AUTOMATIC AIRCRAFT COLLISION AVOIDANCE SYSTEM FOR AIR COMBAT MANEUVERING

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Abstract

Auto-ACAS is a joint US-Swedish program aiming at developing and flight testing an Automatic Aircraft Collision Avoidance System. This paper will present the Auto-ACAS system including a more detailed description of the algorithm.

The overall Auto-ACAS objectives are:

- *Detect potential collisions.*
- *Activate and execute an avoidance maneuver at the latest possible instant.*
- *Nuisance free operation.*
- *Failure safe operation.*

1 System requirements

The system consists of a data link for communication between the aircraft, the algorithm described below and the electric flight control system (EFCS), which is used for executing the avoidance maneuver. If the aircraft is already equipped with a data link no additional hardware is needed in which case the Auto-ACAS system can be implemented by software changes only.

2 Claim Space Method

This 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 in a predetermined way by the Auto-ACAS algorithm using the EFCS, 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 EFCS 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 EFCS to make the aircraft follow the stored trajectory.

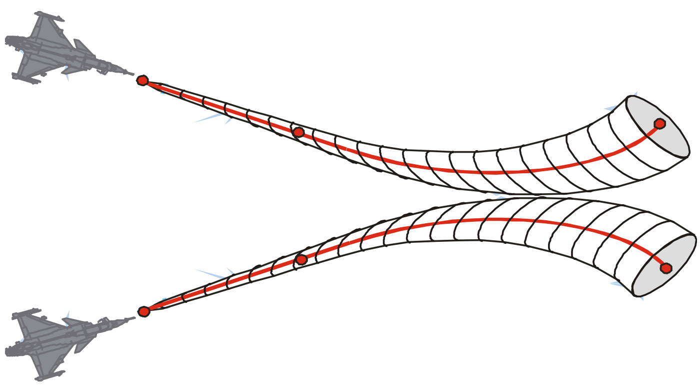

Fig. 1. Collision detection using predicted escape maneuvers

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.

3 Handling of time delays

Due to the time delays (varies between 0.1 and 0.5 seconds) between the algorithms computed in the different aircraft the transmitted escape trajectory initially contains a 0.3 seconds predicted flight path after which the escape trajectory is added. As this prediction is done in the own aircraft, current accelerations and angular velocities as well as velocities can be used in the prediction.

To be able to compensate for the rest of the asynchronous delay, the data contains the time when it was produced. The received data from the other aircraft is dead reckoned to current time using transmitted velocity vector only. This means that no dead reckoning is needed if the actual time delay is 0.3 seconds between two Auto-ACAS algorithms. The data used for the own aircraft (own claimed space) in each iteration is chosen as the one having the closest timestamp to the other aircraft data used in that specific iteration. Thus time corresponding data is used in all aircraft which forces all algorithms to use the same data and thus executing the escape maneuvers at the same time.

4 Failures affecting the algorithm

Data dropouts, due to errors identified through parity check of the link data, “shadowing” or misalignment of the antennas etc., causes the established communication between two algorithms to disappear. To allow dropouts, even close to an activation, and still supply protection against collision, the change of escape direction is limited as a function of actual distance and estimated time to activation. This limitation of change is balanced by the requirement that the escape maneuver shall be optimal and thus having the ability to change fast. At data dropouts the claimed space for the aircraft which the communication is lost for is also expanded in the own aircraft to handle unknown maneuvering and change of escape direction of the other aircraft.

Navigation degradation, due to loss/degradation of GPS, air data sensors, inertial navigation system or terrain navigation etc. is inherently handled by the algorithm. As the size of the claimed space is computed using the current navigation uncertainty a degradation of navigation performance only expands the claimed space according to the new uncertainty.

Failures in other sensor data, used in the computation of the predicted escape trajectory, is handled dependent of how eminent the activation is. Close to an activation (collision) the latest computed own predicted escape trajectory is dead reckoned and the size of the claimed space is increased correspondingly for 4 seconds. After this time of normal collision detection the system goes to failed state. When no activation is eminent the system goes directly to failed state. Failed state also stops the sending of own messages over the link.

5 Formation flying logic

To enable aircraft, equipped with Auto-ACAS, to rejoin and fly in formation the algorithm contains logic, which inhibits the activation of Auto-ACAS against aircraft who fulfill the lower condition in Fig. 2. (The condition also contains a hysteresis to be less sensitive to noise in the transition phase).

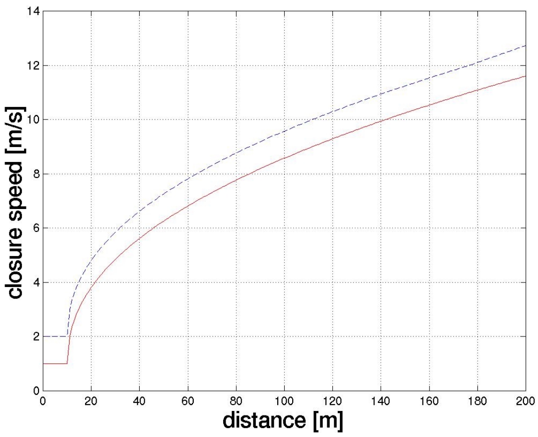

Fig. 2. Inhibit condition in Formation Flying Logic

If the distance between the aircraft becomes less than the claimed spaces at the first point along the escape trajectory, Auto-ACAS is inhibited for all aircraft. This is done to ensure that Auto-ACAS does not activate a maneuver, which could cause a collision. An activation of a maneuver when the algorithm is not sure of the relative position of the aircraft (i.e. they are inside each others position uncertainties) might turn the aircraft into each other.

When Auto-ACAS is totally inhibited in the aircraft fulfilling this last condition, the algorithm in all other aircraft are set to yield to this formation. This includes boosting their claimed space and re-computing/predicting the trajectory of the formation to be along the velocity vector of the formation. This makes aircraft not flying in formation do all of the maneuvering in case of an activation.

6 Simulation results

The algorithm is currently implemented in c-code and integrated in non-linear 6 DOF equations software flight simulators. Two different environments are used. ARES, Saab's simulation environment used in the company's simulators and desktop workstations and D-SIX, a PC-based desktop simulator (product of Bihrle Applied Research. Inc).

6.1 Parameters used during the simulation

Wingspan is set to 8 meters and position uncertainty to 24 meters for all of the aircraft. The "collisions " are set to occur 10 seconds after initiation at lat, long = 0.0, altitude = 4000 meters.

The predicted escape maneuvers as well as the fly-out performed by the EFCS are set to allow a maximum roll rate of 150 deg/seconds and a maximum loadfactor of 5.5 g.

6.2 Definition of plotted variables

The two most left plots show the current bank angle and the earth fixed absolute evasion angle (dotted), i.e. the angle the EFCS would make the aircraft get to if the algorithm activated, for the two aircraft in the scenario. The upper corresponds to the northbound aircraft at M 0.8.

The upper right plot shows distance - the actual distance between the aircraft and MinSSD - the shortest (time corresponding) distance between the claimed spaces (dotted).

The lower right plot shows Tmin - where (in time) along the claimed space the shortest distance between the claimed spaces would occur and TMR – estimated time remaining until the algorithm will activate its maneuver.

The "o" on the plot indicates when the evasion was sent to the EFCS and the "*" indicates when the maneuver ended and the control was given back to the pilot.

6.3 Head on case

Two aircraft on head-on collision coarse, both at M 0.8 results in maneuvers and variables according to Fig. 3 and 4.

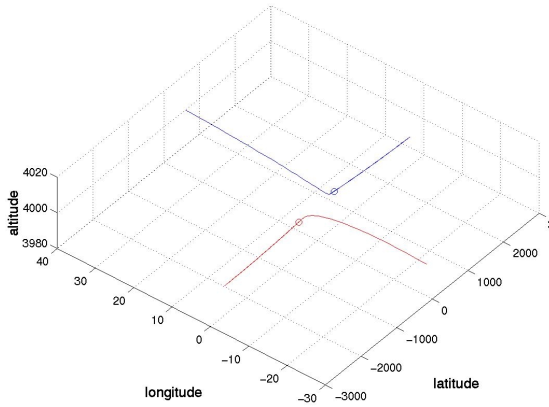

Fig. 3. Aircraft traces during head-on scenario

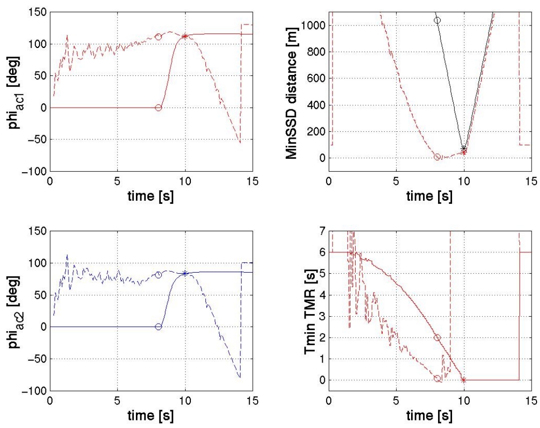

Fig. 4. ACAS variables during head-on scenario

The aircraft heading north performs a roll to +110 deg, the other to +84 deg. The evasion starts when the distance is 1050 meters and lasts for 2 seconds, resulting in a missed distance of 69 meters.

6.4 Beam case

Two aircraft on beam collision coarse, both at M 0.8 results in maneuvers and variables according to Fig. 5 and 6.

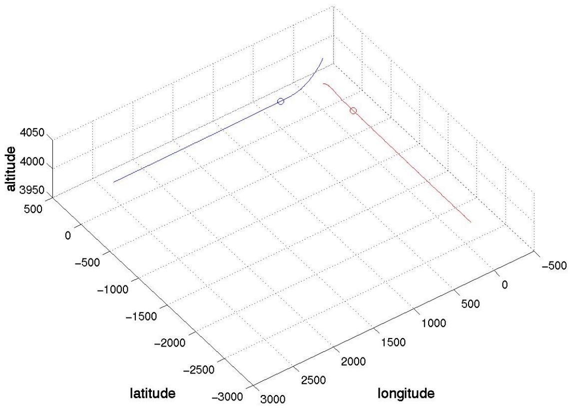

Fig. 5. Aircraft traces during head-on scenario

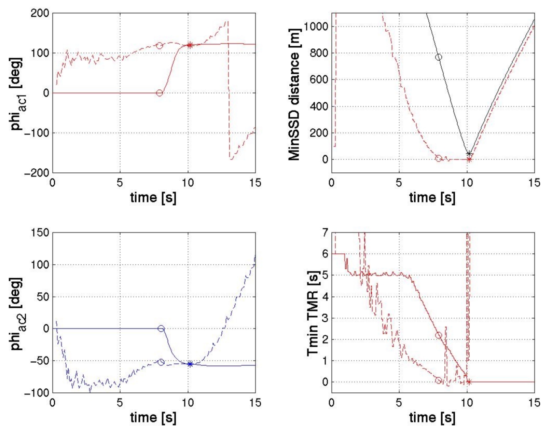

Fig. 6. ACAS variables during beam scenario

The aircraft heading north performs a roll to +120 deg, the other to –50 deg. The evasion starts when the distance is 770 meters and lasts for 2.2 seconds, resulting in a missed distance of 44 meters.

6.5 Catch up case

Two aircraft are heading the same direction one at M 0.8 and the other at M 0.6 results in maneuvers and variables according to Fig. 7 and 8.

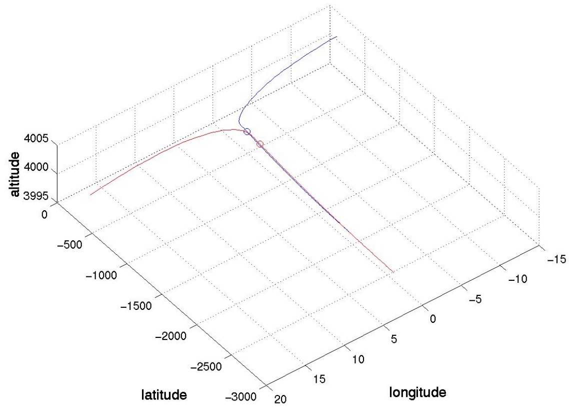

Fig. 7. Aircraft traces during catch up scenario

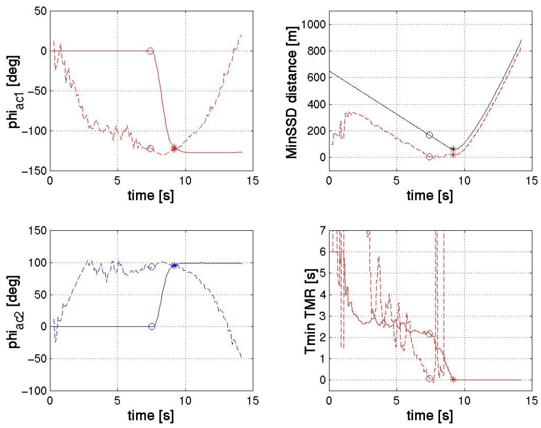

Fig. 8. ACAS variables during catch up scenario

The aircraft at M0.8 performs a roll to -120 deg, the other to 95 deg. The evasion starts when the distance is 170 meters and lasts for 1.8 seconds, resulting in a missed distance of 61 meters.

6.6 Bleed off turns

Two aircraft almost on a beam collision coarse (one slightly ahead of the other) performs right bleed off turns at 9g causing a potential collision. Both aircraft are initially at M 0.8, resulting maneuvers and variables according to Fig. 9 and 10.

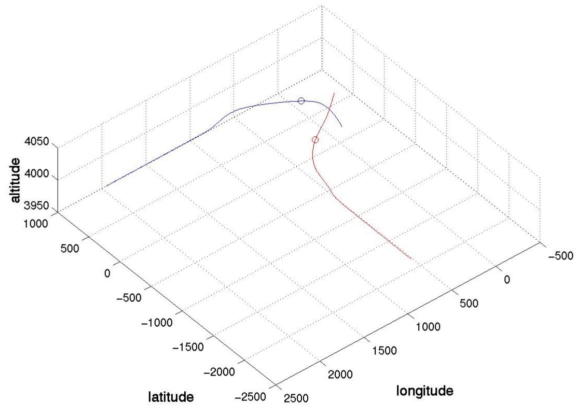

Fig. 9. Aircraft traces during bleed off turn scenario

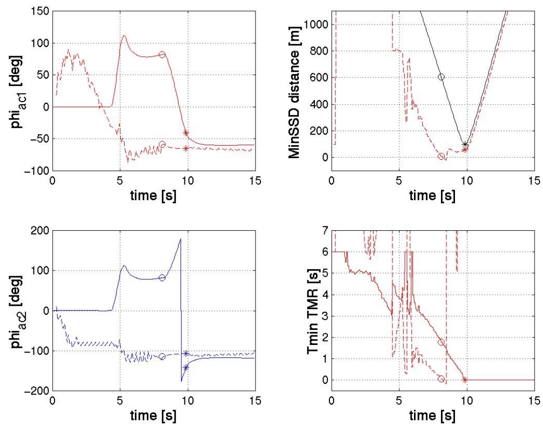

Fig. 10. ACAS variables during bleed off turn scenario

The aircraft initially heading north performs a negative roll to -60 deg, the other performs a positive roll to –120 deg. In this case both aircraft unloads to the demanded 5.5g during the evasion. The evasion starts when the distance is 600 meters and lasts for 1.8 seconds resulting in a missed distance of 100 meters.

6.7 Nuisance checks

A rerun of the cases above with offsets of more than 45 meters (e.g. in altitude) does not result in any activations. The separation between the claimed spaces will approach zero but as long as they do not cross each other the algorithm will not activate the chosen maneuver.

6.8 Simulator testing

In June 2002 a simulator test was performed with 8 pilots from both countries. Two of the simulators at Saab and two PC's running D-SIX, all equipped with Auto-ACAS, were connected with a HLA network simulating the link communication between the aircraft. 150 runs were performed split up between 60 scenarios, including air combat maneuvering and historical accident cases. In all of the collision scenarios Auto-ACAS protected the aircraft from colliding.

7 Concluding remarks

The approach to detect collisions by comparing predicted escape trajectories, previously applied in the implemented and tested Automatic Ground Collision Avoidance System (Auto-GCAS), works well in avoiding other maneuvering aircraft. The optimization in the Claim Space method gives coordinated escape maneuvers at coordinated times.

The current implementation of the algorithm gives reliable, predictable results both in low and high dynamic scenarios. No nuisance is observed when aircraft are maneuvering outside the safety zones currently used in the Swedish Airforce and activations are performed in cases where collisions would be unavoidable.

The Auto-ACAS algorithm is generic in the sense that it can accommodate different aerial vehicles such as fighters, transports, tankers, UAVs etc. with a minimum of aircraft specific adaptation. Any aircraft that can predict its avoidance trajectory 5-10 seconds ahead and communicate that information via a data link can be protected with Auto-ACAS.

The algorithm will be integrated on two F16 during 2002 – 2003 and a flight demo phase in June – July 2003 will crown the current development of the algorithm.