Automatic Ground Collision Avoidance System  
(AUTO GCAS)

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Abstract - Currently, all collision avoidance systems on fighter aircraft depend on the pilot taking action whenever a warning is issued by the manual system. Any future substantial reductions in mishap rates require extending the collision avoidance technology to systems that not only warn the pilot but also take control and fly the aircraft out of danger before returning control to the pilot. This paper will discuss the requirements, design methods, and testing of Auto GCAS. It will show why a nuisance warning is considered a higher priority than the aircraft recovery and how an automatic system can be designed to basically eliminate nuisances. It will discuss how the design of a modular automatic collision avoidance system can be transitioned to any number of air vehicles with minimum changes to the basic design. Integrity management will be discussed. The process of testing an automatic system including both simulation and flight test will also be discussed. Discussions on flight test activities including both current and past experience in Auto GCAS is included.

Key-Words: - automatic, mishap, system, nuisance, simulation

1. Introduction
Auto GCAS is a technology that will virtually eliminate mishaps in compatible fighter aircraft. The system operates by projecting the aircraft trajectory over a Digital Terrain System (DTS). The DTS contains a digital map consisting of Digital Terrain Elevation Data (DTED). The system uses an Inertial Navigation System (INS) to accurately position the aircraft over the DTED. All functions required to determine when to initiate the fly up maneuver are calculated multiple times-a-second. A terrain profile is generated from the local terrain map based on the aircraft’s location and current maneuvering. The predicted trajectory is calculated and then compared to the terrain profile to determine if a collision is imminent. Should an imminent collision be estimated, the system immediately performs the recovery. This recovery maneuver has been defined from previous flight test efforts. It consists of a roll to wings level combined with a pull up at 5g or the maximum g available. It is meant to be at least as aggressive as the recovery maneuver of a pilot. If inverted, it counters gravity and aggressively rolls to wings level in the direction to reach the upright position in the shortest time. Once past 90 degrees of bank, the aggressive 5g normal acceleration pull up is commanded. Integrity monitors and redundancy will be used to insure that no failures or subsystem errors cause an unsafe recovery or prevent a recovery from being completed. The system is a combination of modular
software programs meant to be hosted in existing aircraft processors. A modular design allows the separation of aircraft tailored code versus non-specific vehicle code. This improves configuration control, refinement and update efficiency. The requirements for an automatic system in order of importance are.

1. Do not Cause a Mishap
2. Avoid Impeding Operations
3. Avoid Collisions with Terrain

2. Problem Formulation

2.1 Do not Cause a Mishap
In addition to being nuisance free, the system must operate safely. The automatic system utilizes a high-authority autopilot to execute the evasion maneuver. This autopilot must only be engaged when there is high certainty that the evasion maneuver will not be further jeopardizing the aircraft and aircrew. The automatic system must be able to manage a failure of a major sub-system or components. When a failure of these systems occurs, it must disable engagement of the auto-pilot in order to prevent it from causing a possible mishap. Therefore, the system must be fail safe.

2.2 Avoid Impeding Operations
Two critical issues were identified over the early years of exposure to an automatic collision avoidance system. The first was the significance of nuisance warnings in a collision avoidance system. The second was the difficulty in defining and presenting nuisance warning data such that it could be used for design and development.

Research suggested that the primary limitation of automatic technology at that date was the excessive occurrence of nuisance warnings. Pilots quickly learned to “tune out” manual warnings or turn the systems off entirely to avoid these false warnings. This rendered these systems ineffective. No criteria existed to indicate the threshold between valid warnings and those that would be considered nuisances by the pilots. This was evidenced by the fact that Controlled Flight into Terrain (CFIT) remained the number one cause of fatalities in aviation even in platforms which had installed one or more manual ground proximity warning systems.

2.3 Avoid collisions with terrain
The primary purpose of the Auto GCAS is to avoid collision with terrain. One would presume that this requirement should be number one. However, if the system would cause a mishap or become a nuisance, it will become ineffective. If an automatic engagement of the system should occur, the pilot could turn off the system. This would have the same effect as in the manual system where a pilot ignores the warning.

2.4 Ground Testing for an automatic system
Initial tests consist of standalone and integrated tests. The stand alone tests are conducted on individual software portions of each Auto GCAS sub-system. The integrated tests are conducted with each of the sub-systems connected together. The integrated tests are done using the handling qualities simulator. Failure modes are introduced into the system during the integrated tests. These failure modes are used to ensure failures in the system are detected and resolved.

2.5 Flight testing for an automatic system
Flight tests begin with flying the aircraft in normal operation to determine if any nuisance activations occur. Testing then activates the Pilot Activated Recovery System (PARS). The PARS is designed to allow a pilot to manually initiate an activation of the automatic system. The PARS, when initiated, will cause the aircraft to automatically recover to wings level and 1G. It is used when a pilot becomes disorrientated and loses situational awareness. A switch in the cockpit controls the activation of PARS.

Once the nuisance and PARS tests are complete, the Auto GCAS is tested. This is accomplished by flying the aircraft towards the terrain until the system activates. The flight test mode of the system can change the altitude above terrain where the system activates. The tests are begun at higher altitudes above terrain and are decreased progressively until the system activates at the
desired final altitude above ground determined by the 1.5 seconds time available.

3. Problem Solution

3.1 Safe operation
To ensure the Auto GCAS is safe and will function properly, failure modes testing must be successful. A study is conducted to determine what functions in the system when failed cause the Auto GCAS to fail. These functions are failed while the Auto GCAS is operating in the simulator. The Auto GCAS is designed to go to a failed state when these failures are detected properly. The software used to detect failures is located in a redundant subsystem.

3.2 Nuisance criteria development
In 1995, AFRL began addressing the nuisance warning issue through the conduct of a study on a fighter aircraft. The purpose of this study was to develop criteria that automatic system designers could use to optimize their systems to avoid nuisance warnings. A flight test was developed to determine a boundary above which the initiation of a dive recovery was considered unwarranted. The premise of the criteria was defined by the following logic. During any approach to a collision, a pilot must make a judgment of the distance required to avoid the collision-threat given the conditions at the initiation of the recovery. The point to be made is that the pilot’s opinion as to whether a recovery initiation is warranted must be made at the initiation of the recovery. It can also be reasoned that the dividing line between a valid warning and a nuisance warning is the point where an aware pilot feels an aggressive recovery must be initiated to avoid collision. A warning issued after that point, logically, could not be considered a nuisance by that pilot, since he had already decided that a recovery was warranted. Likewise, a recovery initiated earlier than that point could, under some circumstances, be considered a nuisance. Identifying the locus of points where the pilot feels an aggressive recovery must be initiated would lead to criteria defining the boundary between valid recoveries and recoveries that may be considered nuisances.

The test procedures called for the pilot to establish the flight conditions and maintain them while assessing the approaching terrain. When the pilot reached his comfort threshold concerning the approaching terrain, he was to initiate a recovery. The Pilot Activated Recovery System (PARS) was used to initiate the recovery so that the recoveries would be consistent across all pilots regardless of technique. The pilot rated the timing of recovery initiation, anxiety level and the precision/aggressiveness of the maneuver for each run. From this data, it was discovered that it was not altitude, but time available that each pilot used to determine when to recover the aircraft. The average time available was about 1.5 seconds.

The flight test was constructed utilizing 6 pilots having a broad difference in experience. Although all were fighter pilots, some came from a combat background while others from extensive flight test. Some had many thousands of hours in the F-16 while others less than 50.

Test runs required the pilot to establish a broad spread of conditions approaching terrain with variations in dive, bank, air speed and load factor. Runs were conducted against both smooth and mountainous terrain. Additionally, one run (a 5 degree wings level dive at 450 knots over smooth terrain) was repeated by each pilot at the beginning and end of each sortie over the entire flight test effort to track any personal variations in perception due to increased familiarization to the low altitude environment as the flight tests progressed.

3.3 Ground test resolution
The ground tests for the Auto GCAS provide a means to ensure that the system is safe to fly. These tests also ensure that failures of the Auto GCAS will be detected and the system goes to standby or fail depending on the circumstance. Auto GCAS is called a fail safe system. This means that the system when not available has no effect on the operation of the aircraft. When Auto GCAS is off, the aircraft is the same as before Auto GCAS was present. Of course, the aircraft has no protection during this time period.

3.4 Flight test
The flight test for Auto GCAS begins with flying over smooth terrain. A buffer altitude is used to allow the system to initiate at higher altitudes to determine that it is operating properly. Instrumentation aboard the flight test aircraft is used to monitor critical parameters. Other parameters are recorded on board the aircraft to provide the test engineers data to analyze the operation. The analysis is conducted prior to flying at lower altitudes. The testing progresses to lower altitudes until the desired level of 1.5 seconds time available is achieved. The testing then proceeds to mountainous terrain using the same build down approach as in the smooth terrain.

4. Conclusion
Most aircraft utilize manual warnings to provide the pilot time to recover the aircraft. These warnings can be in the form of aural, visual, or both. The timing of these warnings is the basic issue as to why an automatic system is superior. The timing depends on the specific pilot and how he/she perceives a warning. A warning too soon can be perceived as a nuisance for some pilots and too late a warning may not give the pilot enough time to react. The balance on timing can never be designed correctly do to the fact that everyone has different perceptions and capabilities. Many studies have been conducted both in simulation and in flight to try to obtain a correct design but mishaps have continued over the years.

In contrast, an automatic system does not depend on pilot reaction. The system makes the decision to react and can be adjusted to react at the last instant so that the perception of nuisance is virtually eliminated.

The loss rate per flight hour for Controlled Flight into Terrain (CFIT) has not changed for over 40 years. And over these years, many types of manual warnings have been provided. This is the primary reason that automatic systems are necessary. As discussed in this paper, automatic systems must be designed to initiate after the pilot would normally recover the aircraft. This allows automatic recovery to be nuisance free. The automatic design does not completely eliminate the nuisance factor. In fact it becomes more important. The pilot/operator must be satisfied that the automatic maneuver activates at the proper time and accomplishes the correct maneuver. If an automatic maneuver activates too soon, the pilot/operator will have the perception that he/she could have performed the maneuver and not need the automatic system. Of course if it activates too late the result would be catastrophic. A too early activation will also create the nuisance factor. It needs to activate after the pilot/operation would normally activate the same maneuver.

The design discussed here is for fighter aircraft. Automatic recovery can be utilized on any type of aircraft. However, an air vehicle requirement for automatic recovery is to have a digital flight control computer to provide the integrity management which is discussed in this paper. This is just the beginning of achieving a long awaited system that will prevent mishaps. The payoff is huge due to the cost of these air vehicles and due to the lives saved by preventing these mishaps.

References