Come Fly with Me—the eCFI

Uh, yeah. You could use one.

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"Gauges are worthless unless you look at them"—*Lyle S. Powell Jr.*

This series of three articles is a tribute to all Certificated Flight Instructors (CFIs), whose combined skills have led to an astonishing statistic: Student pilot flights with human CFIs aboard have a lower fatal accident rate than even air carriers. This fact suggests that an electronic CFI (eCFI) might dramatically improve the safety of personal aircraft. The following fictitious story illustrates the point.

John carefully buckled his 4-year-old grandson, Nate, into the child restraint system in the back seat of his homebuilt Experimental aircraft, Alpha Tango. John had promised Nate a visit to the Pacific Coast Air Museum in Santa Rosa, California, a short 130-mile flight from Merced. The weather that morning was gorgeous and, after takeoff, John climbed to 6500 feet and then flew direct on a heading of 289°.

As Alpha Tango settled into a 130-knot cruise in smooth air, John heard a voice in his headset say, "Tailwind is 30 knots. Advise reduce power." It was Alpha Tango itself, talking to John through an array of electronics that he had been developing for just over a year.

Illustrations/Photos: Steve Karp, Brien Seeley

The system, nicknamed the "eCFI" by John's admiring hangar friends, was designed to serve as an electronic CFI like a second set of eyes and hands in the cockpit.

John was highly knowledgeable about electronics, having retired after 20 years of designing software that enabled sensors to talk to computers. His eCFI was modeled after the electronic assistant for personal air vehicles (PAVs) being explored at NASA. It included 11 pounds of sensors, software and servo controls that John had installed to operate Alpha Tango's side-stick control, flaps, avionics and throttle. A machinist friend had customized an electronic throttle servo from a late-model car, and the side-stick control was a duplicate of that in the Questair Venture. John's goal was to make Alpha Tango the safest plane in the sky.

A few minutes later, the eCFI issued a slightly gruff "Ah-humm" in John's headset. Surveying the cockpit, he realized that while pointing out the sights to Nate he had drifted 7° off course and climbed 200 feet. As he made these adjustments, the eCFI said, "Better. You are in command."

Although John knew his eCFI was no substitute for the real thing, he was delighted by the usefulness of the relatively simple system. By monitoring the flight and his piloting actions, it would alert him to possible hazards. John found this capability helpful for both in-flight awareness and post-flight review. He found himself wanting to add more and more sophisticated monitoring functions to the basic system. His latest project was programming the eCFI to initially present somewhat indirect prompts for minor problems, such as the sound "Ah-humm." John felt that this would enhance his own piloting skills while the eCFI maintained its vigilance as a backup that monitored his corrections. Little did John know how important his eCFI would be that Saturday with little Nate aboard.

As they flew over Mount Diablo, John heard the eCFI say, "John, blood oxygen slightly low." John's neighbor, a nurse anesthetist and pilot, had helped him integrate a pulse oxymeter into his eCFI. The oxymeter was unobtrusively clipped on his ear and continuously monitored his pulse and blood oxygen levels. His experience had convinced John to set 6500 feet as his personal maximum altitude without supplemental oxygen. Smoking a pack a day had taken a toll, and experience with the eCFI had convinced John that he needed to kick the habit.

Emergency

As Alpha Tango flew over Bennett Valley just 12 miles from the Santa Rosa Airport, John felt himself losing his grip on the side stick. The weakness rapidly spread to his left leg. Within seconds, John was unconscious from a stroke. He slumped in his seat with shallow breathing, his hands folded in his lap and his legs curled under the seat. Like many children, little Nate, snug in the back seat, had fallen asleep and was unaware of his grandfather's collapse or that he was now in a pilotless aircraft. However, Alpha Tango's eCFI immediately sensed that something was very wrong.

Strain gauges on the control stick sensed that there was no longer any stick force being applied by the pilot. Other sensors detected that Alpha Tango had deviated from course in a steepening left bank, and that it had lost altitude and was increasing its airspeed in a dive. The wireless pulse oxymeter read John's pulse at just 44 beats per minute and blood oxygen saturation below 90% and falling. Programmed to recognize these ominous indications, the eCFI instantly launched the set of actions that John had also programmed and tested in case this very situation might occur.

Studies have shown that student flights with human flight instructors aboard have a lower accident fatality rate than even air carriers. The electronic equivalent can serve almost as a co-pilot, monitoring a variety of functions and parameters that might otherwise go unnoticed.

eCFI to the Rescue

First, the eCFI used its small but powerful actuators to clutch the underpinnings of the control stick and halt the steepening spiral. It simultaneously presented three buzzes per second with a voice prompt to John's headset that said, "Alert: Off-course, altitude loss" and applied a rumble strip type vibration to the side-stick controller, expecting John to wake up and correct the errant flight path. Sensing no response from John after 2 seconds, the eCFI assumed full control, registering the situation as "possible pilot incapacitation." It continued to issue alerts to John to no avail. He remained unconscious and did not respond with the necessary double click on the stick button that would have signaled the eCFI to relax. Pilot incapacitation was now confirmed.

At this point, after re-trimming for straight and level flight, the eCFI used digital electronic commands to simultaneously perform multiple tasks:

1. It searched the GPS database for the nearest airports and gave priority to those that had rescue equipment and large runways. Santa Rosa (STS) was instantly identified as suitable, being within fuel range, 11 miles away.

2. It set the transponder to the Emergency Code of 7700.

3. It turned on special flashing landing lights to indicate to others that Alpha Tango was now essentially a UAV (unmanned air vehicle).

The eCFI then selected the STS tower radio frequency of 118.5 MHz, and used its voice synthesizer to report as John had programmed it for this eventuality. Programmed to identify the airport, Alpha Tango's position and predicament, and the runway with which it was aligned for the approach, the eCFI announced, "Santa Rosa Tower: Mayday, Mayday. Experimental Alpha Tango 11 miles South at 6500 feet. Pilot incapacitated. Landing Runway 32. Squawking 7700 with flashing landing lights. Alert traffic. Repeat. Pilot is incapacitated. This is an automated message."

The STS tower controller, who had already identified the 7700 transponder code on her radar scope, responded, "Alpha Tango, how do you hear?" Receiving no reply after two transmissions, the controller announced that a pilotless aircraft was approaching from the southeast for a straight-in landing on Runway 32 and that all runways and traffic patterns must be cleared immediately. Fortunately, traffic was light and all of the pilots quickly complied.

Meanwhile, the eCFI adjusted the throttle to initiate a 500-fpm descent while trimming Alpha Tango to 90 knots. Pre-programmed with Alpha Tango's known glide ratio of 16:1 and stall speed of 45 knots, the eCFI had flown to a point 1500 feet AGL and 4 miles from the approach end of Runway 32, where it made a gentle turn to the final approach heading of 320° and tracked inbound using the GPS signals. Since the eCFI had no actuators for Alpha Tango's disc brakes, John had programmed it to check wind and to land into the wind. As Alpha Tango began its final approach, the eCFI noted the requisite headwind, with its GPS groundspeed reading 15 knots less than the true airspeed.

The eCFI extended the flaps and used the aircraft's automated gear-extension system to prevent a gear-up landing. It now re-trimmed to maintain a final approach speed roughly 1.3 times the aircraft's stall speed. A slight crosswind required a crab of 3° to the right of the runway heading to maintain a ground track exactly aligned with the runway centerline.

The eCFI's coupled approach was

near perfect. At a GPS height of 35 feet AGL, cross-checked with local altimeter, Alpha Tango crossed the end of Runway 32. At this point, the eCFI began re-trimming to further reduce airspeed to just 5 knots above stall speed. This resulted in a gradual flare as the aircraft settled into ground effect, just 4 feet off the pavement, wings level, nose high and 3° to the right. As Alpha Tango's left maingear squeaked onto the pavement, its tricycle gear righted the yaw angle as the other two tires touched down. As the landing gear's "squat switches" made contact, the eCFI closed the throttle and turned off the magnetos as programmed in the "pilot-incapacitated" situation. The propeller stopped as the aircraft slowly rolled to a halt in the gravel on the right side of the runway, not far from the fire truck that had been alerted by the tower operator.

Happy Ending

Firefighters unbuckled a sleepy little Nate and drove him to the fire station, while paramedics attended to John. The ground crew found Alpha Tango completely intact and turned off its master switch as well as its independent power supply to the eCFI. As they rope-towed the plane clear of the runway and toward the transient parking ramp, normal traffic pattern operations resumed at STS.

John was admitted in serious but stable condition to the local hospital. While Nate's parents drove to Santa Rosa, the airport manager and rescue crew gave Nate a special tour of the fire station and the Pacific Coast Air Museum.

This story brings up several questions about the eCFIs in our future:

1. *Since pilot incapacitation is very rare, what other, more common types of accident might a homebuilt eCFI prevent?*

According to the 2004 Nall Report from AOPA's Air Safety Foundation, pilots cause 78% of fatal accidents and mechanical or maintenance problems cause another 10%. The main causes of fatalities in homebuilt aircraft are as follows:

- 39% Maneuvering, with almost equal numbers due to loss of control and hitting terrain, wires or trees.
- 11% Weather, about 90% of these involved flying VFR into instrument meteorological conditions (IMC).
- 11% Fuel mismanagement.
- 8% Descent/approach.

Together, these account for nearly 70% of fatal homebuilt accidents. The extremely low accident rate of flights on which an active CFI is aboard would argue that the majority of such accidents could be prevented. It is not possible to have a real human CFI on every flight. However, eCFIs, even basic homebuilt ones, might someday substantially reduce these types of fatal accidents.

2. *What kinds of things could an eCFI sense and do?*

Homebuilt eCFIs could sense roll and pitch angles, angle of attack, G forces, airspeeds, altitude above ground level, and flap and landing gear position. They could monitor fuel quantity, water-

in-fuel, cabin carbon monoxide and smoke, as well as the pilot's pulse, blood oxygen level and even alcohol breathalyzer. Further, eCFIs could sense engine parameters such as CHT, induction icing, oil temperature/pressure, oil contamination and fuel pressure. Higher tech devices could use uplinked data to monitor turbulence, weather, traffic and changes in airspace restrictions.

Prompts of graded urgencies issued by an eCFI could alert the pilot to any sensed parameters that were changing or out of normal range. This could include rising engine temperatures, induction icing or falling oil pressure. More sophisticated eCFIs could help avert loss of control, guide and control approaches, and forewarn of Controlled Flight Into Terrain (CFIT) using the GPS Terrain Awareness Warning System (TAWS). These are all capabilities that an eCFI could implement with today's technology.

By comprehensive, simultaneous monitoring of multiple channels of information, the eCFI will provide a better scan than the best of pilots, but the brain of the eCFI must be programmed to correctly interpret the facts it detects and respond appropriately. It must present its information to the pilot in a way that is easy to comprehend. Each component of the eCFI system must be super reliable and redundant whenever possible. A failure of just one component must not result in failure of the entire system. All eCFI interventions must be fail-safe and have internal self-checks that continuously validate their data's integrity.

3. *What about the time it takes for the eCFI to figure out that it must act?*

Every fraction of a second counts as the eCFI analyzes the sensor data, decides what to do and then does it. The shorter the delay before intervention, the more types of accidents can be prevented. The ideal system would assign a priority/time-pressure to each hazard and be able to react in nanoseconds if necessary.

NASA's Naturalistic Flight Deck (NFD) was developed as part of its Personal Air Vehicle Sector program. As the trendsetter for eCFIs, it has a very sophisticated "haptic control" system with fly-by-wire control plus elaborate sensors and feedback for the pilot. A guiding principle for the NFD is that the pilot must remain engaged and participating rather than merely relying on fully automatic flight.

Basic homebuilt eCFIs can be developed to provide valuable first-alert capabilities that save lives. These eCFIs would present lower time-pressure alerts such as to steer clear of restricted airspace, staying on course/altitude, checking fuel supply or engine temperatures. Basic eCFIs can evolve toward faster systems such as the seamless, near-instantaneous hazard awareness and aversive

When John and little Nate took off in Alpha Tango, they never expected its homebuilt eCFI to save the day.

actions of NASA's fly-by-wire, force-feedback side-stick in its Naturalistic Flight Deck (NFD).

Andy Hahn's excellent report *Next Generation NASA GA Advanced Concept* (available at http://cafefoundation.org/v2/pav_pavchallenge_studies.php) compares the operation of Ken Goodrich's NASA NFD to riding a horse; thus, it is called "H-mode":

"The H-mode is a full authority flight control system that, theoretically, is capable of fully autonomous flight. If the pilot stays fully engaged and makes no mistakes, then he will never know that the H-mode is there…Pilot and machine communicate intent through tactile feel and each does its part. The pilot does not directly manipulate control surfaces, just as the [horse] rider does not place each individual hoof… If the pilot tries to perform a dangerous maneuver, the H-mode will attempt to take corrective action, just as the horse will balk when the rider instructs it to do something that might harm it…the pilot is always in command and can always override the H-mode simply by applying more forces."

4. *How will eCFIs interface with avionics?*

Advanced eCFI systems must be able to operate avionics in order to make autopilot landings. For this important safety advance to happen, avionics manufacturers and software service companies need to participate by supplying reference guides that detail data streams and standardized interfaces (such as USB, NMEA, ARINC, etc.) to knowledgeable eCFI developers. Such developers could then use that information to extend the capabilities of their eCFIs. Access to data streams from uplinked weather and traffic services could allow eCFIs to assist pilots in steering clear of thunderstorms, severe weather and traffic.

5. *What if the eCFI-equipped aircraft attempted to auto-land at an extremely busy airport like LAX or O'Hare or at a smaller non-tower field using Unicom?*

The early versions of eCFIs will likely not have auto-landing capability and instead be much simpler monitoring and alert systems. Once a life-saving auto-landing capability evolves, it should not imperil the lives of others. Its rare occurrence as an inconvenience or annoyance would, one hopes, be tolerated and accommodated by those in the existing ATC system, as in the case of Alpha Tango. With enough grass-roots adoption and quality development, disruptive technologies such as the eCFI can earn a place in ATC and the Next Generation Air Transportation System (NGATS).

6. *Should an eCFI deploy a ballistic parachute?*

Yes. Cases involving an unrecoverable spin or a structural failure from a mid-air collision, if high enough AGL, are examples where assisted or even automatic deployment of a vehicle parachute by the eCFI could save lives. In the Alpha Tango scenario, the eCFI landed an intact aircraft at a place where skilled paramedic and fire-fighting resources were alerted and on hand. Alpha Tango never lost control and no person or structure on the ground was injured.

7. *Can an eCFI serve as a flight instructor to the pilot?*

Unofficially, yes. Although no replacement for real CFIs, an eCFI could be an important tool in improving the quality of time spent with a CFI and in helping pilots maintain proficiency. NASA estimates that systems like the eCFI could offer a substantial time reduction in pilot training, thus reducing the cost of obtaining a pilot certificate. In addition to presenting a pilot with alerts, warnings and advice, eCFIs can record, grade and issue comments on a pilot's performance on each flight. They can score pilots on the tasks and scenario drills normally taught by flight instructors and thus enhance the goals of the recently enacted FAA/Industry Training Standards (FITS) program (faa.gov/avr/afs/fits). Ideally, the future eCFI, like a human CFI, will be capable of salvaging a pilot's deteriorating landing or preventing loss of control through increasingly strong cues and interventions, including ultimately taking control of the aircraft. Any eCFI that a pilot purposely disabled should be designed to turn itself back on after 30 seconds or so.

8. *Are there any other benefits from the eCFI?*

Yes. The eCFI could facilitate standardization of flight controls such as the side-stick controller and single power lever. It could also help personal aircraft develop consistent, user-friendly handling qualities similar to those found in rental cars. Such user-friendliness will be a key factor in growing general aviation's user base in the second century of flight. This is why user-friendliness will be a major factor in determining the winner of the $25,000 NASA Personal Air Vehicle Handling Qualities Prize in 2007 (to learn more, visit www.cafefoundation.org).

In today's airspace, the scarcest commodity in the cockpit is the pilot's attention. The eCFI can tremendously extend that attention. However, as avionics and sensors have advanced to display more and more information, their complexity demands that pilots take lengthy classes to learn how to master them. The head-down-display fixation that pilots tend to get from the cluttered screens of today's moving maps can be hazardous. The head-up-display (HUD) should become the new standard. Advanced displays with traffic/weather information and synthetic vision will need simplifying and standardizing to become more interpretable at a glance. This will demand attention to the neurology of how humans best perceive and act. The goal should be to develop eCFIs that reduce pilot workload while maximizing situational awareness.

Builders of homebuilt aircraft can be important contributors to such development. The CAFE Foundation plans to openly share and promote eCFI technologies through its web site. A generic side-stick control, whose underpinnings, sensors and wiring harness could be fitted to many different LSAs, PAVs and homebuilts, is a worthwhile and attainable design challenge for EAAers. With care taken to assure the pilot's ability to maintain command with manual override, such devices could be rigged so as to safely flight-test them on VFR days in low-traffic areas.

Now is the time for EAA's "garage bands" to start building eCFIs. If we are to grow general aviation's user base to a sustainable size, we will need to adopt and implement technologies like the eCFI. Next month, in Part 2, we'll look at some hardware solutions. ✈