In the future airspace, a growth in small aircraft movements is forecasted by the US Small Aircraft Transportation System (SATS) and the European Personal Air Transportation System (EPATS) programs. The main reason for this growth is due to an increasing demand for people to access more communities in less time. With the introduction of improved, reliable, and cost-efficient technologies, it is even expected to become an attractive alternative to road transportation. In the general aviation segment, however, accidents are not rare. Therefore, measures must be taken to guide this growth in a safe manner.

TEXT Ir. Wouter Falkena, Researcher, Control and Simulation & dr.ir. Clark Borst, Research Associate, Control and Simulation

CHALLENGES
Currently, an average number of seven accidents per 100,000 flight hours dominate the general aviation segment. By looking more closely at accident analyses, the majority of all causes in general aviation accidents can be traced back to “stick and rudder” mishaps (72%). Simultaneously performing the tasks of aircraft handling, communication, navigation, and planning can be rather difficult, especially for less-experienced pilots. In terms of aircraft handling, misjudging the coupling of aircraft states and the effects of external disturbances can put pilots in unsafe regions of the flight envelope. To resolve these issues, control augmentation techniques — such as those employed in commercial aircraft — can be used to create easy and safe aircraft handling characteristics.

Commercial aviation has a long history of utilizing fly-by-wire control systems to shape ideal aircraft responses. To increase safety, modern commercial aircraft, such as a Boeing 777 and an Airbus A380, are also equipped with so-called Flight Envelope Protection (FEP) systems to protect against stall, excessive over-speed, limit the angle of attack and load factors. These techniques greatly reduce handling and control accidents in the commercial aviation segment. However, simply downscaling these advanced fly-by-wire platforms for general aviation aircraft is not a viable option as it would significantly increase the cost of such aircraft.

SMALL AIRCRAFT FUTURE AVIONICS ARCHITECTURE
In the Small Aircraft Future Avionics Architecture (SAFAR) program, an ongoing European seventh-framework project in which the Delft University of Technology participates, a low-cost fly-by-wire platform will be developed for small aircraft by using technologies originating from the automotive industry. The platform will comprise computing resources, a human-machine interface, a mainly satellite-based fault-tolerant altitude/navigation system, and a safety-critical electric power supply with all-electric actuators. In order to cope with the challenge of “low-cost” for the small aircraft category, synergies with advanced absolutely safety critical drive-by-wire platforms (10^{-4} safety capability) from automotive developments will be used.

The SAFAR team consists of several partners from the industry as well as academia. Rheinmetall Defence Electronics GmbH, Deutsche Flugsicherung GmbH, Diamond Aircraft Industries GmbH, Grupo de Mecánica del Vuelo, Honeywell International s.r.o., and Septentrio NV represent market leaders in their respective fields and have therefore good economical backgrounds for bringing this new technology to market. The University of Stuttgart are experts in integrated modular
avionics, and x-by-wire platforms for the automotive industry. Finally, the contribution of the Delft University of Technology is to provide flight control and guidance software along with a primary pilot interface for enhanced situational awareness.

The ultimate goal of the SAFAR consortium is to introduce new and innovative technologies into the small aircraft aviation segment: everything from avionics, navigation up to aircraft manufacturing. This will be a completely new transportation system for small aircraft that will make it more available to everyone and should provide safe and affordable air transportation.

VALIDATION PLANE
The objective of this project is a full concept and technology proof by means of in-flight validation. Consequently, the full platform including all sensors and actuators will be implemented onto a Diamond DA-42 TwinStar aircraft showing full degree of redundancy and full fault tolerance. Although, the platform is designed not to rely on any mechanical backup, a mechanical control backup will be implemented onto the DA-42. This is done in order not to burden this research program with the full load of formal certification activities required for a platform without any mechanical backup.

FLIGHT CONTROL DESIGN
Flight control is used to change the behavior of an aircraft as seen from the pilot's perspective. Before this behavior can be redesigned, however, first an accurate description of the current aircraft behavior is needed. A six-degrees-of-freedom nonlinear mathematical model has been created in the beginning of the project that captures the dynamic behavior of the DA-42. Using this model, feedback loops can be established that use the current state (attitude, position, velocity, etc.) of the aircraft to calculate which control surface deflections are needed to end up at a desired state. What state is actually desired is still controlled by the pilot.

If pilots want to steer an aircraft along a predefined Earth-fixed trajectory, they have to close three loops (attitude in the inner loop, flight-path angles in the middle loop and position in the outer loop) with each of the control loops having their own constraints and response characteristics. Depending on the desired level of automation, a number of these loops can be closed by an autopilot. For the demonstrator aircraft, only the fast changing attitude angles (inner loop) will be automatically controlled. However, this already brings a tremendous benefit to the ease of flying. A reference attitude is set by the pilot and disturbances, such as turbulence, are rejected by the autopilot. Also, since the reference attitudes can be set independently, the autopilot decouples the control of the aircraft states. For example, a larger elevator deflection command is automatically issued as soon as a turn is initiated, to prevent the aircraft from pitching down while banking.

Not only can flying be made easier using automation, also safety can be increased. Using a FEP system, the aircraft is preventable from going into unsafe regions of the flight envelope (e.g., slower than stall speed or exceeding the maximum load factor). Again there are several design options on how this can be achieved. The control surfaces can be limited, commands fed to the control systems can be altered or the control system can be replaced by an advanced controller that is able to handle state constraints. Preliminary research and simulator studies have shown that for the demonstrator aircraft command limiting is the favorable option. This option does not rely heavily on model and sensor accuracy nor is it expected to be very difficult to certify.

FUTURE PERSPECTIVES
If we assume that fly-by-wire technology will penetrate the small aircraft market, other challenges may emerge. These challenges can be similar to those that were faced during the evolution of commercial aviation.

For example, increasing the level of automation in commercial aircraft has brought success as well as failure. That is, on the one hand automation has reduced pilot workload, improved flight-technical performance, and increased flight safety. On the other hand, issues such as low pilot situation awareness and skill degradation have become undesirable side effects that can eventually compromise the benefits of automation. Thus, the challenge for future investigations will be to actively involve pilots in the control and decision-making loops.

Currently, conflicts between the Delft University of Technology to mitigate loss of pilot situation awareness in various terrain and traffic scenarios include, for example, advanced conflict visualizations on 3- and 4D Synthetic Vision Displays and Navigation Displays adopting Cognitive Systems Engineering principles.

All these actions bring us closer towards a personalized air transportation system in which flying an aircraft will be fun, easy, and above all, safe!

References
http://www.fp7-safar.de
http://www.epats.de
http://sats.nasa.gov/

Figure 1: SAFAR modifications of the DA-42 aircraft

Figure 2. Synthetic Vision Display showing 3D flight-path visualization