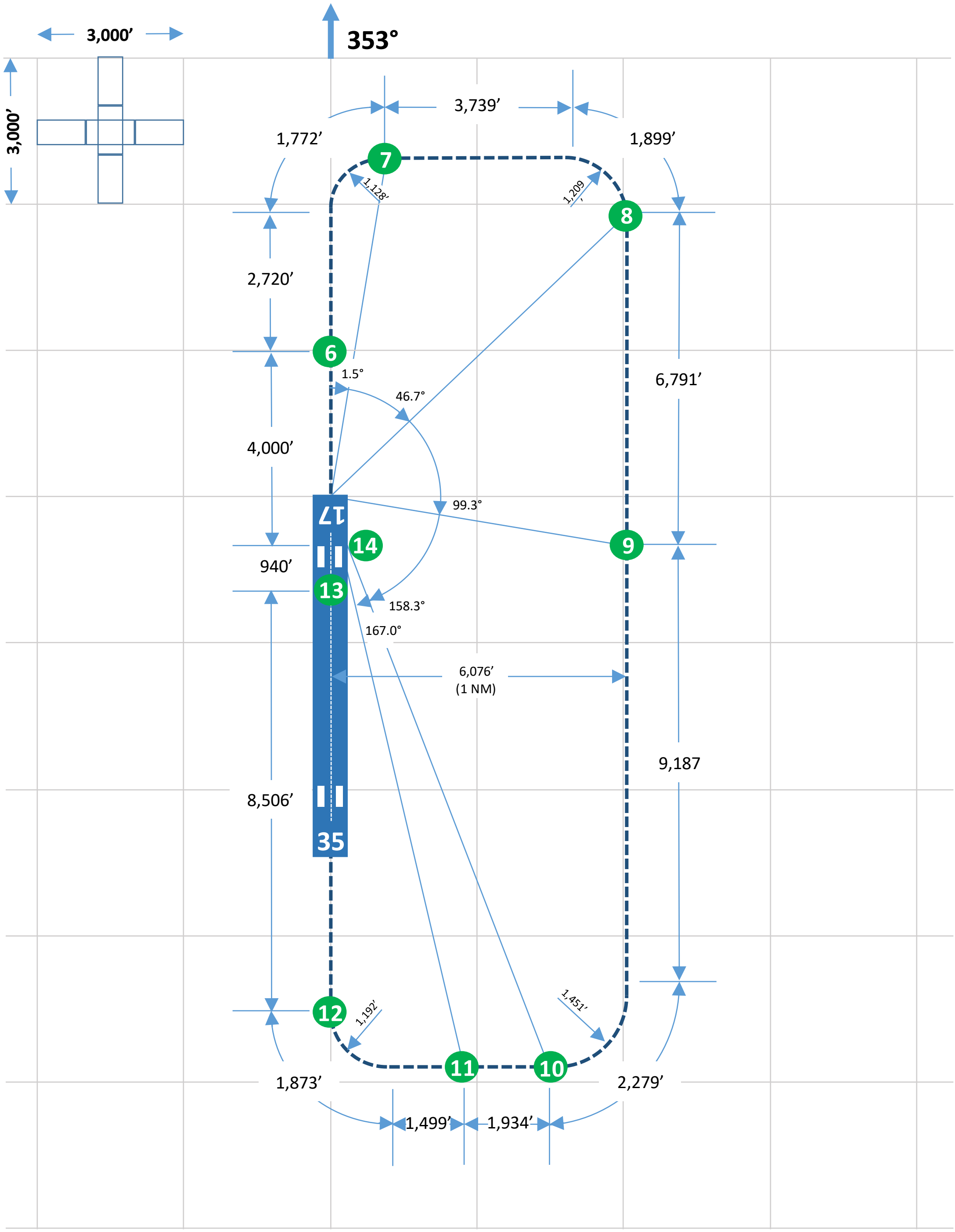


Figure 4. Iteration points 6-14 are shown with their precise angular orientation and distance from the runway threshold.

Unfortunately, Redbird was unable to supply an executable file which contained the pitch attitude, throttle, or flap settings. Because the Redbird-supplied data was referenced in Latitude and Longitude, and to ensure that the orientation and distance from the Runway 17 threshold were as desired, we programmed each of the iterative points manually. This process required a manual reposition of the aircraft based on angular direction and straight-line distance from the Runway 17 threshold. The starting aircraft heading, altitude, and airspeed were set for each of the iterations. Once the data was as desired, the simulation point was saved in the Redbird profiles for our university and titled with the respective iteration number and standard FAA traffic pattern nomenclature.

The airspeed, even though programmed in the starting conditions, was not instantaneously available at simulation release from freeze. Airspeed was restored within one second, but this delay always caused an immediate, nose-down, pitching moment from which the STD would have to recover to the desired pitch attitude for the leg.

STD Recruitment

A presentation, more precisely a solicitation, was made at the Fall 2019 program mandatory start of the semester All-Pilots meeting for eligible STD who met required criteria (adult, of at least 18 years of age, ProPilot declared major student, and no previous flight training experience) and preferably desired criteria (minimal-to-no exposure to flight simulation programs or games, no previous exposure to light, general aviation aircraft, and no previous (pilot) flight time in any light, general aviation aircraft).

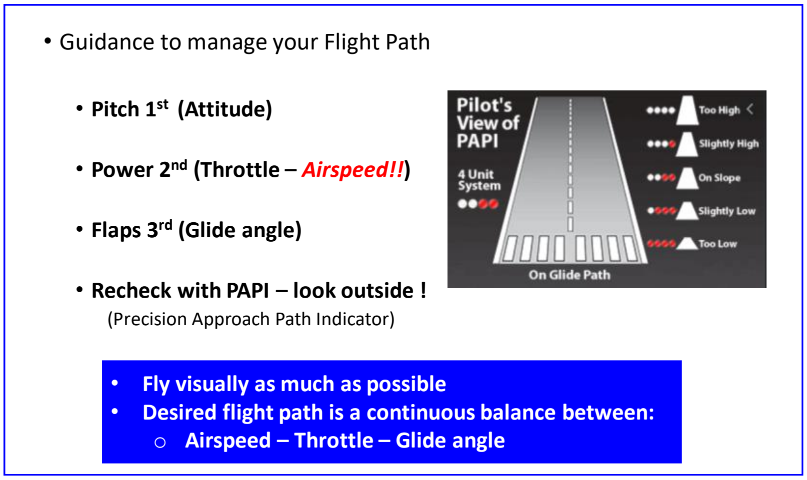
Seventeen STD returned signed research consent and signed eligibility forms meeting either or both sets of criteria. The four STD participating in the backward chaining research were selected based on their academic schedule compatibility with the overall university flight schedule and their match-up with an available CFI. All four participants met the required criteria, none met the complete set of desired criteria.

STD Orientation

A minimal investment of a one-hour, classroom orientation to flight was made as an appropriate consideration for the STD lack of flight training knowledge. Topics covered in this session included: a) backward vs. forward chaining; b) research objective; c) the standard FAA airport traffic pattern; d) expectations of student; and e) flight/cockpit orientation.

The following expectations were communicated in the orientation: a) two simulator sessions of ~ 60-90 minutes each, no more than one week apart, and scheduled as close as possible to your actual flight training start date; b) follow instructions to be given at each step (iteration); c) be eager, willing to make mistakes, and willing to learn; d) ask questions; and e) try to enjoy the experience and have fun!

It was, however, the flight/cockpit-orientation subject which was the most important as this topic would attempt to academically explain the basic principles of aircraft flight to a STD who had never flown before. The topic was broken into three pieces: 1) differences from driving, 2) instrumentation, and 3) general guidance to manage their flight path. The fact that automobiles only yaw, and aircraft pitch, roll, and yaw was covered first. Followed by a G-1000 cockpit orientation to include the location of attitude, airspeed, altitude, heading, rate-of-climb/descent data, throttle, and flap levers. The last, and potentially most important, component of instruction is shown in Figure 5. This offered guidance and was viewed as critical for the new STD to understand and apply. It was perceived if the new STD could understand and apply this simplistic approach to flight, they could manage their glide path with attitude, throttle (analogous to airspeed), and the precision approach path indicator (PAPI).



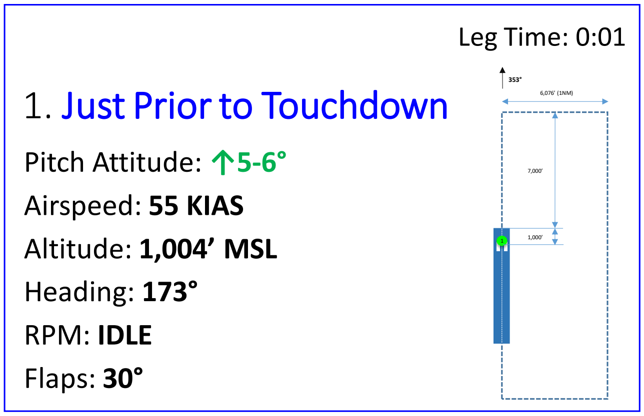
- Guidance to manage your Flight Path
  - **Pitch 1st (Attitude)**
  - **Power 2nd (Throttle – *Airspeed!!*)**
  - **Flaps 3rd (Glide angle)**
  - **Recheck with PAPI – look outside !**
    (Precision Approach Path Indicator)

- **Fly visually as much as possible**
- **Desired flight path is a continuous balance between:**
  - **Airspeed – Throttle – Glide angle**

Figure 5. Summarized flight guidance offered to STD in the one-hour orientation briefing.

Flying STD in the Simulator

To assist the new STD further, a folded cardstock tent (½ of an 8.5” x 11” piece of cardstock) was placed on the cockpit dash for each iteration and reviewed with the STD prior to simulator unfreeze. Figure 6 shows an example of this card for the first iteration. Each of these cards showed the same parameters but were adjusted for the starting conditions at the respective iteration. A black notation was a statement of the starting condition. A green notation was to indicate an immediate action the STD needed to take upon simulator unfreeze (in this case, raise the nose to 5-6° above the horizon). With only one second to touchdown, there really was insufficient time for the STD to effect a nose attitude of 5-6° pitch up with precision, especially considering the Redbird, upon simulation unfreeze, would pitch down.



Leg Time: 0:01

1. Just Prior to Touchdown

Pitch Attitude: ↑5-6°

Airspeed: **55 KIAS**

Altitude: **1,004’ MSL**

Heading: **173°**

RPM: **IDLE**

Flaps: **30°**

Figure 6. Sample leg iteration card displayed on the cockpit dashboard to the STD during the execution of each leg.

Each STD was brought to the simulator for a minimum of two sessions within two weeks of the projected date that would formally start flight training. Each session lasted about 1.5 hours. The objective of the first session was always to complete Iterations 1-7. In fact, each STD was able to complete at least one, Iteration 8 (Turn-to-Base). During the second simulator session, the remaining iterations were completed.

The STD was allowed (encouraged) to repeat each iteration as many times as they desired. Typically, two or three repeats of an iteration were completed. As the iterations progressed, the STD was progressively taxed. In Iterations 1-5 there was only one aircraft manipulation required, starting with Iteration 3 (Ground Effect), the reduction of the throttle to idle. Flap deployment to full (30°) occurred for the first time on Iteration 6 (Final Approach). Iterations 1-6 did not require a heading change other than for fine alignment with the runway. Iteration 7 (Turn-to-Final) was the first time the STD was required to make a significant heading change of 90°; this required respect of the pitch attitude (0°) and bank angle (~ 22°) during and upon roll out of the turn. The parameters shown previously in Figure 3 are those placed on each of the 14 cards.

Flying STD in Actual Aircraft

As soon as practical, ideally on the same day as completing their second simulation session, the STD were offered the opportunity to experience actual flight in an aircraft equipped identically as the Redbird MCX: a C-172S with G1000 avionics suite. Two of the four STD flew on the same day, one the next day, and the fourth flew five days after completing his second simulation session (due to a weather delay). All students flew with the primary paper author (an experienced, CFI/CFII/MEI) occupying the right, front seat.

Results

As of March 2020, four enrolled STD with no prior flight experience have completed the planned backward chaining methodological steps under the direct in-flight supervision of the primary author (CFI) and research assistants. Table 1 tallies the simulation experience.

Table 1

Simulation Experience Results

		Iteration	1 Just Prior to Touchdown	2 Flare	3 Ground Effect	4 Entering Ground Effect	5 Short Final	6 Final Approach	7 Turn-to-Final	8 Turn-to-Base	9 Abeam Intendend Point of Landing	10 Turn-to-Downwind	11 Top of Climb (TOC)	12 Turn-to-Crosswind	13 Upwind Climb	14 Take-Off			
		Alt (AGL)	4	8	16	32	64	200	400	700	↓ 700	1,000	1,000	↑ 700	↑	0			
		Time to Touchdown (sec)	1	2	3	6	12	37	76	121	169	245	269	284	353	363			
	Pilot	Start															Stop		
3-May-19		**0802**	**2**	**1**	**2**	**1**	**3**	**1**	**1**	**1**							**0903**	1 hr 01 min	
6-May-19	**1**	**1306**							**1**	**1**	**2**	**1**	**1**	**1**		**3**	**1420**	1 hr 14 min	**2 hr 46 min**
8-May-19		**1235**														**3**	**1307**	0 hr 32 min	
12-Dec-19	**2**	**1314**	**2**	**3**	**1**	**3**	**6**	**4**	**4**	**2**							**1427**	1 hr 13 min	**2 hr 27 min**
13-Dec-19		**1217**								**1**	**3**	**1**		**2**		**3**	**1331**	1 hr 14 min	
13-Dec-19	**3**	**1032**	**2**	**1**	**3**	**2**	**3**	**6**	**5**	**4**							**1158**	1 hr 26 min	**2 hr 44 min**
16-Dec-19		**1133**								**2**	**4**	**2**		**1***		**3***	**1251**	1 hr 18 min	
14-Jan-20	**4**	**0732**	**2**	**2**	**2**	**3**	**4**	**3**	**5**	**1**							**0849**	1 hr 17 min	**2 hr 32 min**
16-Jan-20		**726**								**4**	**1**	**2**		**1**		**4**	**0841**	1 hr 15 min	

* w/ Trim

Table 1 indicates on the left the four STD who completed the backward chaining simulation, the dates, start/stop and cumulative time spent in the simulator, and most importantly, the number of occurrences of each iteration. The average number of iteration repeats was three (Note: generally, Iterations 5-7 and 14 were the most heavily repeated, and

Iterations 11 and 13 were not completed since judged unnecessary in the moment by all pilots). The overall, average simulation time was surprisingly consistent. As denoted by the *, the third pilot was using pitch trim to remove control pressures in Iterations 12 and 14.

Table 2 shows flights completed in the C-172 aircraft on the following dates, with respective aircraft model, flight times, environmental conditions, and whether a second observing CFI was present in the aircraft as an observer.

Table 2

Completed Flights

Date	C-172	Flight Time	Winds	Second CFI?
May 9th, 2019	R	1	Light/Variable	Yes
Dec 13th, 2019	R	0.7	Light/Variable	No
Dec 17th, 2019	S	0.7	Left Quartering, 5-6 KTS	Yes
Jan 21st, 2020	S	1	Right Quartering, 8-10 KTS	No

All aircraft movement, starting with taxi, was completed by the STD, except for the first circuit in the traffic pattern (which was demonstrated by the primary author [CFI]). After the one demonstrated circuit in the pattern, each STD completed three unassisted circuits in pattern. The first three flights occurred on KSWO Runway 17, as was done in the Redbird; the fourth flight, however, was completed on KSWO Runway 35 due to prevailing winds that day from 050. Each STD was able to easily transfer the simulation protocols learned through the backward chaining to the aircraft in a forward chain. There was clear, increasing confidence in each STD with each pattern circuit. They were also able to integrate the G1000 track vector into their orientation, maintaining rectangular pattern integrity and not allowing wind to modify their pattern shape dramatically.

One frequent challenge for all four STD was the nose attitude in flare, which was judged by the primary, right seat CFI as insufficient. In those cases, the right seat CFI, in addition to requesting the STD do so also, exerted slight additional back pressure on the yoke to prevent, at a minimum, a three-point landing. On the fourth flight, the right seat CFI also inputted the appropriate left rudder/right aileron pressure in the flare to ensure the longitudinal axis of the fuselage remained aligned with the runway at touchdown.

It would have been ideal to have completed all four flights in light/variable wind conditions and with a second CFI observing from the backseat, but this was not possible. Considering these were non-revenue generating flights, each flight needed to be completed when the opportunity presented itself. Having the second CFI (who was also a research assistant in this research) aboard was of significant safety value and, in hindsight, should have been a predication for all flights. For example, on December 17, 2019, the pattern at KSWO was busy, and the control tower was saturated with both VFR pattern traffic and inbound IFR traffic to the point where in coordination with the primary right seat CFI, the second CFI (in the rear seat) accepted external-to-the-aircraft situational awareness (SA) responsibility. This significantly allowed the primary CFI in the right front seat the privilege of shepherding, observing, and mentoring the new STD flying from the left front seat. If the second CFI had not been present, this research flight would have been compromised by the traffic density and the responsibility of the primary CFI to maintain external-to-the-aircraft SA.

Figure 7 is a collection of feedback from the STD and the second CFI (research assistant) who accompanied two of the four flights. These solicited, but unedited, comments are a testament to the value experienced by three of the four STD (the fourth STD commenced U.S. Army basic training immediately after his flight and was unavailable for comment) and the observing CFI (research assistant) on the actual flights.

"You're welcome! It was a good experience watching what good can come from two sim sessions!"

December 17, 2019

CFI

"Flew with (first name) this evening. He landed twice without me touching the controls at all! Very impressive.“

December 19, 2019

CFI

"The backwards chaining research was a very motivating method of training as I got to see rapid improvement of my skills from the beginning of it to the initial flight. It made me want to keep going to see more and more progress."

December 13, 2019

STD 2

"Throughout the Backwards Chaining research that I participated in with (Primary Researcher) I learned how to fly a flight pattern "backwards". Instead of immediately jumping into a cockpit without knowing how anything works, the study created a way for me to grow accustomed to a cockpit and even helped me land a Cessna 172 the very first time I flew. In my opinion, I think that the research put me one step ahead of other students and allowed me to feel much more comfortable in the cockpit on my first few training flights."

May 8, 2019

STD 1

"In my experience with the "Backward Chaining" research project, I can confidently say through each flight sequence in the simulator, I felt more and more comfortable controlling the aircraft. We started slow, which was necessary for easing into learning how to maneuver the plane, and as we continued, each iteration became easier and easier, until I was able to fly in the pattern from takeoff to landing. Once I took what I had learned from the simulation and transferred it to an actual aircraft, I felt very comfortable and confident in my ability. Going into this project, I did not expect to be able to do what I did, and looking back on my experience, I am amazed with the progress I made."

January 22, 2020

STD 4

Figure 7. Unedited comments from participating CFI and STD 1, 2 and 4.

Discussion

While encouraging, the entirety of these results should be appropriately viewed as a "think piece" of what may be possible in future flight training. The small number of four sampled STD is an indicator but not a statistically significant set of results. Completing additional STD and tracking them through solo (Lesson 12) in our university flight training syllabus to see if there is a statistically significant reduction in the number of lesson repeats prior to initial solo would be prudent to validate the benefits of backward chaining prior to initial solo. Notwithstanding the small sample size of four STD, the flight-training-acceleration merit of backward chaining in the simulator prior to exposure to actual aircraft appears promising.

Focusing flight training first on the historical impediment to solo (i.e., learning to land the aircraft) could be a significant, positive STD confidence builder.

Upon reflection, the following adjustments will be considered for any future installments of this research, whether they remain exploratory or move to a formal research study.

a) Retention of Iterations 11 and 13 in the planning and description of the research and its execution, but removal of Iterations 11 and 13 as backward chaining start points.

b) A second observer CFI carried on all flights for the purpose of increased situational awareness, safety, and to allow the primary CFI to focus on data collection.

c) After the first simulation session, additional ground instruction on the benefits of and use of pitch trim – and the conceptual and operational approach to dealing with crosswinds in the pattern (crab angles and ground track) and on final approach (in the flare, transition from crab to slip-to-land to ensure the fuselage longitudinal axis remains aligned with the runway).

d) Three simulation sessions of ~ one hour each, instead of two at ~1.5 hours each. The third session would be a "solidify the learnings" session, only forward chained, and focused on eradicating the effects of wind on pattern integrity / proper, crosswind-landing control inputs.

e) Soloing a STD on the first flight lesson will require all the mandatory components of FAR §61.87 Solo Requirements for STD be incorporated in the knowledge session, simulator, and/or aircraft. The additional FAR §61.87 requirements would obviously expand the time required both in simulation and the actual aircraft, but possibly not as much as expected.

If your institution/flight school is interested in trying the backward chaining, pre-solo techniques this exploratory research has presented, the authors would be privileged to share any of the discussed methodologic steps and planning files as well as answer your questions.

References

Bailey, J., Hughes, R. G., & Jones, W. E. (1980). Application of backward chaining to air-to-surface weapons delivery training, AFHRL-TR-79-63, Williams AFB.

Barata, J. M. M., & Neves, F. M. S. P. (2017). The history of aviation education and training. *Open Journal of Applied Sciences, 7*(4), 196-205. https://doi.org/10.4236/ojapps.2017.74017

Boeing. (2012). Boeing chief pilot: Training must transform to maximize full pilot potential. *PR Newswire*.

Brady, T. (2000). Pilot education: The beginnings. *Journal of Aviation/Aerospace Education & Research*, *9*(2). https://doi.org/10.15394/jaaer.2000.1251

Brady, T., Stolzer, A., Muller, B., & Schaum, D. (2001). A comparison of the learning styles of aviation and non-aviation college students. *Journal of Aviation/Aerospace Education & Research*, *11*(1). https://doi.org/10.15394/jaaer.2001.1286

Brandon, B. (2003). Last things first—The power of backward chaining. *The e-Learning Developer's Journal*.

Bravenboer, D., & Lester, S. (2016). Towards an integrated approach to the recognition of professional competence and academic learning. *Education and Training, 58*(4), 409-421. https://doi.org/10.1108/ET-10-2015-0091

Burgess, S. (2016). Book review: Competency-based education in aviation: Exploring alternate training pathways. *International Journal of Aviation, Aeronautics, and Aerospace, (3)*3. https://doi.org/10.15394/ijaaa.2016.1139

Covey, S. R. (1989). The 7 habits of highly effective people. Free Press. ISBN 0-7432-6951-9.

Cox, J. (1990, April). Burt Rutan, Sport Aviation, EAA.

Endsley, M. R. (1995). Measurement of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37*(1), 65-84. https://doi.org/10.1518/001872095779049499

Ennis, E. A. (2009). Evolution of simulation in aviation flight training. Proquest.

Fanjoy, R. (2000). Collegiate flight training programs: In search of cognitive growth. *Journal of Aviation/Aerospace Education and Research*, *11*(2). https://doi.org/10.15394/jaaer.2002.1296

Federal Aviation Administration (FAA). (2017). Airmen certification standards informational briefing. Retrieved from https://www.faa.gov/training_testing/testing/acs/media/acs_briefing.pdf

Federal Register. (2005). Second-in-Command Pilot Type Rating, U.S. Government National Archives. Retrieved from https://www.federalregister.gov/documents/2005/08/04/05-15376/second-in-command-pilot-type-rating

Franks, P., Hay, S., & Mavin, T. (2014). Can competency-based training fly? An overview of key issues for ab initio pilot training. *International Journal of Training Research, 12*(2), 132-147. https://doi.org/10.1080/14480220.2014.11082036

Goettl, B. P., & Shute, V. J. (1996). Analysis of part-task training using the backward-transfer technique. *Journal of Experimental Psychology: Applied*, *2*(3), 227-249. https://doi.org/10.1037/1076-898X.2.3.227

Goetz, S., Harrison, B., & Robertson, M. (2012). Use of simulation in visual flight training: The effect on time to solo. *Collegiate Aviation Review, 30*(2), 1-10. https://doi.org/10.22488/okstate.18.100431

Hughes, R. G. (1979). Bridging the gap between in-flight and simulator-based models of flying training, AFHRL-TR-78-96, Williams AFB.

Kearns, S. K., Mavin, T. J., & Hodge, S. (2016). *Competency-based education in aviation*. New York, NY: Routledge. https://doi.org/10.4324/9781315563220

Keller, J., Mendonca, F., Cutter, J., Suckow, M., & Dillman, B. (2020). Justification and development of competencies to transform a collegiate aviation flight program. *Competency-Based Education, 5*(3). https://doi.org/10.1002/cbe2.1216

Lintern, G., Roscoe, S. N., Koonze, J. M., & Segal, L. D. (1990). Transfer of landing skills in beginning flight training. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 32*(3), 319-327. https://doi.org/10.1177/001872089003200305

Matheny, W. G., Gray, T. H., & Wates, B. K. (1975). AFHRL FT capabilities in undergraduate pilot training simulation research, AFHRL-TR-75-26.

Melvin, E. (2018). Getting started with competency based training. Retrieved from https://elearningindustry.com/competency-based-training-cbt-getting-started

Page, R. L. (2000). *Brief history of flight simulation.* SimTecT 2000 Proceedings, Sydney Convention and Exhibition Centre, Sydney, Australia, 11-17.

Rouse, M., & Haugh, M. (2018). Definition-backward chaining. Retrieved from https://whatis.techtarget.com/search/query?q=backward+chaining

Smith, G. J. (1999). Teaching a long sequence of behavior using whole task training, forward chaining, and backward chaining. *Perceptual and Motor Skills, 89*(3), 951-965. https://doi.org/10.2466/pms.1999.89.3.951

Todd, M. A., & Thomas, M. J. W. (2013). Experience, competence, or syllabus? Influences on flight hours at licensing of commercial pilots. *The International Journal of Aviation Psychology*, *23*(2), 169-180. https://doi.org/10.1080/10508414.2013.772851

Watkins, D., Newcomer, J. M., Earnhardt, M. P., Marion, J. W., Opengart, R. A., & Glassman, A. M. (2016). A cross-sectional investigation of the relationships education, certification, and experience have with knowledge, skills, and abilities among aviation professionals. *International Journal of Aviation, Aeronautics, and Aerospace, 3*(1). https://doi.org/10.15394/ijaaa.2016.1101

Wightman, D. C., & Sistrunk, F. (1987). Part-task training strategies in simulated carrier landing final-approach training. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *29*(3), 245-254. https://doi.org/10.1177/001872088702900301

Wong, J. (2018). *Enhancing Competency-based training through a sociocultural approach at the Singapore Aviation Academy*. AviAsian2018 Conference, Singapore, China.