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SUMMARY OF PERSPECTIVES IN ACTIVE SIDESTICKS DEVELOPMENT FOR SMALL AIRCRAFT FLY-BY-WIRE SYSTEMS

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Abstract: *The use of passive sidesticks in large transport aircraft equipped with Fly-By-Wire (FBW) has shown several problems related to the lack of force feedback. In the context of the current trend to find ways of introducing FBW systems also in small general aviation and future Urban Air Mobility vehicles, it will be necessary to address, how to control these machines and whether the adoption of passive controls from transport aircraft will be acceptable. This paper summarizes the benefits and challenges associated with the potential application of active sidestick in future small FBW aircraft.*

Keywords: force-feedback, active sidestick, artificial feel, flight control

1. Introduction

The growing popularity of sport flying as well as the opening of air transport to the general public has led to pressure to improve the reliability and safety of aviation technology. The nature of the causes of aviation accidents has evolved over time, with an increasing number of accidents where human error has been identified as the primary cause. In the 1950s, it was reported that 20-50% of aviation accidents were human-caused (Vilemeur, 1991). Today, this proportion is around 80% (Schimidt-Skipiol et al., 2015). Thus, to further improve safety, the human-machine interface and improving pilot situational awareness need to be addressed.

The technological cutting edge in modern control systems is Fly-By-Wire (FBW), which has extensive flight envelope protections and high flight automation thus reducing the crew workload and offering a higher piloting comfort. The disadvantage is the high complexity of these systems, which places high demands on crew training, and, last but not least, the cost of these systems. For these reasons, FBW was initially the domain of large transport aircraft only. In 2005, the first business jet with FBW was introduced, the Dassault Falcon 7X, and later, for example, the Gulfstream aircraft (Hamel, 2017). However, all these machines still fall under the EASA CS-25 category.

Civilian aircraft with modern FBW control systems are most often controlled by a so-called sidestick. Compared to a conventional control column, the sidestick offers several advantages, mainly improved cockpit ergonomics, instrument vision, and lesser control forces. In most of these aircraft, the sidestick is passive, meaning that the control forces are usually generated by a spring that returns the sidestick to neutral and the forces are thus proportional only to the deflection. (Gibson et al., 1997). Changes in aircraft configuration, airspeed, etc. do not affect the magnitude and gradients of the forces, which is a significant difference from mechanical control systems used in small aircraft. The controls at the right and left pilot positions are also not mechanically linked so that manipulation of one sidestick or control inputs from the autopilot are not transferred to the movement of the other sidestick. This lack of feedback impairs the crew's situational awareness and places additional demands on their training.

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A solution may be the use of active sidesticks, which have already found application in some military and civil aircraft. Although they compensate for the shortcomings of passive sidesticks, they are not currently a more widespread technology.

2. FBW and the issue of passive controls

The essential parts of the FBW system are the flight control computers, which work with inputs from the pilot or autopilot, monitor the behavior of the airplane, and on the basis of a set of rules called control laws, set the appropriate control surface deflection to achieve or maintain the desired flight regime. In transport aircraft, there are usually 3 control laws - normal, alternative, and direct. The aircraft is in normal law most of the time. The alternate and direct control laws are degraded modes that the system transitions to during flight when faults occur on the aircraft which do not allow the normal control law to be maintained. These may be, for example, malfunctions in the flight control computers, failures in the electrical system, engine shutdown, or loss of hydraulic power.

In a normal control law, the aircraft is controlled as a load demand. In this type of control, the deflection of the sidestick represents the demand for the g load to be invoked. The return of the sidestick to the neutral position is the signal for the flight computer to maintain a g load of 1. This is a very comfortable and safe way to control the aircraft. In a normal control law, the flight control computer will not allow control surfaces deflections that would endanger the airplane, e.g., by overloading the structure or stalling the airplane. These features are called flight envelope protections (Moir et al., 2008).

If the system transits to a direct control law, the response of the aircraft to inputs from the sidesticks changes. The sidestick deflections are directly proportional to the control surface deflection, as is typical for the mechanical control system. In this situation, the flight computers no longer provide any of the flight envelope protection and it is therefore entirely up to the pilot not to put the aircraft into unsafe flight regimes or overload the airframe. The small ranges of sidestick movement combined with the low forces that do not represent control surface aerodynamical loads make the controls quite sensitive. In emergency situations, this way of control results in an additional increase in workload for the pilot. Inadequate handling of the controls has been noted in the investigation reports of several accidents, e.g. Aeroflot flight 1492 or AirFrance 447. In transport aircraft, problems with lack of linkage of sidesticks movement are often mentioned, where the pilot monitoring loses track of the pilot's flying handling of the controls or there might be a moment during emergency management when both pilots are trying to control the aircraft.

3. Active stick

Active sticks or inceptors are those that contain programmable elements that allow the adjustment of forces in the control (force feedback) or the provision of other haptic stimuli, most often by electromechanical actuators and vibration motors. Active inceptors are not necessarily only sidesticks, but also throttles, foot pedals, and, in helicopters, cyclic and collective control levers. These devices were first developed for military aircraft such as the F-22 or F-35. The first civilian aircraft to use an active sidestick was the Gulfstream G500/G600 introduced in 2019.

3.1 Active sidestick design and function

The most common design of sidesticks is with the use of servo drives. The use of actuators has been tested as early as the 1990s by Honeywell (Hegg, 1995) and is part of the active sidesticks in use today in Gulfstream aircraft from BAE Systems. A design of these actuators has been published in the recent past (Fergani et al., 2016). Different solution is based on hydraulics. However, this concept has not found wider application, although some variants have also been patented (Sikkens, 2008). The main problems with these sidesticks will be the cost and the difficulty of maintenance. The last design tested was electromagnetic. The MAGSI (Electro-magnetic sidestick) sidestick (Hanke, 1999) is characterized by a much smaller dimension, compared to a design using actuators, which would make it more suitable for use in small aircraft. However, the reported peak current draw of up to 25 A is quite large even if the entire aircraft electrical system has to be sized differently due to the FBW system.

Whatever the design of the feedback mechanism is, it is always necessary to provide an alternative means of centering the sidestick in the neutral position for cases where, due to malfunctions, it is no longer possible to generate artificial control forces. The most common solution is the use of a spring, which makes the sidestick passive with all the disadvantages described above, but the controllability of the aircraft is maintained. The basic block schema of the system is shown in Fig. 1.

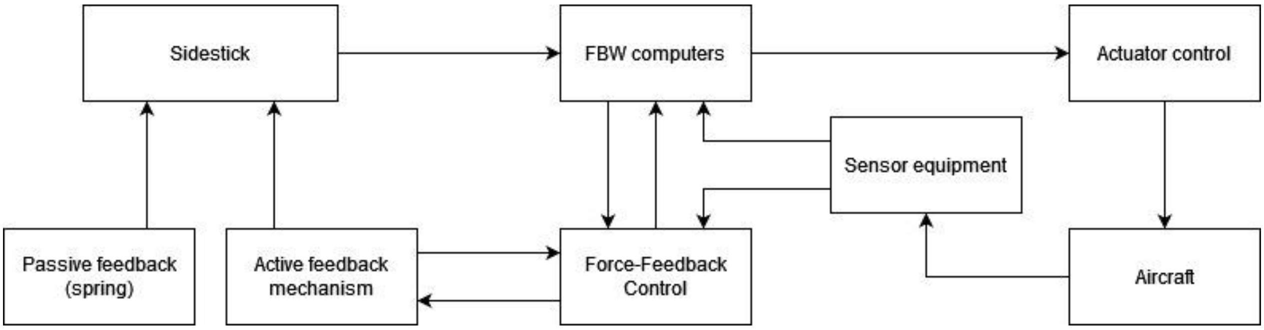

Fig. 1: Block diagram of the feedback system connection to the FBW system

A problem that also needs to be taken into account in the design is the risk of complete blockage of the sidestick movement due to feedback failure. An alternative way of inputting instructions can be solved e.g., via pressure sensing on the handle of the sidestick, but this method of control is quite challenging for the pilot, as has already been demonstrated in tests on F-16 aircraft (Gibson et al., 1997).

3.2 Benefits of active sticks

The benefits of active sticks have been studied with military pilots (Coldsnow et al., 2009). Three FBW configurations have been compared - with software flight envelope protections, without flight envelope protections, and without flight envelope protections but with an active sidestick. The result was that if the control computer provided flight envelope protection, then the pilots did not go outside the flight envelope in all maneuvers, however, without the computer to perform control surface deflection corrections, the flight envelope was exceeded for 39% of the maneuvering time. With the active sidesticks, the flight envelope was exceeded only 10% of the time, a significant improvement over the passive control.

Similar research was conducted with civilian participants and using a simulator (Schimidt-Skipiol et al., 2015). An approach to Innsbruck airport was simulated with three system settings – completely no feedback, passive sidestick, and active sidestick, with which the pilots showed the best retention of the aircraft inside the flight envelope. Force feedback as a means of increasing pilot situational awareness of flight envelope boundaries was also tested. Haptic feedback provided a faster learning rate compared to no-haptics (Van Baelen et al., 2021).

4. Inevitability of force-feedback function in small FBW aircraft

In the last 10 years, efforts can be traced to the introduction of FBW also in small EASA CS-23 category aircraft and new Urban Air Mobility (UAM) assets. These aircraft will be very different from large transport aircraft. The problems associated with passive sidesticks that occur in airliners can be expected to be carried over and probably exacerbated. For small general aviation aircraft, it seems obvious to model the feedback behavior of the mechanical control systems typically used in small aircraft, to which pilots are accustomed. Typically (and especially for small aircraft), both the latest small aircraft equipped with glass cockpits and aircraft 20 or more years old with analog instruments are operated in parallel. It can be expected that even with the introduction of FBW aircraft, these will be operated together with aircraft equipped with conventional mechanical control systems even for decades to come. Similarities in controls might therefore be desirable and would ease the transition of pilots between these two types of aircraft.

However, load demand control logic, used in normal law is a problem because the neutral position of the sidestick represents g load 1 which means a signal for the flight computer to keep the actual regime for example steady horizontal flight, climb, etc. but in the mechanical control system, stick force neutral position changes with a lot of parameters like the center of gravity, speed or angle of attack. If the feedback were to change the neutral position of the sidestick in this way, then false control inputs would be induced. This problem can be solved by correcting the position output signal to the flight computer by filtering out the influence of feedback operation.

The simulation of forces from a mechanical control system is possible in direct law where sidestick deflection directly represents control surface deflection in the same way and it might help to reduce the workload of the pilot. However, in the direct control law, it must be considered that some of the data required for feedback control may no longer be available due to other malfunctions on the aircraft. Running research has the potential to extend the ability to provide force feedback for pilots in degraded control modes, which can be done also using the prediction of missing parameters. Application of mathematical methods in prediction algorithms can include probability theory, fuzzy, or other applicable tools.

The significant difference is also in training between large airliners pilots and sports pilots. General aviation pilots are not forced to return to training after they get their license, except for situations such as not reaching the minimum number of flight hours within two years or license expiration. However, the degraded flight control system regimes and other emergencies, which are possible in complex FBW need to be periodically practiced. Without modification of the training curriculum, high flight automation would be required. For example, the concept of an Easily Piloted Vehicle (EPV), where the pilot can only take over the controls when the aircraft is inside the flight envelope, but throughout the flight from take-off to landing, the possibility of automated flight is assumed and no degradation of control is allowed (Hammel, 2017).

5. Conclusions

When modern FBW systems will be used in small general aviation aircraft together with passive sidesticks, there is a risk of transferring the problems associated with this type of control from large transport aircraft. Design solutions have been in development since the 1990s, but for use in small aircraft, some modifications are still needed. The application of force feedback in load demand mode is problematic, however, the flight envelope protection software already works very well in this mode. A significant benefit would be the use of feedback in direct control law, where an increase in pilot situational awareness can be expected, as suggested by previous studies.

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References

Coldsnow M., Driver A., Kirkland C., Rippy D. and Uyberreta P. (2009) Limited Investigation of Active Feel control Stick System (Active Stick). United states Air force, Air force flight test center, Ewards (in California).

Fergani S., Allias J., Briere Y. and Defay F. (2016) A novel structure design and control strategy for an aircraft active sidestic. In: Proc. 24th Mediterranean Conference on Control and Automation (MED), Athens, pp. 1114-1119.

Gibson J. and Hess R. (1997) AGARDograph 332 Stick and Feel System Design. AGARD, Neuilly-sur-Seine, France.

Hamel P. (2017) In-flight Simulators and Fly-by-Wire/Light Demonstrators: A Historical Account of International Aeronautical Research. Translated by Jategaonkar R., Springer, Switzerland.

Hanke, D. and Herbst, C. (1999) Active sidestick technology – a means for improving situational awareness. Aerospace Science and Technology, 3, 8, pp. 525-532.

Hegg J., Smith M., Yount L. and Todd J. (1995) Features of Active sidestick Controllers. IEEE AES Systems Magazine, pp. 31-34.

Moir I. and Seabridge A. (2008) Aircraft Systems: Mechanical, electrical, and avionics subsystems integration. 3rd edition. John Wiley, Chichester, United Kingdom.

Schimidt-Skipiol F. and Hecker P. (2015) Tactile Feedback and Situational Awareness-Improving Adherence to an Envelope in in sidestick-Controlled Fly-By-Wire Aircrafts. In: 15^{th} AIAA Aviation Technology, Integration, and Operations Conference. Dallas, Texas.

Sikkens B. (2008) Hydraulic Manipulator Joystick. (patent no. WO2009/093901A1), Netherland.

Van Baelen D., Van Paassen M., Ellerbroek J., Abbink D., and Mulder M. (2021) Evaluating Stick Stiffness and Position Guidance for feedback on Flight Envelope Protection. In: Proceedings of the AIAA Scitech 2021 Forum. Virtual/online event.

Vilemeur A. (1991) Reliability, Availability, Maintainability ans Safety Assessment: Volume 2 Assessment, Hardware, Software and Human Factors. John Wiley, Chichester, United Kingdom.