SOFT WALLS – MODIFYING FLIGHT CONTROL SYSTEMS TO LIMIT THE FLIGHT SPACE OF COMMERCIAL AIRCRAFT

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Soft Walls

Motivation

Many things changed on September 11, 2001. Among them, civilian aircraft became potential enemy weapons systems, and air traffic control changed from a civilian problem to a military one. This working document describes a technological response that is practical and implementable and goes a long way towards ameliorating the risk of a repeat.

This is a working document in early stages; it contains several unanswered questions.

Summary of the Approach

The approach is to create "no-fly zones" that are enforced by the flight control system in aircraft. As an aircraft approaches the boundary of such a zone, the flight control system creates a virtual pushing force that forces the aircraft away. The pilot feels as if the aircraft has hit a soft wall that diverts it.

For fly-by-wire aircraft (which will eventually be all of them, most likely), this modified control system is conceptually easy to implement. The aircraft carries a three-dimensional model of the earth's atmosphere, annotated with the topology of the surface (which creates real "no-fly zones") and the topology of regulatory constraints on flight space (which creates virtual "no-fly zones"). The virtual no-fly zones would shield, at a minimum, major cities, government centers, and military installations. The model is updated only rarely, and is coarse grain; the zones are large, representing the overall structure of cities, not individual buildings.

The boundaries of these zones are called "soft walls" because the aircraft is gently diverted by its own control system when it attempts to enter these zones. Pilot feedback could be provided by a heads-up display that is (at least) active when the walls are nearby.

The control system of the aircraft would work as follows. As the aircraft approaches a no-fly zone, from any direction, the control system responds by biasing the aircraft away from the zone. As the aircraft gets closer to the zone, the bias gets stronger. The soft wall seems to push back. The control system ensures that the aircraft remains within safe flying parameters, and the pilot never feels like he or she has totally lost control.

Technical requirements

For this to work, the control system needs to reliably know where it is in physical space, and what its orientation is. The orientation information is a normal part of the flight control system, and hence is already available to the software in fly-by-wire aircraft. The location in physical space is available from GPS systems and a suite of backup mechanisms, including ultimately inertial navigation systems, which reside entirely on the aircraft.

In addition, the control software must mediate all pilot requests, including engine control (for example to prohibit engine cutoff when approaching a soft wall from above) and control of all flight surfaces that affect the trajectory of the aircraft. This makes the technique expensive to implement on older aircraft that do not have fly-by-wire control systems.

Is there some solution for older aircraft?

Will this be acceptable to the FAA and to pilots?

In normal circumstances, nothing is any different from the way things are now. As long as the plane is not threatening to enter one of the no-fly zones, it is still under the complete control of the pilot or (entirely separate) autopilot. Hence, this proposal does not address the air traffic control problem.

Robustness

External access

The control system is entirely local, on board the aircraft, depending only on having accurate localization information (GPS would be the first order solution). As such, it is less hackable than more networked solutions. There is no override mechanism on board the aircraft, and the hardware and software is not accessible from the passenger compartments on the aircraft.

Technical simplicity

The system does not depend on visual or radar sensors to determine where obstacles are, and thus does not face the serious technical problems of distinguishing, for example, an inappropriate approach to a building from an appropriate approach to a runway that is close to an airport terminal.

Dependence on localization

The requirement that the aircraft know where it is creates a vulnerability. Conceivably, a sophisticated attack could spoof the GPS system, effectively overriding the soft walls. Encryption of the GPS signal could prevent spoofing.

Is such encryption currently done? Is it feasible?

Jamming the GPS system would cause the system to fall back on other navigation technologies. Ultimately, the inertial navigation system would be used, and the pilot would be alerted that an emergency landing is necessary before the drift of the inertial navigation system renders the soft wall system itself a threat.

How quickly does an inertial navigation system drift? Recall that the soft walls are coarse grained. The typical rate of drift may define a minimum feature size for the no-fly zones.

Destruction of the control system

The soft walls system could be disabled by destruction of the fly-by-wire control system. However, this would render the aircraft uncontrollable, which is probably not worse than having a malicious pilot. The control system can be made inaccessible to the passenger areas of an aircraft, so that destruction of the control system could only be accomplished by destruction of large portions of the aircraft. This technology, obviously, does not reduce the need to keep bombs off commercial aircraft.

Cost

I believe this could be deployed at a very low incremental cost over existing fly-by-wire systems. Memory for the 3-D database and enough cycles for slightly more complex control laws is all that is required.

Retrofitting older aircraft could be considerably more expensive. However, one phase-in approach that might reduce the risk in critical areas would be to require aircraft flying in certain regions to be equipped with soft walls. For example, the FAA could require all aircraft flying into the Washington DC area to be so equipped. This would make it safer to re-open Reagan National Airport. Although rogue aircraft (not equipped with soft walls) might still get in, there would be advance warning.

Side Benefits

A side benefit is that maybe some other air accidents might be prevented, where aircraft run into real obstacles due to poor visibility or other problems.

Regulatory Issues

Because the soft walls reduce flyable space, some discipline must be applied in determining the geometry of the no-fly zones. For example, it would probably not be a good idea to make all land surface part of a no-fly zone, because it would result in the pilot having less control in an emergency landing away from an airport. The location and geometry of the no-fly zones is partly a political, military, and ethical question. Some thought will have to go into how to determine these zones. The extent of these zones should be minimized, subject to these non-technical considerations, so that pilots have as much flyable space as possible.

Potential Objections

Taking control away from the pilot is not a good idea

As long as the pilot remains in legal airspace, nothing operates any differently than it does today. The soft walls system kicks in only when the aircraft is endangering other interests.

In reality, the world already has "no-fly zones" that are strictly enforced. One cannot, for example, fly through mountains. This proposal creates artificial no-fly zones where enforcement is gentler. As such, although it seems to reduce usable airspace, it only reduces it by removing the space where flying is totally unacceptable anyway.

Prohibiting engine cutoff when approaching a soft wall from above implies some risks. Consider for example an emergency where there is an engine fire.

Is this risk acceptable?

Collisions may become more likely when at a soft wall

Anytime the pilot's control of an aircraft is impaired, collision with other aircraft in the vicinity becomes more likely. However, this risk occurs only if two or more aircraft are simultaneously approaching a soft wall. Under normal circumstances, it would ideally be years between events where an aircraft approaches a soft wall. This makes the increased risk of collision very much smaller.

Moreover, the soft wall could probably be designed to impose a coarse grain control on the aircraft, allowing the pilot to still retain fine-grain maneuverability. This maneuverability may be sufficient to prevent collisions.

There is no override

The surest way to make the system effective is to prohibit override in any form. Manual override on the aircraft is certainly out of the question. Override from the ground is perhaps doable, but the security of the communications becomes a problem, and the human authorization of the override creates a vulnerability.

Note that it might be possible to permit TCAS or ACAS (advanced collision avoidance system) to override the soft walls systems for brief periods of time, long enough to avoid a collision, since soft walls will probably operate at coarser granularity than TCAS.

Does this create additional complications and risks that offset the added safety?

The three-dimensional model will need to be updated

Assuming the three-dimensional model is sufficiently coarse grained, updates will be needed only infrequently. Construction of new buildings does not affect the model. Construction of new cities or new military installations does.

Could infrequent updates be handled as part a periodic FAA recertification?

The ability to update the model creates a vulnerability. Model data should be encrypted so that it is very difficult to construct a valid model.

Making it Happen

Realization of soft walls requires expertise in software, avionics, and control systems. Fortunately, DARPA has a two-year-old program, Software-Enabled Control (SEC), that has already assembled a superbly qualified working team that contains exactly this combination of expertise. This program has been focusing on autonomous coordinated flight. Redirecting this program to focus on soft walls might be the most effective way to get the effort started.

A timeline needs to be defined, with milestones.

Technical questions

A number of technical questions need to be answered.

1. Given the maneuverability of aircraft, what are the geometric constraints on no-fly zones so that safe avoidance is always possible (at least by an intact aircraft)? This is a math problem.

2. What control laws for flight control will provide the soft pushback effect safely? Can fine-grain maneuverability be maintained? This is a control theory problem.

3. How will localization be reliably provided if GPS fails? If inertial navigation is used, how will its drift constrain the geometry of the no-fly zones?

4. What is the cost of implementation on existing and future aircraft? This cost must include the certification cost of embedded software in the critical control system of an aircraft.

5. Given the answers to the above, does the system provide adequate protection of critical installations to be worth the cost? In particular, can cities and key government sites be protected while still allowing access to urban airports?

Obviously, the critical question to answer is the last one.