# Development of an Active Flight Envelope Warning Method for General Aviation Aircraft

**PROPOSAL**

Submitted to The Engineering Honors Committee

244 Hitchcock Hall

The Ohio State University

2070 Neil Avenue

Columbus, OH 43210

By


Steven R. Scherer

88 E Lane Ave., Apt. 3

Columbus, OH 43201

Advisor: Clifford A. Whitfield, Ph. D.

Department of Mechanical and Aerospace Engineering


14 February 2014

**Abstract**

Loss of control incidents in flight are the primary cause of fatal general aviation accidents. Giving a pilot sufficient warning to correct dangerous situations is crucial in preventing loss of control. Existing warning methods are based on physical margins of aircraft limitations and rarely consider how much time the pilot may have left to safely react. This research focuses on the development of a cost-effective method that uses real-time inertial and aerodynamic data to calculate and improve warnings of flight envelope limitations.

**Introduction**

Loss of control (LoC) in flight generally occurs when an aircraft enters a flight condition that exceeds the normal realm of flight operations, known as the flight envelope. Cockpit distractions, lack of situational awareness, or mishandling of the aircraft can contribute to an LoC event. In these situations, inappropriate flight control inputs (or lack of inputs) can quickly turn into a deadly stall or spin. LoC incidents are the primary cause of fatal general aviation accidents.[1]

There are several methods, regulations, and aftermarket systems that can aid in preventing LoC events. One method of LoC prevention is use of a pilot's operating handbook (POH) for an aircraft, which is a passive defense for LoC incidents. Ideally, through the POH, a pilot is aware of the flight envelope and limitations of their aircraft and can estimate the aircraft's position in the flight envelope using instrument data. However, in high workload situations, such as approaching a runway for landing, pilots continually scan for traffic, communicate with air traffic control, adjust the aircraft's configuration, and are less able to pay close attention to instruments in the cockpit to prevent an LoC event. Relying solely on visual instrumentation that indicates proximity to a potential LoC event only increases the pilot's optical scanning and mental workload. As a result, aural and aerodynamic stall warnings were developed to alert a pilot who has lost focus on the aircraft's flight regime and is nearing aerodynamic stall.

To prevent LoC due to aerodynamic stall/spin, Federal Aviation Regulations (FARs) require all certified small aircraft to have a 5-knot margin stall warning in wings-level flight.[2] For other specified stalls, a warning is required to give the pilot enough time to react and regain control of the aircraft. However, continued LoC incidents indicate these minimum requirements may offer insufficient warnings for pilots to safely correct rapidly changing situations that have small safety margins, such as turning the aircraft onto final approach of a runway. Worse still, experimental or amateur-built aircraft do not have stall warning standards and may not possess any stall warning method, exposing pilots to grave risks.

Highly active methods can also be used to prevent loss of control. Fly-by-wire (FBW) systems can consider the aircraft's current flight condition, pilot control inputs, and the normal flight envelope before deciding how to deflect control surfaces. These systems limit or ignore dangerous pilot control inputs. "Stick-pusher" systems have also been created for mechanically controlled aircraft.[3] These devices consider the flight envelope of the aircraft and use a servo motor to resist dangerous pilot input in critical flight conditions. While FBW and stick-pusher systems have taken on widespread applications in commercial and military aircraft, they are still in development for general aviation. These active systems are being developed for some new general aviation aircraft, but their prohibitive cost and relative difficulty of retrofitting will deter the vast majority of general aviation pilots from installing them in their cockpits.

For these reasons, it is crucial that more cost-effective methods are developed to complement stall warning devices and enhance pilot situational awareness. To be valuable, a system must provide more time than traditional warnings to safely react to and minimize LoC events. A system that proactively warns pilots of aircraft limitations based on the time they have left to react is needed to enhance situational awareness in the cockpit and reduce LoC events.

**Objective**

This research addresses the primary cause of fatal general aviation accidents and seeks a cost-effective means to enhance the pilot's situational awareness in the early stages of potential LoC events. The proposed research aims to develop a proof-of-concept for an active method of warning a pilot of aircraft limitations in flight to supplement traditional stall warning systems. The method will use visual and aural warnings and adjust its warning margin based on the potential for fatal loss of control. Such a system can be integrated into current general aviation aircraft using onboard electronic flight information systems (EFIS). For existing aircraft without EFIS, the method can be implemented on a standalone system that would lower training and cost barriers to bring enhanced situational awareness to a wider audience of pilots, including the growing number of experimental or amateur-built aircraft pilots.

**Methodology**

In order to create an intelligent system that adequately warns pilots of potential LoC situations and flight envelope limitations, this research will be carried out in three phases as detailed in Table 1. The first and second phases will include system logic development and testing using a flight simulator. The third phase seeks to implement the methods developed in phases one and two by developing procedures of integration into existing aircraft systems and building a standalone prototype system as a proof-of-concept.

The first phase of the research will focus on developing the logic that will govern flight envelope warnings. This time will be primarily used to create a detailed physical definition of what flight conditions will prompt a warning to the pilot. Flight envelope information used to develop the warning principles will be based on performance and limitations information from a Cessna 172 POH. The method of determining a warning will consider aeronautical, inertial, and situational information in order to issue a timely alert of a dangerous situation.

The process to warn the pilot of a potential LoC event will be based on pilot reaction time. Some warning systems are based on the physical margin the aircraft has before it reaches the edge of the flight envelope.[4,5] The proposed method, however, seeks to compare physical limitations to current flight conditions (including accelerations and turn rates) and issue a warning based on the time the pilot likely has left to correct for a potential LoC event. Additionally, for a more novel approach, the logic method will consider the phase of flight (i.e. takeoff, landing, cruise) and decide when a more conservative warning would be appropriate. For an aircraft in a condition of high stall entry rate at low altitude, such a time-based warning method could increase warning times more than 200%. Once developed, the method's logic will be tested and continually revised in phase two until performance expectations have been met.

In the second phase, the program logic developed will be evaluated in the simulation of a Cessna 172. X-Plane 10, a thoroughly developed and realistic flight simulator used by Cessna, Cirrus, NASA, Boeing, and others, will be used for simulated flight on a capable personal computer.[6] Figure 1 depicts a Cessna 172 flight simulation in X-Plane 10. A software plugin will be created for X-Plane 10 that utilizes the developed logic structure from phase one to govern flight envelope warnings based on the flight conditions from X-Plane. This C/C++ based software will be able to provide visual and aural cues in the simulated cockpit. Simulated time history flight data will be examined for a number of situations to ensure the program's logic is working correctly. Additionally, the feedback of other Cessna pilots using the modified X-Plane simulator will be sought before moving on to phase three.

Phase three will focus on developing a detailed plan for implementation. Solutions for aircraft with EFIS, as well as those without, will be investigated. A small prototype system will be developed to demonstrate the practicality of the method developed in the simulation models. This prototype system will have intentions for use in small aircraft without EFIS computers or FBW systems. The device will be based on an Arduino or similar microcontroller development board with a minimum of a connected inertial measurement unit, barometer, airspeed or angle of attack sensing system, and a user input device to provide necessary physical parameters. A sample hardware setup diagram is shown in Figure 2. The prototype hardware is expected to cost less than $200, less than 10 percent of the cost of a very low-end EFIS. The prototype will be tested and subsequently evaluated in a wind tunnel with potential for flight testing.

**Capability**

As a private pilot since 2012, I have the knowledge, perspective, and background to execute and evaluate simulations and tests of the proposed warning methods. In addition, I have experience with the fundamentals of flight dynamics, aerodynamics, and flight controls gained from aerospace engineering coursework and an internship at Boeing. Through execution of this research, I will be able to build upon my knowledge of flight dynamics and flight testing while simultaneously becoming a safer pilot. My prior exposure to X-Plane 10 and fluency in the C/C++ programming language provide the skills to develop and test the program logic required. I have gained electronics and microcontroller skills from two additional internships at NASA Glenn Research Center and participation in the Fundamentals of Engineering for Honors program at The Ohio State University. Together, my foundational skills as a private pilot and developing aerospace engineer ensure successful realization of the proposed research.

**Table 1:** Projected timeline of research

| Task | Projected Timeframe |
|---|---|
| Literature Review | June 2014 – August 2014 |
| Logic Development (Phase 1) | August 2014 – September 2014 |
| Simulation and Plugin Development (Phase 2) | August 2014 – October 2014 |
| Evaluation and Logic Revisions (Phases 1 & 2) | November – December 2014 |
| Hardware Acquisition (Phase 3) | November 2014 |
| Prototype System Development (Phase 3) | December 2014 – February 2015 |
| Thesis Preparation | January – March 2015 |
| Oral Defense | March/April 2015 |

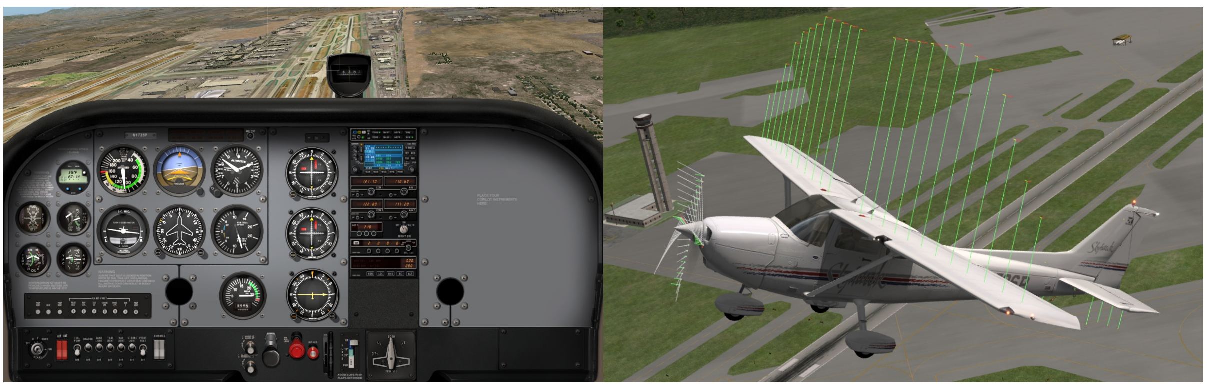

**Figure 1:** Cessna 172S flight simulation in X-Plane 10

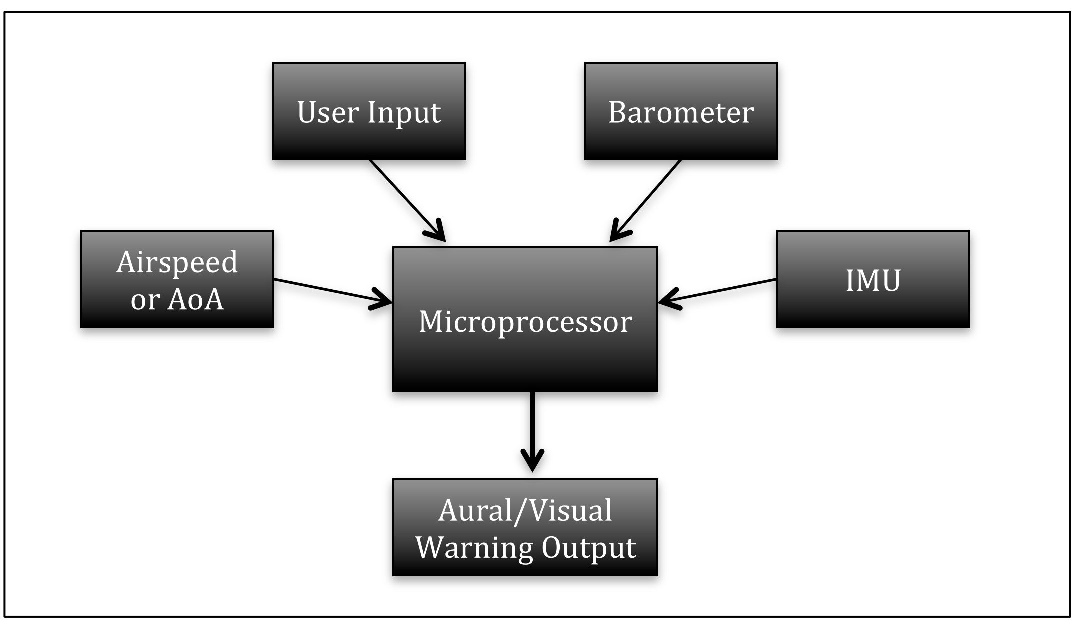


**Figure 2:** A sample microprocessor setup with a microcontroller, inertial measurement unit (IMU), airspeed or angle of attack sensor, barometer, user entry/input

## Cited References


1. Oord D, Clover K, et al. Loss of control, approach and landing, final report www.gajsc.org: General Aviation Joint Steering Committee 2012 September 1.

2. Stall Warning, 14 CFR 23.207, 14 CFR 23.207 (1996).

3. Duerksen NJ, Johnson JC, Williams JS, inventors. **Envelope protection for mechanically-controlled aircraft**. Garmin International, Inc., assignee. US patent US8195346 B1 2009 January 21.

4. Brown JA, inventor. **Stall avoidance system for aircraft**. The United States Of America As Represented By The Secretary Of The Army, assignee. US patent US4590475 A 1985 August 16.

5. Martin ML, Baciak MG, Seiler LW, inventors. **Banked flight stall warning device and method**. Inc Exigent International, editor. US patent US 6169496 B1 1999 January 12.

6. X-Plane 10 Global [Internet]: Laminar Research; c2014 [cited 2014 January 10]. Available from: www.x-plane.com.


## Additional References


7. Anderson JD. 2012. Introduction to flight. 7th ed. New York: McGraw-Hill.

8. Schmidt DK. 2012. Modern flight dynamics. 1st ed. New York: McGraw-Hill.