Computerized Air Combat Simulation—A Digital Approach and Its Application

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The air-to-air capabilities of foreign threat aircraft have improved at the same time that the development cost of domestic fighters has spiraled upward. These two factors have combined to regenerate interest in the simulation of air combat. In this article, a comparison of two simulation approaches, analog and digital is given, and a currently operating three-dimensional digital program, ATAC/FW, is examined. The general approach, the program structure, and the variety of output forms are discussed. In application, this program has demonstrated considerable versatility, believability, reliability, and economy in numerous design studies. Four examples of these studies are presented.

Nomenclature

h = altitude
M = Mach number
P_s = specific excess power
R = range between combatants
t_1 = time at beginning of a time step
t_2 = time at end of a time step
t_f = flight time of launched projectile
T/W = thrust to weight ratio
W/S = wing loading
β = pointing angle (between velocity vector and line of sight to opponent)
λ = angle off (between tail vector of opponent and line of sight between aircraft)

Introduction

THE seemingly endless list of factors which influence the outcome of true air battles includes individual pilot technique, control response, propulsion system response, onboard avionics, weapons, external assistance (e.g., GCI vectoring), visibility characteristics, and battle environment (e.g., cloud cover and sun position). Combined with the basic airframe-engine effects, even such a partial listing characterizes the complexity of the air combat situation. If all but the airframe-engine characteristics are ignored, the air combat situation still remains enormously complicated because of the arbitrariness of the proper control of these characteristics.

Because of the inherently complex nature of combat between aircraft, an adequate mathematical evaluation long eluded the military aviation industry. Lacking such a description, the aircraft designer resorted to the evaluation of a few performance criteria such as specific power, turn rate, and roll rate which, at best, gave instantaneous implications of total battle effectiveness. The ability to describe air-to-air combat accurately is now imperative because of the penalties incurred for failing to define truly air-superior fighters. These penalties have been magnified in recent years by improved threat capabilities and increased development costs.

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Approaches

This paper concerns aircraft in pre-hardware stages of development; therefore, actual fly-offs between competing designs are not possible. Since the problem is far too complex for manual manipulation, the only remaining alternative is simulation on a computer. One such approach has been the development of aircraft simulators using two analog computers (one for each aircraft) interconnected in such a manner that each pilot is given an appropriate visual and/or radar display. The control and force characteristics of each aircraft are provided to each simulator. The second approach utilizes the digital computer through a program which stores the characteristics of each aircraft and defines a guidance logic to apply these characteristics in a realistic manner.

Comparison of Approaches

These approaches contain significant differences which force the choice between them to be based on the particular problem to which the simulation is applied. The digital approach generally requires less computer time than the analog, but this will vary, depending on logic intricacy and programing technique. The analog approach requires considerable development of specialized, expensive equipment, whereas the digital computer facilities are usually available and share expenses with other programs. For these same reasons, the over-all program development time is considerably longer for an analog simulation. A digital program requires a relatively small staff of developers and users, whereas the analog approaches require many engineers and technicians during development and a significant crew of operators and pilots during studies.

Pilot Effects

The differences of greatest impact result from the existence of a human pilot (analog) or lack of one (digital) in the loop to provide the guidance logic. The human pilot would at first seem desirable because of the realism (and thus believability) he injects into the simulation. Indeed, for studies where the pilot effects are the important study parameter, the human pilot is hardly replaceable. However, when considered as an engineering design tool, the pilot creates many problems, mostly resulting from the wide variation in pilot technique. Repeatability of engineering studies is certainly desirable, and the digital program with its fixed deterministic logic has this quality. In the analog approach, the wide variation of technique even for a given pilot makes the exact repetition of a given study highly improbable. For the same reasons, it is extremely difficult to obtain continuity of study results with the analog approach. A very large number of battles is required to smooth out the pilot effects. The last statement is particularly important if the sole purpose of a study is the optimization of the hardware for air combat.

Choice of Digital Approach

For the aforementioned reasons, the digital approach would appear to be more desirable in the majority of engineering design problems so long as the developer takes care that the guidance logic reflects a reasonably realistic average pilot technique. It is emphasized that the simulation need not duplicate real air battles, but merely simulate those portions most demanding on aircraft maneuverability.

The Flight Mechanics Group of the Fort Worth Division of General Dynamics applied the digital computer to the simulation of air combat for the purpose of evaluating the aircraft hardware. This has resulted in the development of program ATAC/FW (Air-to-Air Combat). This program and its application is the subject of this paper.

Program ATAC

Method

Computer program ATAC is a three-dimensional combat simulation procedure in which two maneuvering and reacting aircraft fly aggressively over a flat, nonrotating earth in a lead pursuit manner. Each aircraft is completely described by program input through the definition of basic aircraft limitations (angular rates, normal load factor, dynamic pressure, etc.) and the provision of aerodynamics and propulsion data. Initial conditions for the battle such as position, attitude, and velocity along with certain logic control parameters are provided for each battle.

Following program input, the battle begins with the ensuing maneuvers of each aircraft being controlled by an internal situation-dependent guidance logic. Because this guidance logic is common between the two aircraft, there are no inherent advantages for either except through their respective characteristics and initial conditions. The battle progresses in incremental time steps (on the order of 1.0 sec) in such a manner that the chosen schedule of the control variables, angle of attack and roll angle, for each aircraft produces the minimum value of pointing angle, β, after integration of the equations of motion over each time step. The pointing angle is defined as the angle between the a/c velocity vector and the line of sight to the opponent (Fig. 1).

Where the desired control variables cannot be predicted, an extremely efficient Fibonaccian search technique[1] is used

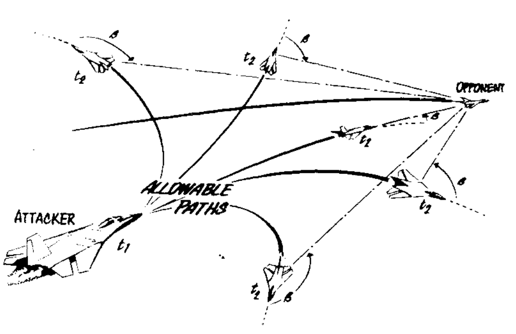


Fig. 1 Application of the basic pursuit guidance law.

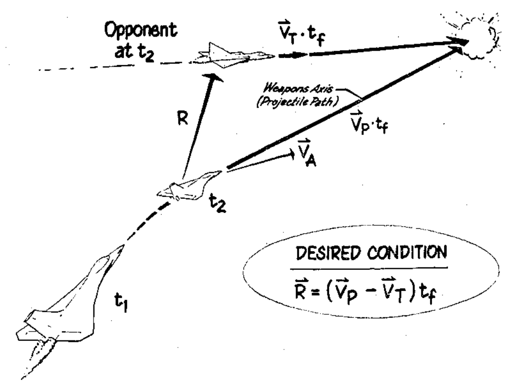


Fig. 2 The guidance law used in a firing approach.

for their selection. The aim point used to define relative position and attitude of an aircraft for purposes of control-variable selection may be the actual or the projected target position. Either of these aim points may be modified by a parameter-controlled variable lead to provide optimum target approaches. At no time in a battle is either aircraft allowed to choose an angle-of-attack/roll-angle combination which results in violation of that aircraft's limitations.

During a battle, either aircraft may enter possible firing situations. This aircraft is then controlled so as to produce a proper gun or missile lead on its opponent. This is accomplished by selecting the control variables which best satisfy a weapons vector equation, described in Fig. 2. Here, it is assumed that the target aircraft and the projectile follow a straight-line path for a total trajectory time, t_f.

Features

Special features of this program include 1) the optional variation of wing geometry (e.g., variable sweep or camber) and/or variation of throttle setting for proper closure and turn effects, 2) automatic terrain avoidance, 3) optional breakaway under low fuel or poor defensive situations, 4) climb stall avoidance, and 5) optional closure rate control through use of thrust reverser and/or speed brake devices.

The battle performance of each aircraft is measured by a scoring system that accumulates a total of incremental scores for each aircraft. These scores indicate the relative advantage of each aircraft over its opponent. Secondary indications are provided by conversion time and/or number of conversions. Conversion is declared upon satisfaction of a simple kill envelope involving angle off the target's tail vector, range, launch load factor, and weapon aim angle.

The output of ATAC is generated by the computer in five forms: 1) printed time histories of significant quantities for each aircraft during the battle; 2) three-view drawings of the battle, showing the flight paths of the two aircraft with symbols each 10 time steps along the path; 3) perspective drawings of the battle in which the two aircraft are depicted as triangles spaced along the flight paths at their proper spacial orientation (wing tip trails are shown, resulting in a ribbon-like flight path); 4) 16-mm animated moves similar to the perspective drawings; and 5) time-history plots of selected aircraft-state variables. Examples of forms 2 and 3 for one example battle are presented in Figs. 3 and 4. A more detailed description of the program is given in Ref. 2.

Applications

The development of a program such as ATAC, which purports to simulate a situation as complex and arbitrary as air-to-air combat, is challenging and subject to careful acknowledgement of the assumptions and representative scope of the simulation. The programer must be constantly aware of the limitations of his program. The user of the

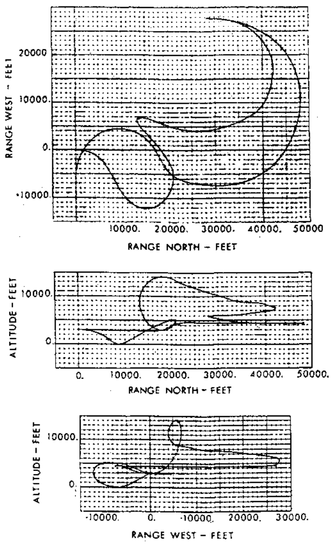


Fig. 3 An example of the automatic three-view plotting capability.

program must be no less so. As in most complex computer programs, the admission that the program representation is not truly real-world does not label it as useless, but merely serves to emphasize the responsibility of the user to examine closely the extent of program applicability to a particular problem. Such examination of and experience with program ATAC have indicated applications of special interest.

Comparison of Current Systems

One of the major problems facing planners is the decision as to which, if any, of current weapons systems is sufficiently responsive to the requirements of a particular mission, particularly one involving a probable phase of air combat under various conditions (bomb loads, fuel remaining, etc.). A program such as ATAC allows the planner to compare (cognizant with other requirements) the performance of an aircraft during the close-in combat phase to other current systems against the same threat under the same conditions.

Operational Procedures

The development of combat tactics and operational procedures has, in the past, been the result of experience and/or intuitive considerations. While tactics currently appear to be too complex and experience-dependent for simulation procedures such as ATAC, the determination of recommended operational procedures such as best relative approach position and velocity for ensuing battle dominance lends itself quite readily to evaluation on such programs. Also of importance to variable-wing geometry aircraft are recommended wing-geometry schedules for optimum battle performance.

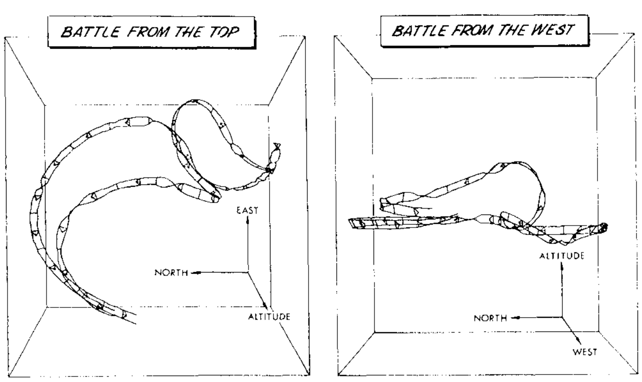


Fig. 4 An example of the automatic perspective drawing option.

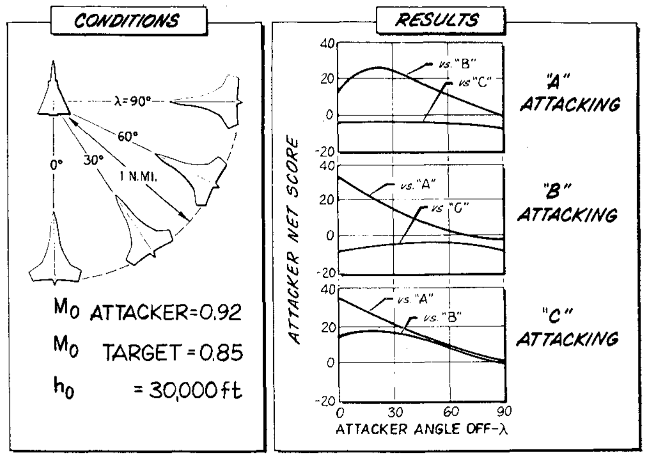


Fig. 5 Carousel—a study comparing three prospective configurations.

Optimization of Configurations for Air Combat

The most important assignment for the combat simulation program is its evaluation role in the design process. As a design tool, the program finds great practical utility in determining optimum values, or more accurately, optimum regions of significant design parameters such as thrust loading and wing loading. It is also valuable as an insight into the tradeoffs between applying funds and manpower into one design area (such as the structure) and another (such as aerodynamic improvement).

Example Studies

Four example ATAC studies are presented which demonstrate types of application, study approaches, and methods of evaluation. In most of the discussion, the particular aircraft involved have not been designated for security reasons.

Carousel—Systems Comparison Study

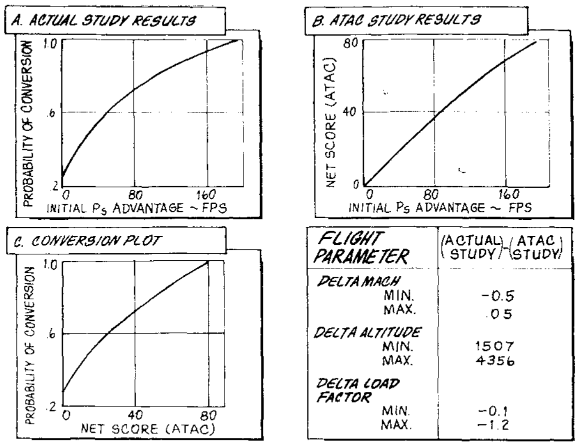
The purpose of this study was to evaluate the air combat ability of three prospective configurations. The three aircraft engage each other two at a time in three series of eight battles. The initial geometric conditions of each series of battles are shown in Fig. 5. The first four battles allow one aircraft an offensive advantage (zero initial pointing angle) at four angle-off positions. The following four reverse the roles of attacker and defender.

Results are shown in Fig. 5 as the excess score over each opponent as a function of attacker angle off, attacker assignment, and target assignment. Inspection reveals a similar level of dogfight ability of aircraft A and B, since each is able to maintain approximately the same advantage against the other. The definite superiority of C is demonstrated by its ability to successfully reverse battle advantage when in the target role, as manifested by the negative excess scores when A and B are attacking. This is emphasized by its performance over A and B when in the attacking role.

Such results by themselves would be a strong recommendation of configuration C. Proper use of such results, however, would consider other standard requirements such as endurance, range, etc.

Grapple—Configuration Optimization Study

The true motivation behind this study was to investigate the credibility of the program by comparing ATAC with actual flight data and study results.



FLIGHT PARAMETER	(ACTUAL STUDY)/(ATAC STUDY)
DELTA MACH	
MIN.	-0.5
MAX.	.05
DELTA ALTITUDE	
MIN.	1507
MAX.	4356
DELTA LOAD FACTOR	
MIN.	-0.1
MAX.	-1.2

Fig. 6 Grapple—study comparing Program ATAC with a real-life study.

This study is the ATAC equivalent of a real-life study conducted in 1967 in which the effects of thrust-to-weight advantage in air combat were evaluated. Two current fighter aircraft were given five minutes to effect a gun conversion from a basic set of equal-advantage initial conditions. The two aircraft were unconstrained except that one of the aircraft had maximum power restrictions enforced through the use of a mechanical link on the throttle control. The same conditions were applied to program ATAC in four battles, which restricted one aircraft to 1) full military power, 2) one-third between, 3) two-thirds between military and maximum afterburner, and 4) maximum afterburner.

The results of the real-life study were translated at the Fort Worth Division to probability of conversion as a function of initial specific power advantage, as shown in plot A, Fig. 6. The same conditions run on program ATAC yielded excess battle score over the opponent vs. the specific power advantage, shown in plot B of Fig. 6. Agreement of the two studies is emphasized by the combination plot, plot C of Fig. 6, relating the ATAC scores and the conversion probabilities of the real-life study. Further comparisons involving general battle trends and covering many state variables such as Mach, altitude, and load factor also support the credibility of the program. One such comparison of maximum and minimum values is shown in the table of Fig. 6. The changes in state variables in program ATAC, while slightly more severe and numerous, were not radically different from the real combat time histories. Battles from both studies have the same decreasing trend in Mach and altitude and a preference for medium to high load factors.

The most significant difference lies in the fact that the real-life study required 6 months, 3 pilots, 2 aircraft, 72 flights, a large number of crew and a great deal of equipment. Program ATAC required 15 minutes of computer time.

Project Tallyho—Configuration Optimization Study

A study more representative of the configuration optimization use of ATAC has been labeled Tallyho. In this study, the objective was to provide a measure of the tradeoff between total mission radius and combat maneuverability for variations in thrust loading and wing loading.

A matrix of three thrust loadings and four wing loadings for one aircraft was studied. The loadings are expressed in this paper as ratios to base values for security reasons. The opponent always had the thrust and wing loading ratios (to the same base) of 0.834 and 1.285, respectively. Always starting with a basic set of equal-advantage initial conditions, the study aircraft for all study variable combinations dominated the opponent. The net scores by the study aircraft over the opponent were obtained from ATAC as a function of thrust and wing loadings. Standard performance methods provided the dash radius for each point. The resulting tradeoffs between air combat effectiveness and range capability are shown in the carpet plot of Fig. 7. This study demonstrates the compatibility of the simulation with other standard engineering techniques.

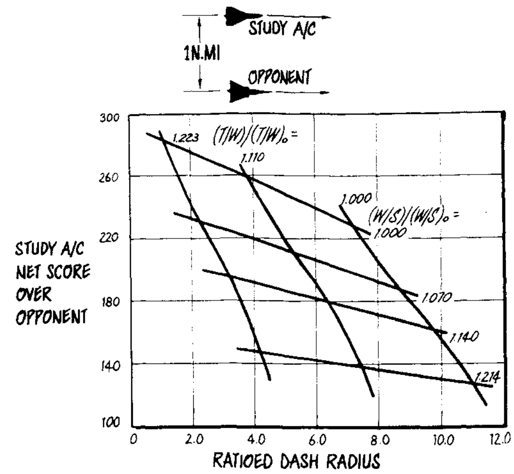


Fig. 7 Tallyho—a typical configuration optimization study.

Engine Comparison Study

This study provided a measure of the gain to be achieved in a basic vehicle's combat potential by replacing the current engine A with an advanced engine B.[2] For this purpose the study was separated into two parts: general combat and tail chase only.

In the first part, the basic vehicle, first with A engine and then with the B engine, engaged an enemy threat at three altitudes: 6000, 10,000, and 30,000 ft. In each battle the combatants were initially at the same altitude, heading, and Mach number and were separated by 7000 ft. As shown in the left plot in Fig. 8, the B engine considerably enhanced the basic vehicle's combat performance.

In the second part of the study, the enemy threat was given an initial breakaway advantage of Mach 1.0 compared to Mach 0.6 for the basic vehicle—again, first with the A and then with the B engines. From an initial separation of 1 naut. mile, the basic vehicle with the A engine required over 220 sec. to close to the 1000-ft conversion range. The basic vehicle with the B engine required only 90 sec. The fuel savings with the B engine is shown by the fuel-remaining

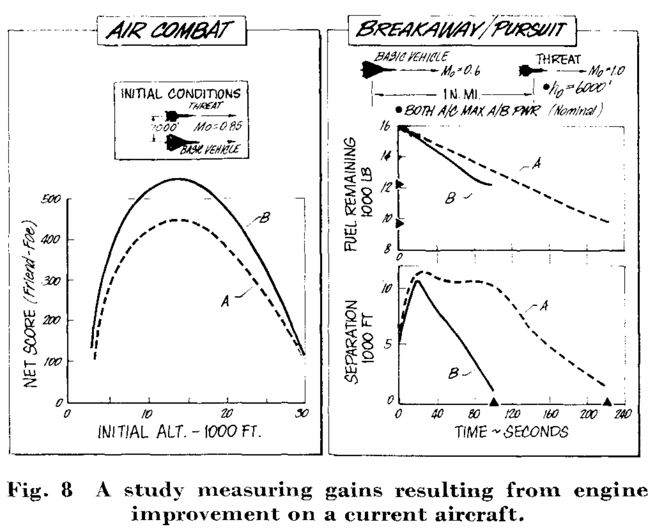


Fig. 8 A study measuring gains resulting from engine improvement on a current aircraft.

curve in Fig. 8. The basic vehicle with the B engine was left with an additional range capability of 320 naut miles. The benefits of such a tactical advantage are obvious.

Conclusions

The necessity of simulating the air combat situation has magnified in recent years and the tools for accomplishing this task, namely the large and fast digital and analog computers, are now available. Thus, programs such as the Fort Worth Division's digital computer program ATAC are now practical.

Much remains to be done, however. More of the total combat situation must be represented, particularly with respect to the energy-demanding maneuvers that are usually the result of pilot experience and battle projection as opposed to instant-by-instant decision making.

More recognition must be given to the effects of an aircraft's goal in determining whether its role should be aggressively, passively, or defensively oriented. The important phases of detection and early battle maneuvering for advantage should be represented. Additional consideration should be given to the influence of weapons capabilities, attainable performance characteristics, etc., on guidance selection. The possibilities for extensions are unlimited.

Air combat simulation, while young, is already making significant contributions to technology as manifested in the few studies outlined in this paper. There should be even more contributions in the future.

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[1] Johnson, S. M., "Best Exploration for Maximum is Fibonnacian," P-856, May 1956, Rand Corp., Santa Monica, Calif.

[2] Wenham, R. J., "Computer Program ATAC, Air-to-Air Combat Model," FZM-5341, April 1969, Fort Worth Division of General Dynamics, Fort Worth, Texas.