Engineering Notes

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One-on-One Helicopter Combat Simulated by Chess-Type Lookahead

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Introduction

THIS paper describes an air combat logic based on a chess-type lookahead technique and presents results of a computer implementation of same.

We follow a well-established technique of approximating a continuous game as a sequence of selections from a small set of maximum load maneuvers.[1-3] The observation that air combat normally proceeds through maximum load maneuvers may help explain why such an approximation can be adequate.

The relative position of two aircraft may also be approximated in terms of discrete cells. An optimal strategy for combat can be developed off-line in terms of these. However, in the case of helicopters, which fly and fight in nap-of-the-Earth, the details of terrain form part of the situation. It is no longer practical to list all possible situations; as in chess, the lookahead approach becomes preferable.

Terrain is the reason for employing the lookahead technique, but the present study does not include the effects of hilly terain. It is intended to explore the details of the lookahead technique itself and its effectiveness.

The lookahead approach has been applied to air combat by Austin et al.[4] The implementation presented here differs from the previous art in that 1) the decisions of the players are staggered rather than simultaneous, and 2) all scoring and propagation of scores is done within the framework of the theory of probability. Some of the principles in the above approach have been suggested in Ref. 5, but to the best of our knowledge these have never been implemented.

Lookahead in Air Combat

Following previous art, we allow the combatants discrete decisions of selecting among a small number of maximum load maneuvers. In the present study we allowed 11 maneuvers, which include straight and level flight, acceleration, deceleration, and eight cases of maximum lateral load applied at 45-deg intervals, starting with up.

We use the resulting game tree to propagate scores and let Blue and Red select the branches leading to the highest and lowest scores, respectively.

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Unlike chess, kill in the air combat tree is probabilistic rather than deterministic. Also, it occurs along a branch rather than at a node. For this reason, the discrete score function of chess (with values 1,0, −1 for win, draw, or loss, respectively) is replaced by the expectation value of the corresponding variable in air combat:

$$V = \begin{cases} 1, \text{ if Red is killed and Blue survives} \\ -1, \text{ if Red survives and Blue is killed} \\ 0, \text{ otherwise} \end{cases} \tag{1}$$

$$S = \langle V \rangle \tag{2}$$

Blue's goal is to maximine S, Red's to minimize it, with S being limited to the range $[-1,\ldots,1]$.

Propagation through the game tree requires estimates for the following probabilities for each branch:

P_b = the probability that Blue is killed
P_r = the probability that Red is killed
P_s = the probability that both survive

Armed with these, it is possible to propagate the score S along the branch from the node at the $i+1$ level to the node at the i level by

$$S_i = P_r - P_b + P_s S_{i+1} \tag{3}$$

If the node i corresponds to Blue's decision, the highest propagated score and corresponding branch are selected. The lowest score is selected at Red's decision.

We estimate the probabilities based on time spent in the opponent's gun envelope. The details are presented in the Appendix. When terrain is taken into account, time spent too high and out of cover may be similarly penalized.

It must be stressed that this probabilistic formalism does not represent the kill mechanism of the simulated engagement. In the present study, there is no kill mechanism. We merely observe how the combatants persist in their efforts to bring the opponent into the gun envelope. Conversely, one could, in principle, simulate individual or grouped projectiles and determine kill based on hit or miss. The probabilities given earlier serve only for the thought processes of the adversaries, i.e., for the lookahead process.

The score at a terminal node is a heuristic estimate of $\langle V \rangle$ based on the conditions there. The form used for the present study is

$$S_f = (1/2)[\cos(A_b) - \cos(A_r)] \tag{4}$$

where A_b is the angle between Blue's body axis and his line of sight to Red, and A_r is the angle between Red's body axis and his line of sight to Blue.

This form takes account of relative orientation only and rewards each player for facing his opponent. The results show that it leads to tenacious players who always turn toward their opponent.

Another aspect of the air combat tree that differs from chess is that a specific time is associated with each node. The time is not necessarily the same for nodes at the same depth. If held too long, a maneuver may outlive its potential benefit, and any advantage it may have provided could be lost. A turn-

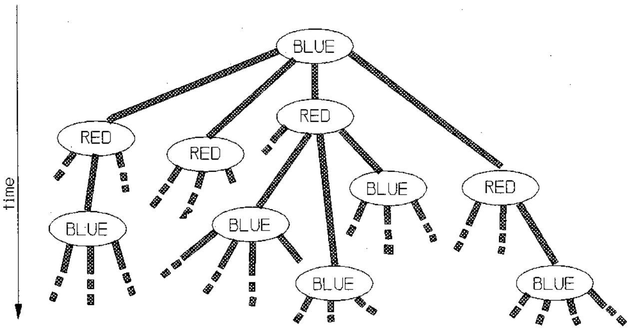

Fig. 1 Air combat tree with alternating decisions.

ing maneuver may improve a player's position by aligning his gun with the opponent, but if held after this is achieved, the advantage would be lost.

The solution is to determine the duration of each maneuver by estimating the time by which it achieves its effect. This could take the form of following the progress of the score function S and creating a new node when it peaks, i.e., when it reaches a local extremum. The result is that the branches of the air combat tree (Fig. 1) are unequal in length.

Figure 1 shows a tree in which decisions are taken by the players in turns. With alternating decisions, each node must be created in advance of the time when the current maneuver is played out. It is equally possible to let both sides make their decisions simultaneously. That is the approach taken by Austin et al.[4] On the face of it, both approaches tend to the continous game as the decisions become dense. However, the nature of such a limiting process could be profoundly affected by this detail. (Compare the limiting process in representing quantum mechanics by functional integrals).[6] The effect on the limiting process in the present application is not known.

Note that the discussion of staggered decisions does not apply to decisions actually made, but rather to the ones that each combatant "imagines" himself and his opponent making, as he searches for his next decision.

Results for Infinitely Fast Logic

In this section, we discuss engagements between identical combatants, both employing the combat logic discussed here. The simulated engagement made no allowance for the time it took to compute a lookahead decision.

The players made their decisions simultaneously. Starting with their initial condition, each constructed a game tree (with staggered decisions) and, using it, reached a decision. No allowance was made for the time this process consumed — the decisions were made available to the players while they were still at their initial position. Each then implemented his decision until it was time for the next decision.

The lookahead tree contained two plies (one level for the decision maker and one for his adversary) and reached up to 4 s into the future. A new tree was constructed, and a new decision reached at intervals of 1 s. Low-level logic supplied control inputs to the flight model at intervals of 0.1 s. These were calculated to maintain the maneuver last selected.

It should be observed that the general laws of motion of the players and their logic are invariant under a group of transformations consisting of translations, rotations around a vertical line, reflection in a vertical plane, and exchange of the two players. Given an initial condition that is invariant under a transformation belonging to the group, all subsequent states, as the engagement unfolds, must maintain the symmetry. This provides a powerful check. Deviations from symmetry betray errors in logic or coding. Three types of symmetry were sampled:

1) Symmetry in reflection through a vertical line (same as rotation of 180 deg around a vertical line) (Fig. 2)—These engagements remained in the vicinity of the vertical line, with the combatants descending or climbing together while constantly turning into each other and aiming for a collision course. No collision avoidance was included in the combat logic. No effects of collisions were incorporated in the flight dynamics. Collision courses were preferred because they put the adversary in the center of the gun envelope. The amount by which precise head-on collisions were missed was the result of the granularity of the available maneuvers and decision times.

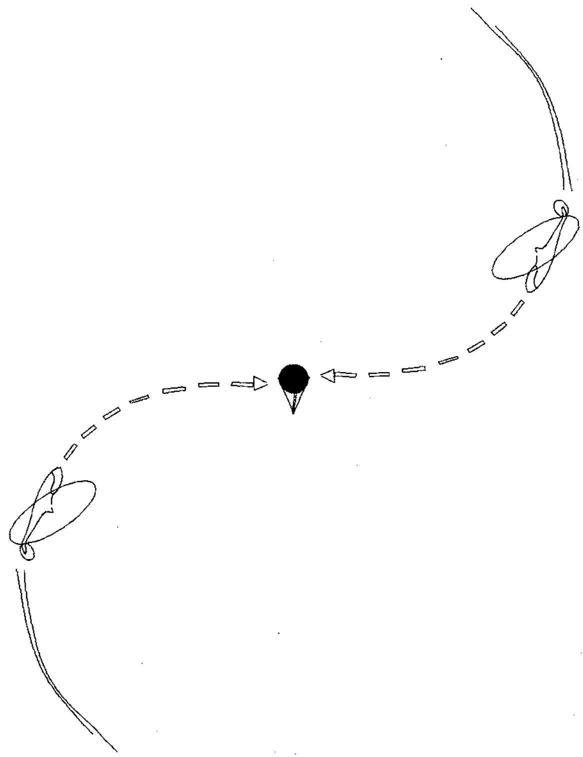

Fig. 2 An engagement symmetric in reflections through a vertical line (shown as a pole), perspective view.

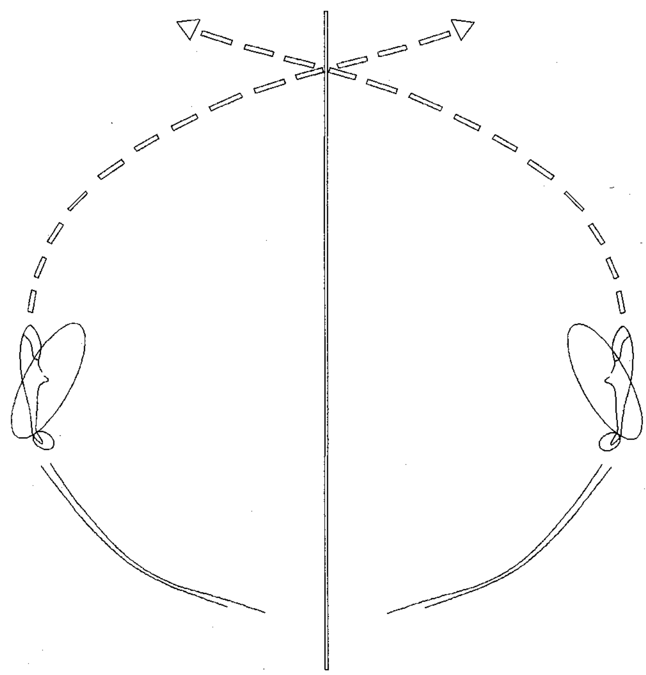

Fig. 3 An engagement symmetric in reflections in a vertical plane, top view.

2) Symmetry in reflections through a vertical plane (Fig. 3)—These engagements remained in the vicinity of the plane of symmetry and proceeded along the plane. The players kept turning into each other and flying through each other at the

plane of symmetry. The battle proceeded horizontally one way along the plane, then tracked back the other way.

Neither player could gain an advantage in either case 1 or 2.

3) Unsymmetric initial conditions—In this case, the combatants were started at different speeds and altitudes. They employed different tactics. At one point, one player gained a position on the other's tail and, for a while, maintained it by what looked like scissoring.

Effect of Compute Time

In any application of combat logic to either combat or real time simulation, account must be taken of the time it takes to compute a decision. The computation cannot start until the initial position is known. By the time the decision is made, the compute time has elasped, and the condition assumed in the computation no longer prevails.

We make the simplifying assumption that the time to compute a decision is equal to the time interval between decisions. This should be the case when the system performing the lookahead computation is dedicated to this task and is ready to start a new lookahead as soon as one is concluded. This effect was simulated by applying the lookahead to the last step conditions rather than the current step conditions.

The three symmetry cases listed above were redone with the delay accounted for. The symmetry check still applies. The delay is reflected in a slower reaction on the part of the players. It takes them about a second longer to start turning toward each other once they had passed each other. The engagement is not as tight as it was, and the area over which it unfolds is increased.

Certain pathological cases also arise, where one or both players move away and fail to turn back. Instead they alternate right and left turns. The response appropriate for the opponent's previous maneuver is always reversal of the current turn. This can happen with the opponent directly behind (either following or also moving away) and is dependent on the exact synchronization of the players' decisions. It is unlikely to occur when confronting a human or otherwise different opponent.

Apart from this pathology, the players are unchanged in nature. They are still aggressive and tenacious.

The three cases were also redone with the initial conditions projected over the delay period before they are input into the lookahead. In this case, much of the effect of the delay was canceled.

Summary

We find that the lookahead is a viable approach for air combat and yields impressive results with very simple-minded tools. This is not unusual in applications of a practical nature.[7] The timing assumed is such as can be easily accommodated by embedded microprocessors. The technique is, therefore, ripe for use in real time simulation.

Appendix: Estimate of Probabilities

This Appendix presents the simple method of estimating probabilities that was employed in the present study.

We assume that the probability of kill over an infinitesimal time dt spent in a lethal environment is proportional to dt:

$$\mathrm{d}P = C\,\mathrm{d}t \tag{A1}$$

The probability P_0 of surviving a period $t + \mathrm{d}t$ may be decomposed as

$$P_0(t + \mathrm{d}t) = P_0(t)\,(1 - C\,\mathrm{d}t) \tag{A2}$$

which leads to

$$\frac{\mathrm{d}P_0(t)}{\mathrm{d}t} = \begin{cases} -\mathrm{C}, & \text{when in lethal environment} \\ 0, & \text{otherwise} \end{cases} \tag{A3}$$

This integrates to

$$P_0(t) = \exp\{-C\,t\} \tag{A4}$$

where t is the cummulative time spent in a lethal evironment. The probability of kill is

$$P_1(t) = 1 - P_0(t) \tag{A5}$$

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