A New Approach to Onboard Real-Time Optimum Computations for Aerial Combat Games

T. K. Campbell* and L. B. Hartsook†
Northrop Corporation, Hawthorne, Calif.

Theme

THE following is a description of a technique designed to ultimately permit on-line real-time optimal control calculations for aerial combat maneuvering commands. One-on-one aerial combat as studied here consists of one aircraft under our direct control maneuvering to release weapons against a second aircraft flying unpredictable maneuvers. The nature of this situation is that time lags exist between evader action and pursuer reaction with imperfect information about the evader always being present. A realistic study of this type of aerial combat required the mathematical models developed to assume no knowledge of the opponents performance data, capabilities or intentions. Information available to the attacking aircraft concerning the evading aircraft has been restricted to that measurable by the onboard sensor/computer system, such as altitude, Mach number, and relative distance. Results demonstrating the applicability of this approach are presented, together with a preliminary assessment of the airborne computer requirements.

Contents

The approach presented here for onboard real-time optimum computations for aerial combat maneuvering centers around an airborne library of optimum maneuver segments generated by optimal control theory calculations performed on the ground. These maneuver segments, which are a function of the pursuer/evader state space vectors, are "patched" together on a real-time basis by the onboard computer system, based on data gathered by the onboard sensors. The results are displayed to the pilot and/or fed directly to the aircraft control system.

We have assumed that we have no knowledge of the defender's performance data or capabilities and that only discrete information about its relative position and velocity can be obtained during the course of the engagement. This information constitutes the components of the evader state vector. This state vector is a function of time, but can be constrained to stay within a bounded state space. The state space can be bounded by, for example, upper and lower limits on evader Mach number, altitude, and relative orientation of the aircraft which encompasses the meaningful arena for aerial engagements. This bounded state space can be discretized to form a mesh of possible evader state vectors. Similarly, there is a bounded state space for the pursuer which is well defined and can likewise be discretized to form a mesh of possible pursuer state vectors.

Given an arbitrary combination of these two state vectors, which are taken to be the initial conditions of a segment of the engagement, we can compute the subsequent optimum response of the pursuer, provided we make certain approximations about the subsequent motion of the evader which is necessary for the use of optimal control theory. The approximation employed here is that the evader will continue to fly a hypothetical straight line whose orientation is defined by this initial state vector. The resulting optimal control history, along with the pursuer and evader state vectors constitute an element of the library. The optimal control histories for all possible combinations of the pursuer and evader state vectors from their meshes are then computed on the ground and stored systematically to form the pursuer onboard library of optimal control commands.

During the course of an actual aerial engagement, the sensors onboard the pursuer's aircraft will periodically record and transmit to the onboard computer, both the evader's and pursuer's state vectors. The library of optimal pursuer control commands is then interpolated using these state vectors to obtain the corresponding optimum response. This response or sequence of optimal commands is displayed to the pilot and/or fed directly to the control system, and are followed for a short interval of time. At this point, the pursuer's and evader's state vectors are automatically updated and new responses displayed. This process continues throughout the engagement. Because of the speed of the simple numerical interpolations, real time operations is no problem. The frequency of the updating will be primarily determined by the ability of the onboard sensors to track the evader.

This concept has been tested numerically to determine the accuracy of the process. Results thus far obtained have shown that this chain of approximate maneuvers stays very near the optimum maneuver that would have resulted if the entire evader trajectory had been known a priori.

Figures 1 and 2 compare the results obtained using the library concept with the optimum trajectory obtained by knowing the evader's complete escape path a priori. Even though the 10 sec time interval between updates is much larger than would actually be achieved in flight, assuming the defender is under continuous observation, the two results are

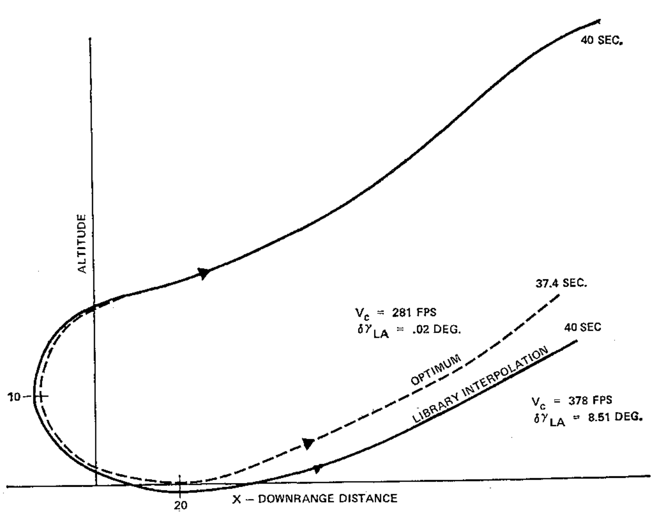

Fig. 1 Vertical plan, optimum and library interpolation comparison.

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* Engineering Specialist.

† Senior Engineer.

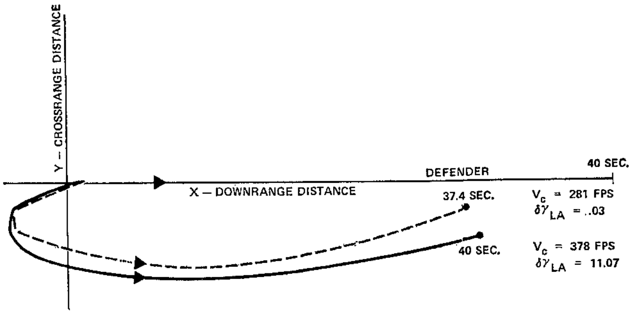

Fig. 2 Horizontal plan, optimum and library interpolation comparison.

remarkably close. The differences in flight time, closing velocity (VC), relative distance and other pursuit parameters are insignificant in magnitude and unimportant since a successful missile release condition has been realized. However, if the observation is interrupted for a duration sufficient to adversely affect the accuracy of the library interpolations, the library usage will be temporarily discontinued until the aircraft has been maneuvered to re-acquire the target where the library usage can be re-initiated.

The number of optimum trajectories required to form a typical optimal control library is a function of the number of variables which make up the evader and pursuer state vectors, the range of values of interest, and the accuracy required. As an example, assume the defenders state vector is constructed from its altitude, Mach number and relative distance from the attacker while the attacking aircraft is constructed from its altitude, Mach number, and angle off. If a mesh size using nine values for each component between the evader and pursuer is used then approximately 20,000 short segment trajectories would be required. It is expected that up to three control variables are to be displayed, e.g., angle of attack, bank angle, and throttle setting. For each optimum trajectory, two values for each control variable are expected to be stored. This is sufficient due to the updating frequency. Therefore, the maximum number of controls to be stored is approximately 118K. The total number of optimum trajectories and control variables to be finally stored will be significantly reduced from the aforementioned values since many of the possible state vector combinations do not represent realistic conditions for aerial engagements.

It is apparent that the magnitude of the total library is larger than the storage capacity of present generation airborne computers. However, since numerical interpolations are the only manipulations performed with the library, the total library need not be in the computer memory continuously.

The operating space of both the evader and pursuer can be partitioned to a number of subspaces so that the search of the library will be localized in the immediate area of the engagement space. This partitioning will permit larger storage of controls in the library and it will reduce the time required to find the actual operating area with respect to the library. The data contained within each of these partitions will readily fit within the memory of present generation airborne computers.

The Northrop Corporation, Electronics Division's NDC-1070 Airborne Computer System, e.g., has a core storage capacity of up to 65,536 words and performs instructions at the rate of 150K/sec. It can accept data at the rate of 500K words/sec. and has magnetic tape for the airborne mode bulk storage. Therefore, if the full 118K words are used in the library, a single partitioning of the data would permit interchange between bulk storage and core storage at a rate near the 500K words/sec. This transfer speed, combined with the rapid instruction execution rate, will permit essentially continuous updating of the pilot display, limited only by the tracking capabilities of the onboard sensors.

Because of the present state-of-the-art of both optimal control theory and computer technology, this approach provides the means to obtain a first generation capability for on-line real-time optimal control computations for air-to-air combat. This approach has the following advantages: the onboard numerical manipulations are simple interpolations; real-time computations can be achieved; the results obtained are nearly the same as optimum solutions; present generation airborne computers can be used; sophisticated programming of onboard computers is not required. It overcomes the problems of computer size, real-time computation and lack of perfect information which are the principal problem areas in applying optimization techniques. The library concept permits a realistic mathematical representation of the evader independent of its performance characteristics. The library of a given pursuer is therefore applicable to any evader. Present generation airborne computers can be used to perform calculations to obtain near optimum control. The on-line real-time computations provide essentially a continuous display of information, limited only by the sensor tracking capabilities. The sophisticated calculations are being performed on the ground, leaving only simple interpolating to be performed onboard the aircraft.

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