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A SENSOR INTEGRATION TECHNIQUE FOR PREVENTING COLLISIONS BETWEEN AIR VEHICLES

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14. ABSTRACT
The use of data links to control unmanned air vehicles (UAVs) from ground controllers over the past several years has become an important concept for military operations. Currently, multiple UAV flights are not performed due to mission requirements. Control algorithm designs can be achieved to provide for multiple UAV operations, but unforeseen circumstances such as ground controllers flying the wrong course could cause air vehicles to arrive in the same airspace at the same time, which could cause a collision. This paper will discuss the integration of data links in the design of an Automatic Air Collision Avoidance System (Auto ACAS) for aircraft, which are intended to prevent air-to-air collisions between air vehicles. This system is not intended to replace existing designs such as the Traffic Alert and Collision Avoidance System (TCAS), but to accomplish a recover at the last instant to prevent a collision.

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Key Words: Automatic Collision Avoidance System (Auto ACAS), Aircraft Response Model (ARM), Auto ACAS Algorithm, Escape Maneuvers, Data Links

Abstract

The use of data links to control Unmanned Air Vehicles (UAVs) from ground controllers over the past several years has become an important concept for military operations. Currently, multiple UAV flights are not performed due to mission requirements. Control algorithm designs can be achieved to provide for multiple UAV operations, but unforeseen circumstances such as ground controllers flying the wrong course could cause air vehicles to arrive in the same airspace at the same time, which could cause a collision. Even in the case of autonomous UAV operation, flight management errors could result in time of arrival errors and air vehicle collisions. As more of these systems are utilized, the methods of controlling them become even more complex and the possibility of air-to-air collisions increases. There is also a desire to operate UAV flights within commercial airspace. This desire cannot be achieved until a proven method to prevent air-to-air collisions is implemented.

This paper will discuss the integration of data links in the design of an Automatic Air Collision Avoidance System (Auto ACAS) for aircraft, which are intended to prevent air-to-air collisions between air vehicles. This system is not intended to replace existing designs such as the Traffic Alert and Collision Avoidance System (TCAS), but to accomplish a recovery at the last instant to prevent a collision. TCAS and other systems in use today provide situational awareness and traffic advisories that enable pilots to perform de-

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confliction and manual avoidance maneuvers, while remaining several miles apart. In contrast, Auto ACAS assumes such de-confliction and manual avoidance attempts have not succeeded and operates in a time span that does not allow for manual pilot reactions, thus it must be highly integrated and automated in operation. An automated TCAS could be used to keep apart aircraft, however this kind of design may be difficult to implement due to the fact that the system was initially designed to instruct the pilot to make course changes and not to automatically take control of the aircraft.

Automatic collision avoidance is necessary if Unmanned Aerial Vehicles (UAVs) are to blacken the sky in massed attacks, accompany manned fighters on combat missions, aerial refuel, or transition civil airspace. These vehicles will, in some manner, have to see and avoid other aircraft. An automated air collision avoidance system will fulfill this requirement. It will automatically maneuver an aircraft, at the last instant, to avoid an air-to-air collision. It will function in a manner similar to a pilot avoiding a collision. It is a system that must be reliable, verifiable, and partially redundant, forming the last line of defense against collisions. It must provide nuisance free operation and allow safe interoperability. The requirements for such as system will be discussed in detail. Of particular interest are criteria to enable a safe, nuisance free system that will have embedded rules of the road for all encounters. Autonomous control of unmanned aerial vehicles is a goal for the US Air Force in the future. However, flying multiple unmanned vehicles in the same tactical airspace with manned fighters presents very challenging problems. Automatic collision avoidance is a necessary step in achieving this goal.

This paper also discusses the planned integration of sensors into the Auto ACAS algorithm to provide complete see and avoid technology for the UAV. Planned use of both active and passive sensors will allow operation in all weather conditions.

1. Introduction

The Air Force of the future will utilize UAVs at a much larger extent than what is used today. These UAVs will also operate autonomously in some instances. A means to prevent collisions between individual UAVs and between UAVs and manned aircraft becomes necessary. Systems have been developed to keep aircraft from flying too close. These systems operate by displaying to the pilot all aircraft within a specific air space and providing information on velocity and direction. The specific air space is quite large (typically on the order of 40-50 miles). UAVs can use the same information to provide safe distance from manned aircraft. The UAV must have a means to obtain the information automatically. In the case of ground control, the information can be displayed at the controller station via a data link. For autonomous UAV operation, the information must provide the capability to automatically maneuver the UAV if it becomes necessary. A system must be designed to provide the capability to prevent UAVs from flying too close to manned aircraft and too close to one another. This system must also allow the UAVs to complete their mission without interference. The system should allow the capability of formation flying and for aerial refueling of UAVs.

2. Automatic Air Collision Avoidance Design Options

The idea of developing an automatic air collision avoidance system (ACAS) originated when the possibility of how to operate multiple UAVs autonomously in the same airspace and how to operate multiple UAVs with manned aircraft was considered. One method would be to have each UAV controlled by an operator and fly them like manned aircraft. This method becomes quite challenging when the number of UAVs gets large, failures occur, or when operator errors occur.

Another method would be to use the existing TCAS and automate it. The TCAS was developed for commercial airlines and operates by warning the pilot when two airliners become too close. The pilot must take appropriate action, which is in the form of a climb or dive. To automate

TCAS, it must be connected to the flight control system so that the warning would be turned into an action and a maneuver. At first glance this would seem to be the answer for the UAVs but there are problems with this design. First, TCAS operates at very large distances (20-40 miles) thus would not allow close formation flying nor aerial refueling. Secondly, TCAS was developed to be a manual system. This fact at first must seem trivial to the reader but the automation of a system that interferes with normal operation of a flight control computer must be designed carefully. The software must go through a more extensive test for a flight control system than for other avionics systems. In most instances hardware and software redundancy is required to obtain the safety requirements demanded by a flight control system. There are methods to allow single thread or non redundant systems to be connected to a flight control system but these methods are not normally applied to manually operated systems.

About the same time as questions were being raised on UAVs, the Air Force Safety Center asked if AFRL could design a system similar to Auto Ground Collision Avoidance System (GCAS) for preventing air-to-air mishaps in military aircraft, specifically fighters.

The approach to obtain an Auto ACAS was to utilize lessons learned from the Auto GCAS and apply them to the new Auto ACAS design. It was assumed from the beginning that an Auto ACAS would be much more complex than an Auto GCAS for several reasons. First, the ground was large and easily identifiable for Auto GCAS operation. Second, we had several years experience in developing different methods to achieve the Auto GCAS design. Lastly, the ground was a stationary target and always in the same place.

The other area that required decisions on how to implement the design was the data between the aircraft. There are basically two options that can be implemented. One of these is to utilize a sensor on one aircraft that measures the required parameters on the other. This can be accomplished with radar or some optical sensor. The other method is to utilize a data link on each aircraft that sends and receives the required parameters from each aircraft. One advantage that the data link has over other methods is that it allows each aircraft to know what the other aircraft is doing at any given time. For the flight test of the Auto ACAS algorithm, a data link will be used. The data link was the least risky alternative during the time period of this program.

4. Auto ACAS Program Plan

The program plan is to design, develop, integrate, and flight test an Auto ACAS algorithm. To achieve an acceptable safety margin, the algorithm would be flight tested first on a manned F-16 platform. One of the platforms of choice is the Variable Stability In-flight Simulator Test Aircraft (VISTA) F-16. This aircraft is easily modified to simulate other aircraft and also can easily host the Auto ACAS algorithm without an extensive integration effort. The second aircraft will be an F-16 modified to accept the Auto ACAS algorithm and data link. The VISTA and the F-16 will be flown together to show how well the algorithm protects each aircraft from colliding. Tests will be conducted to show that the algorithm does not interfere with normal pilot operation and only engages to protect the aircraft from a mishap. It is also planned to program VISTA to simulate a UAV. It will then fly collision courses with the other Auto ACAS F-16 to show that the UAV will maneuver away from the manned aircraft.

The design and integration phase of the program began in August of 2001. Saab and Boeing will design the algorithm with inputs from Lockheed that pertain to the integration on the F-16. Lockheed will integrate the algorithm onto the F-16. The Air Force Flight Test Center (AFFTC) at Edwards AFB will be the Responsible Test Organization (RTO). The VISTA aircraft is located at Edwards AFB and is controlled by the Test Pilot School (TPS). TPS will contract Veridian to modify the VISTA aircraft which includes installing the data link and the Auto ACAS algorithm. Flight test is scheduled for the summer of 2003.

5. Algorithm Design - Claim Space Method

The Auto-ACAS algorithm does not try to identify collisions based on predicted probable trajectories of the aircraft. Instead it claims space along a predicted escape trajectory (time tagged positions were the aircraft will be after an avoidance is executed) which the aircraft will use in the case an avoidance maneuver is necessary. The major benefit of using an escape trajectory is that it can be predicted much more accurate than the probable trajectory which the aircraft will follow if no avoidance is executed. This is because the escape trajectory is executed automatically in a predetermined way by the Auto-ACAS algorithm, whereas the probable trajectory is affected by the change in pilot commands. The size of the claimed space is computed using knowledge of the wingspan, navigation uncertainty and accuracy of the predicted trajectory compared to the one the automatic digital flight control system (DFLCS) will make the aircraft follow if the escape command is given.

Each aircraft sends its predicted escape maneuver and the size of the claimed space along this track to the other aircraft, using the data link. All aircraft will use the escape maneuvers from the different aircraft to detect a future lack of escape, see Fig. 1. If the distance between the escape trajectories is greater than the safety distance, the track is stored as the one to use in case of avoidance. Else the avoidance is executed using the DFLCS to make the aircraft follow the stored trajectory.

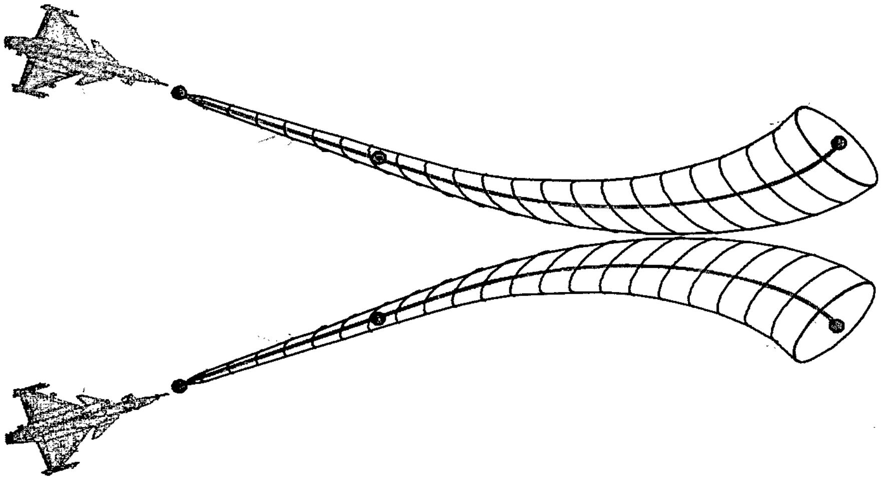

Fig. 1. Collision detection using predicted escape maneuvers

The escape maneuver directions are chosen to maximize the minimum distance between all aircraft. In this way the avoidance will be executed at the last possible instant and the system will thus guarantee a very low nuisance level.

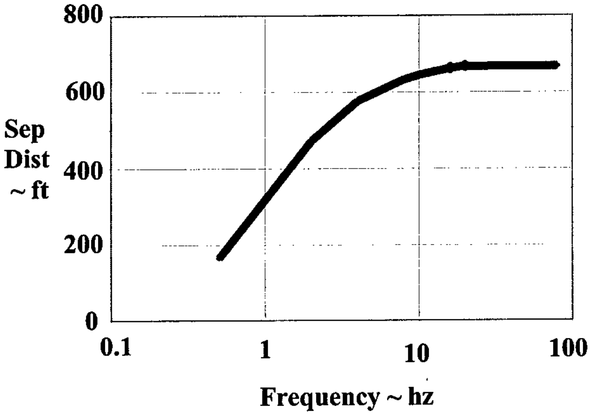

Figure 2 Effect of Algorithm Frequency

6. Data Link for flight test

Using the algorithm as an analysis tool in Figure 2, we concluded that a data link update rate of 10 hertz was optimum. Several potential data links were identified for both flight test and production applications. Lockheed Martin was tasked to accomplish an analysis of available data links that could be utilized for the Auto ACAS flight test. The analysis used various parameters such as availability, cost, and data update rates to determine the optimum choice for the flight test program. The results of the analysis showed that the Situational Awareness Data Link (SADL) would be the best for the flight test.

7. Tailoring the algorithm

The algorithm architecture was designed to allow the algorithm to be easily transitioned to other aircraft. In fact, the only logic requiring significant modification for other applications is the Aircraft Response Model (ARM). The other modules of the algorithm remain essentially unchanged. To facilitate the ease of transition, the ARM was kept as simple as possible, and was designed with explicit features; such as roll rate or load factor onset rate, which can be modified for other applications. In the coming months, the success of this approach will be tested, as the algorithm is adapted to piloted aircraft and a simulated UAV.

8. Flight Test Plan

The flight test plan is to first fly VISTA to test the Auto ACAS algorithm prior to allowing two aircraft operation. Once VISTA is adequately tested, a second F-16 will be tested. The two aircraft will then fly various flight encounters to give several different collision scenarios. Duplication of actual mishaps will also be conducted. The flight test will also show that the Auto ACAS algorithm will not interfere with normal pilot operation and not cause nuisance engagements of the automatic maneuver. VISTA will be programmed to a typical UAV and again be flown with the other F-16 to show UAV encounters with manned aircraft.

9. Other sensor integration

While the data link is a sensor, it must be used as an In-Network function so that all Auto ACAS aircraft can send and receive the required data. This situation does not protect aircraft that are Out-of-Network but a means to solve this problem has been postulated. There are two classes of sensors possible to integrate with the Auto ACAS algorithm; passive and active. An example of a passive sensor is a camera that receives visible or other spectrum information and processes it to determine the parameters necessary for the Auto ACAS algorithm to function properly. An example of an active sensor would be radar that gives distance and track information to the algorithm. A data link is also an active sensor that must be duplicated on each air vehicle in the network. The Auto ACAS algorithm is being designed so that either a passive or active sensor can be integrated easily. Once this is accomplished, Auto ACAS will have complete See and Avoid capability. With this capability an Auto ACAS equipped aircraft can avoid a non-equipped Auto ACAS aircraft which will allow autonomous UAVs to fly safely in the same air space with any piloted aircraft.

10. Conclusions

The design of the Auto ACAS will show that an algorithm can be developed to safely maneuver a manned air vehicle automatically and not interfere with normal pilot operations. It will only be required to function for very short time periods and only to prevent a potentially fatal mishap. It will also provide the capability for UAVs to fly close together and prevent collisions. This will be the first necessary step in providing the capability to allow swarming of hundreds or thousands of UAVs. This program is currently in its early stage but much has been learned about the approach in obtaining a suitable design.