~~CONFIDENTIAL~~ Unclassified Per R.L. Garwin 01/29/81

ADVANCED AIR-TO-AIR SYSTEMS (U)

R. L. Garwin
Member of the Defense Science Board*
Washington, D. C. 20301

Abstract

(U) Although flexible missiles, stabilized optical systems, flexible guns, and head-coupled displays appear individually to have much to offer in an advanced air-to-air fighter, their combined value seems very much greater than that of the individual systems. The author discusses the potential contributions of an avionics/weapons package based upon this concept and contrasts the performance of a next generation fighter so equipped with the performance of a more conventional system. Arguments are presented for redundant development programs and redundant equipment rather than for redundant operating modes of the system, and a design and development philosophy is suggested to provide the highest performance system at acceptable risk.

I. Introduction

(C) Superiority in aerial combat between fighters is a goal requiring the utmost in capability. If the fighter must be designed to fight offensively at short range with a gun, or if it need have high maneuverability to escape short-range attacks by other fighters, maneuverability, visibility, and large excess specific power dominate the entire aircraft design. Even if it is anticipated that close-in, maneuvering combat will be necessary only a small fraction of the time, these same characteristics weigh heavily in the overall design. In fact, growth factors of 5 to 8 are common in advanced fighters (i.e., the gross weight increases by 5 to 8 pounds for every pound which is added in a sub-system, keeping the maneuverability and the range of the aircraft constant). Because of the strong penalty for excess weight, and because a small margin in effective performance or weapons can be expected in the fighter role to provide a substantially larger change in relative effectiveness, it is necessary to have a clear design philosophy of the aircraft system. Quite different philosophies may lead to equally effective fighters, but the details should fit into some guiding scheme. To the statement of my own philosophy some prelude is required, unnecessary for some readers but perhaps useful to others.

Philosophy

(U) Theatre Resources. Shooting enemy aircraft out of the air over enemy territory is unlikely ever to be a high-confidence operation because of the home team's basic advantages of a ground-based air defense system, coupled with the lesser range and endurance required of an air defense fighter, in comparison with the offensive air-superiority fighter. A respectable exchange ratio can result, however, if we put adequate development effort on theatre resources, such as

---AWACS (Airborne Warning and Control System),

---Theatre IFF,

---Defense Suppression (greatly improved attack capability on ground targets), and

---Better survivability against SAM's.

Only then does the particular fighter, its avionics, and its air-to-air weapons enter the picture. Similarly, even the fastest, most tenacious, least countermeasurable missile is of no use if it is on the launcher when the fighter is hit from behind, or if the fighter cannot achieve a firing position before exhausting its combat fuel. The same is true for guns, forcing us to develop and build highly maneuverable fighters with good visibility. A viable alternative is to develop the theatre resources for command and control, etc., necessary to do the whole job with longer-range missiles. That alternative, however, is not the subject of this paper. I must emphasize, however, that even an air superiority fighter must survive the SAM environment if it is to get a chance to carry out its job. Thus, one must choose among the various alternatives for countering SAMS, and in practice against advanced missiles probably has to combine several of these in a coherent program. The alternatives apparently are suppression, warning, maneuvering, jamming of various elements of the SAM system, and finally active defense by destroying the SAM itself at short range.

(U) Degraded Modes. Basic to the design concept of a system is the question of performance in "degraded modes." A philosophy of unreliability has cost us dear. We pay the price in development, procurement, and training for high-performance avionics and other systems, but we do not have the function because the materiel cannot be maintained in

*This paper represents the personal view of the author and not an official position of of the Department of Defense.

021069AAAS

~~CONFIDENTIAL~~ Unclassified

02/10/69 "Advanced Air-to-Air Systems," paper for the American Institute of Aeronautics and Astronautics Tactical Missile Systems Conference, Redstone Arsenal. (021069AAAS) operational condition. Worse, the pilot then ordinarily trains for many contingencies, and with a system built of many subsystems, even a failure at the sub-system level can present the pilot with a task quite different from that with the all-up system. For instance, an inertial navigation system is often buttressed with a doppler navigator, and further with an air-data-derived navigation system. The pilot must be prepared to operate his aircraft and to carry out his mission if any of these elements fails. Specific items of equipment have been in the past so unreliable that pilots have just not turned on the equipment, thus reducing substantially the number of configurations he was required to manage. This philosophy of unreliability has arisen because in the past we have specified what we would have liked to have, without insisting on obtaining it. As regards safety of flight, we insist that the contractor deliver, but neither the contractor nor the client has similarly insisted on reliability in the mission avionics and weapons, either by limiting the avionics to that which can be counted on for the life of the aircraft or by aborting the mission if the avionics failed.

(U) I believe that we should specify the performance and the piloting tasks for a completely-operating system, with no degraded capability to carry out the mission. It is certainly possible to design the system so that most component failures or even sub-system failures do not change the required pilot actions nor affect the system performance very much, but there will always be either individual failures or a combination of failures and damage which will effectively change the configuration. At this point, my philosophy is to have doctrine and hardware which allows the pilot to take over control of an effectively simpler aircraft with the capability of returning to base but not of carrying out the mission.

(U) <u>High-Confidence Development of Advanced Systems</u>. Equipment failure is one threat to the effectiveness of an aircraft, but development failure is another. The greater the emphasis on all-up system capability, the more important it is that every element of the system be available for integration into the whole. In order to achieve high confidence of obtaining on schedule and at reasonable cost a highly-effective advanced system, I lay great stress on competitive prototype demonstration.

---demonstration (as opposed to pure analysis) so that the decision and a commitment can be made by the people who count--the users.

---prototype so that we can move forward rapidly after demonstration. One way of achieving the desired performance will have been demonstrated, and only development for production will have to be done.

---competitive so that there are alternatives in case one contractor fails.

(U) Thus I have sketched an argument leading one to consider an advanced air-to-air system which works perfectly or not at all, and which would be produced following competitive demonstration and validation of completely functional prototypes of avionics plus weapons, installed in modified current-generation aircraft. In this approach, redundancy in equipment is in part supplanted by redundancy in programs, which is obviously better if one is going to make large numbers of aircraft.

(U) Indeed, making assumptions with about the same validity as one does in reiliability analysis of hardware, one can observe that a development consisting of three sub-systems will have only about 34% probability of successful completion if each of the sub-systems has 70% probability of success. On the other hand, if there are three alternative development programs for each of the sub-systems, the entire program fails only if all three competitive programs fail in one or more areas, giving an over-all probability of success of 92%. A system manager would of course use this additional assurance to undertake sub-programs of higher benefit and perhaps thus higher risk, but for a system in which the development costs are fairly small compared with the total buy, it is clear that redundancy in the development program, together with a highly reliable choice (requring prototype demonstration) has real virtue. I firmly believe that competetive demonstration programs working to the same interfaced specifications will each be substantially less expensive than would a single development program. Competition really can work, if only to allow the system manager to cancel one of the developments of programs if it shows signs of getting out of hand. Experience shows that the contractor will keep his best crew on the job so long as he is still in competition, rather than using them to win another contract award.

(U) With the philosophy of single-configuration operation, and with redundancy in the development program, it is still important to make choices now. Talent, experience, and funds are scarce. We must preserve the best of the past and add new capabilities. We must look for those small elements which added to the rest yield extraordinary benefits. We must ask what each element contributes to the total, and we must not incorporate expensive, heavy, and unreliable sub-systems because of tradition or because of excess conservatism.

(U) In describing a set of equipment which will implement this philosophy, I shall concentrate on the air-to-air job. We should not forget that this task must be embedded in a mission and in a force structure, but the details of these latter go beyond the scope of the paper. As an example, however, the saving of one minute of non-combat flight time for a 40,000 pound fighter reduces the fuel consumption by about 100 pounds, yet much more effort is spent on reducing avionics weight by 100 pounds than goes into equipment and tactics for minimizing non-combat fuel consumption.

II. System Elements

(U) The effectiveness of U.S. air operations over enemy territory would be enhanced greatly by an effective AWACS or other command and control system. In principle, such C&C would maintain a real time cooperative radar track on our own aircraft and could see enemy aircraft as they took off and began to engage. Alerting of our own aircraft by giving relative position information, as well as receipt of track information from our own fighter radars, could contribute substantially to economy of force and avoidance of surprise. While we should work vigorously toward this goal, my concern here is the outlining of a set of equipment which will maximize the autonomous fighter capability of an aircraft.

Radar

(U) The air-intercept radar on an air-superiority fighter must detect and track enemey aircraft. It can also provide an effective means of designating the target and of guiding missiles to it, as in the semi-active cw homing Sparrow or Sidewinder. The radar must be able to detect closing enemy fighters against the ground clutter, for which a high-prf pulse-doppler system is an established solution. Mechanically-scanned intercept radars are adequate for the primary job. The choice between X-band and K-band must be made not only on the basis of the increased system gain available from a K-band radiator in a given envelope, but also on the basis of clutter due to rain. More important than the choice of frequency is the degree of countermeasures resistance which can be built into a radar by the provision of four-channel monopulse.

(U) Ground Mapping and Terrain Following. The usual argument for shorter wavelengths, i.e. better ground-mapping resolution, can be eliminated in this system philosophy, because the operating navigating system provides the aircraft with its own position, and the avionics can more readily display stored terrain information as an overlay on the radar than can the radar itself provide such maps. Terrain-following radar seems to add little to the effectiveness of an air-superiority fighter and should probably not be included. The terrain-avoidance or the terrain-following function, on the other hand, can be incorporated by use of the navigation system and the radio altimeter, together with facilities for storing a terrain map of the theatre. Aircraft knowledge of present position and orientation allows a flight path to be generated in the vertical plane (or avoidance maneuvers to be planned in the horizontal plane) just as if one had a terrain-following radar of infinite range and scan angle. The radio altimeter then can provide verification that the aircraft is making good its planned course. The altimeter can even be used, as in TERCOM, to update the navigation system. In any case, the ground map function of the radar should not determine its characteristics or its frequency, and in particular is not an argument for an electronically-scanned phased array radar as opposed to the simpler and lighter mechanically-scanned radar.

Identification

(U) Although good electronic IFF can and should be developed to obviate the need for visual identification, visual identification of radar-tracked targets is the present rule, and may in fact be required in the future. That the pilot can see airplanes to some degree with his naked eye is no excuse for the absence of optical aids for this task. Stabilized optics can provide magnification even in the presence of motion and vibration. Electronically-viewed stabilized optics can provide contrast enhancement as well. The stabilized optics can readily be slaved to the radar to ensure that the target is within the field of view and to provide adequate tracking signals until the target is clearly visible. At closer range, the optics itself can provide the tracking with higher resolution than is available from the radar, but wth some built-in intelligence to avoid losing the target because of temporary obscuration by cloud. Stabilized optics, together with an adequate viewing mechanism, then provides visibility beyond that realizable with a physical cockpit. The optics can look down and backwards, thus avoiding the dangerous loss of target location during maneuver. With little additional weight, stabilized optics can be used to increase the pilot's ability to locate predesignated ground targets, to do route reconnaissance, and to improve his delivery accuracy in air-to-ground missions.

Missiles

(U) Although experience with air-to-air missiles in Vietnam has revealed deficiencies in reliability and in effectiveness, so far as I know, no pilot insists on going into combat with guns alone. With a look-down radar, missiles of intermediate and short range (20 miles to 1000 feet) will become more and more important. The side which has no effective missile will lose aerial engagements. But missiles are heavy and contribute drag. It is important to make the most of these necessary penalties.

(U) Guidance Choices. We must provide air-to-air missiles which will be effective in a reasonable envelope of weather and lighting. On the other hand, every missile firing will be preceded by either radar tracking or visual identification or both. It is logically unsatisfying to provide for the missile a completely autonomous guidance system, although infrared missiles are available now, and improved infrared and electro-optically tracking missiles can be available in the future. For radar guidance, both fully active and semi-active seekers have been considered. For the longest ranges, it is useful to contemplate command guidance of the missile. I believe that the semi-active cw seeker has been given less prominence than it deserves even for short-range intercept. The central spectral line of a high-prf pulse-doppler radar can be used for guidance, without the necessity to incorporate a special illuminator. Although semi-active cw homing is adequate in principle, in this case we are fighting not nature and unreliability, but also a determined enemy. It might be desirable to incorporate home-on-jam, or even infrared terminal homing to increase the difficulty of mounting effective countermeasures.

(U) Lock-on at Large Off-angles. Our present guided missiles are for the most part severely constrained by the requirement that the pilot point the aircraft accurately at the target in order to lock on the missiles. The missile thus has many of the characteristics of a gun, although its maximum effective range far exceeds that of a gun. A missile developed for launch in combat at a maneuvering target need not and should not provide the enemy with a chance to prevent launch by maneuvering away from the forward direction of our fighter. Indeed, combat fuel can be saved and our own vulnerability reduced by providing our missiles with the capability to lock on before launch at large angles to the aircraft axis and with wide gimbal limits for the seekers.

(U) Maneuver Before Boost. Against subsonic and barely supersonic fighters, our present missiles are probably too fast. Further, they boost immediately to about Mach 3 above the launching platform velocity and maneuver at full speed. Since the turning radius at a given transverse acceleration is proportional to v^2, the high speed of the missile greatly narrows the envelope of effective launching positions. Further, boosting immediately to full speed and coasting the rest of the way leaves the missile with shorter range or lower velocity at long range than would be the case either if the same propellent had been burned in a number of pulses or if it could have been burned continuously at an adjustable rate. Thus, two quite substantial improvements in the effectiveness of a fighter armed with missiles might be obtained by

---providing lock on before launch and maneuver before boost, and

---providing multiple-pulse capability from the rocket motor in order to maintain an optimum velocity over the trajectory.

Maneuver before boost is not favored by operational people, from concern that the missile will attack the launching aircraft. Better communication with the missile before launch, providing a minimum fusing delay appropriate to the circumstances, together with an initially long seeker time constant can eliminate this danger. In view of the possible benefits, close attention to the cost of these features seems in order.

Thus I suggest one semi-active cw homing missile to be used both in the intermediate range and in the dog-fighting mode, with lock-on before launch and maneuver before boost, with the seeker commanded by the position of the radar and/or that of the stabilized optics which is tracking the enemy aircraft. A second, short-range, dog-fight missile may be more economical in cost and payload, but this is not entirely obvious. As we shall indicate, there exists another mode for launch of self-guiding (i.e., infrared or electro-optical missiles).

Short-Range Designator

(U) It often happens in aerial combat that an enemy aircraft appears in the pilot's peripheral field of view. With the present generation of semi-active cw homing missiles, it is then necessary to lock the radar onto the target (thus pointing the cw illuminator) to provide energy for guiding the missile. Unfortunately, the ease of use of present radars is not such as to make this transition one without pain. In principle, once the pilot or the observer sees the enemy aircraft, he could designate that aircraft to the illuminator and fire the missile without ever achieving radar lock-on. Present-day fighters in general contain no means for such designation, although it can be implemented simply and conveniently with other substantial benefits.

(U) Helmet-Mounted Sights. If the pilot and the observer are provided with helmet-mounted sights, providing before the eye a reticle at infinity, it is a simple matter for a man to turn his head so that the reticle lies on the target and follows it in its maneuvers. The pilot in the AH-56 compound helicopter uses such a sight to steer the gunner's turret and periscope toward a target on the ground. Lightweight and frangible mechanical linkages, as well as optical systems, can give potential accuracies on the order of 6 mils. Both types of angular pick-off mechanisms have received extensive work, and others are also feasible. An effective fighter should have such helmet-mounted sights to enable the men to designate an aerial target to the missiles or to the cw illuminator, a process which can take place much more quickly and reliably than the aircraft itself can be maneuvered to point at the target. Naturally, the angular information from the head-coupled sight can be used to position a cursor in a display, to provide an input to a theatre communications systems in order to inform theatre C&C of the location of enemy aircraft, to designate ground targets, etc. If some display capability (even a driven reticle) is incorporated into the helmet-mounted sight, then the sight can serve as a means of communication between the two men in an airplane, can be driven by theatre C&C (via the aircraft computer) to aid in the acquisition of distant or indistinct targets, and (driven by the computer) can aid in navigation, in the acquisition of ground targets, in head-up approaches to landing, in ground attack, etc.

(U) Head-Coupled Displays. Several examples exist of TV-type displays, using miniature cathode-ray tubes mounted on helmets. A fixed miniature cathode-ray tube, viewed through a magnifier, provides brightness and image quality, together with freedom from reflection, superior to that of the ordinary radar or TV-display. Helmet-mounted displays have not thus far been completely satisfactory, but very little development effort has been expended to date. I want to indicate here the great value of such a display and to record my conviction that a head-mounted display can soon be developed which will have better performance and greater appeal than standard cockpit-mounted displays.

(U) Because it is important for the air-superiority fighter pilot to keep his head out of the cockpit, there is an unusual benefit in incorporating head-mounted displays into this avionics system. However, serious consideration of a head-mounted display for this purpose leads one to perceive many other benefits and applications in the same avionics suit. Thus, the head-mounted display is the head-up display par excellence. An aircraft with a helmet-mounted display has no need for a conventional head-up display for landing, nor for a gunsight. Further, an aircraft with a helmet-mounted display doesn't need a radar indicator nor a vertical or a horizontal situation display. The ordinary central digital computer can readily provide any of these presentations at the push of the appropriate button. Furthermore, scales, ranges, intensity, etc., can all be remembered from the previous view, and displayed together with the presentation.

(U) For those unfamiliar with helmet-mounted displays, let me sketch three possible types of presentation and their uses. Images or portions of the presentation can be stabilized with respect to

---the pilot's head,

---the airframe, or

---the earth.

Head-stabilized images can be used for important status information, such as fuel, armament readiness, ECM status, altitude above ground level, etc. This information can be displayed in a cluster at the bottom of the field, or around the borders. If the display is to be used as a gunsight or for pointing missiles, a reticle can be generated at the center of the field, so that the superposition of this reticle over an image seen through the effectively semi-transparent sight provides relative target position information via the angles of the helmet with respect to the airframe.

(U) Earth-stabilized images would be used for presentation of terrain maps, for one type of output from the stabilized optics, for television or forward-looking-infrared (FLIR) observation of the ground, or for artificially generated "synthetic runways" for use in instrument landing approaches.

(U) Displays stabilized with respect to the airframe might find the greatest application in transferring to the helmet-mounted display many of the functions now served by status indicators, gauges, and switches in the cockpit. The visual acuity of the eye (0.2 to 0.5 milliradians) is not in itself extraordinary. It is the combination of this 0.5 milliradian resolution with the ability of the eye and the head to view more than a hemisphere which allows the pilot to assimilate so readily so much information from his cockpit instruments. On the other hand, the physical packing of visual indicators leaves much to be desired, presenting problems of reliability, of legibility, and of optimum displayed format. Many possibilities exist for computer-generated displays, ranging from the ridiculous--e.g., a miniature photograph of the cockpit instrumentation, viewed by a small vidicon, serving as background for computer-generated needles or numbers, to those which match better the capabilities of the display and of the computer--e.g., a completely synthetic display with indicators coded by shape as well as legend, the display stabilized with respect to the airframe so that only a portion of it is generated and shown within the field of view at any one time. To view the other indicators, the pilot simply turns his head and finds that they move naturally into the field of view as some of the old indicators move out.

(U) Existing head-coupled display models sense the position of the helemet. It is likely that improved accuracy and less fatigue would result from the incorporation of crude angular accelerometers, which need weigh but a few grams each. Such accelerometers would provide information useful in smoothing the position measurements and in obtaining fine stabilization of the image with respect to the head.

(U) There are further possibilities inherent in the head-mounted display. In an aircraft, frequently-used controls are distinguished by touch and are operated by the pilot, who does not have to look at them. Less frequently used switches and knobs must first be selected visually. The pilot must then move his hand to follow the eye and must finally operate the switch. Although the head-mounted display cannot at present determine the position of the pilot's eye, a fixed reticle in the display can be moved by the motion of the pilot's head until it lies upon a computer-generated synthetic switch. At that time, the pilot could operate that switch by actuating a single standard switch with one of his hands, his chin, or by standardized sound.

(U) Thus, the helmet-mounted display allows the pilot to couple much more closely with his sensors, radar, TV, FLIR, stabilized optics, data link, and with his missiles. It also has the potential to allow him to monitor in great detail the performance of his aircraft and to communicate with it conveniently. This full utilization of the helmet-mounted display would allow the removal of all large cathode-ray-tube displays from the cockpit. Cockpit instrumentation could be reduced to that minimum necessary to fly the aircraft home in case of equipment failure. There are advantages to be realized in improved reliability, as well. The helmet-mounted display is small enough and light enough that operable spares can be carried inside the cockpit. If one display fails or is damaged, the pilot can fit another one to his helmet and have precisely the original capability. I am not aware of reliable estimates of weight, cost, and maintenance reductions associated with the elimination of cockpit displays, gunsights, head-up displays, and instrumentation. Nor are there available good estimates of the improved effectiveness of an aircraft in its various missions, when configured with the helmet-mounted display.

Guns

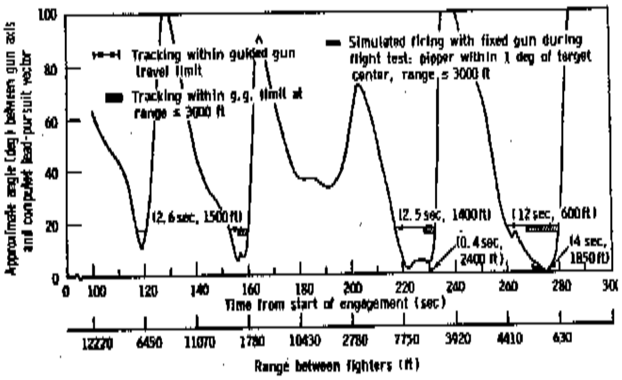
(U) Dogfighting with guns and highly maneuverable aircraft is a fantastically difficult control task. Most such engagements end with the participants running out of fuel and breaking off. Guns have inherent dispersion less than 1 milliradian, which is often intentionally broadened to about 6 milliradians, which, coupled with a high rate of fire (100 rounds per second on the M-61 20-mm cannon), about matches the pilot's aiming error in a dynamic environment.

Rearward-Facing Ordnance

(U) The fixed cannon, aligned with the aircraft axis, severely constrains the fighter pilot. The pilot may wish to maneuver at 2 to 5 g's, in order to maintain his position with respect to the enemy aircraft. The fixed gun, at the moment of firing, dictates the pitch angle and thus the acceleration which can be maintained at that time.

(U) The constraint which a fixed gun introduces can be most readily understood by considering a projectile with zero time of flight. Two aircraft, both pulling maximum g, cannot maintain their relative position if the second aircraft must point directly at the first, since some angle of attack is needed to develop the maneuvering force.

(U) The Guided Gun. In addition to the simple kinematic problems of the fixed-gun, such an installation presents problems of control system lags and accuracy. A gun which could be elevated some 10° or 20° in pitch would often in dogfighting present much earlier firing opportunity, particularly between otherwise relatively evenly matched fighters. Unfortunately, a gun fixed with respect to the airframe but elevated in pitch introduces very large errors due to small roll disturbances and introduces constraints on the engagement beyond those of a fixed gun. A forward-firing gun free to move from -2 to +20° in pitch and perhaps ±2 or ±4° in yaw would very significantly increase the number of opportunities for firing, could increase the accuracy of tracking (since the gun direction would no longer be disturbed by airframe motions) and would reduce greatly the minimum range through which a firing burst could be extended. Some feeling for the worth of the guided gun can be obtained from the flight tests of Project Combat Hassle, a series of simulated dogfights in F-4D aircraft flown by skilled pilots over a fully-instrumented test range at Eglin Airforce Base.[1]

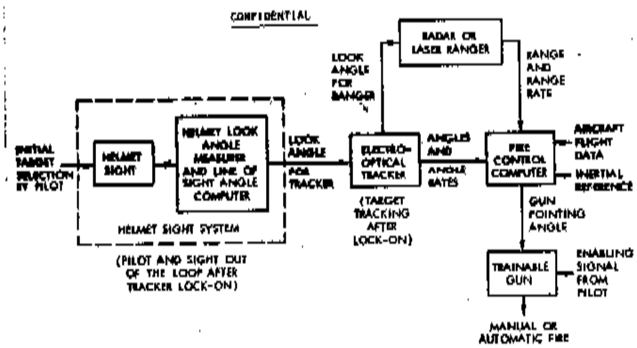


—Range and bearing angle history from COMBAT HASSLE engagement No. 29

(Total burst length and minimum range for each pass shown in parentheses for fixed gun and guided gun firing opportunities at range ≤ 3000 ft)

FIGURE 1. FIRING OPPORTUNITIES WITH A GUIDED GUN

Figure 1, taken from Reference 1, illustrates the extremely brief firing opportunities common in aerial gunfighting. In this particular engagement, the guided gun would have ended the combat at least one minute before the first firing opportunity available with the fixed gun. Figure 2 indicates the integration of the guided gun into the avionics and weapons system.



Schematic control diagram for guided gun

FIGURE 2. GUIDED-GUN INTEGRATION WITH AVIONICS

(U) Indications are that the guided gun will be many times (as much as 20 to 50 times) as effective as the fixed gun, so that the additional installation weight can readily be compensated by reducing the ammunition load from 1000 rounds to 750 rounds, thus saving some 175 pounds. The drag added by a faired slot appears to be less than 1% of total, and is thus probably not significant.

(U) Every effort should be made to strike enemy fighters with missiles so that the actual use of guns, and in particular of guided guns, should be rare. However, neither missiles nor forward guns are of much use in case of gun attack from the rear. In this case, good visibility and good maneuverability can be very helpful, but gun attack in particular can be made much more difficult by the incorporation of rearward-looking radar, optics, and perhaps even of a rearward-fired self-defense missile. It is extremely difficult to provide adequate aperture facing to the rear to allow a high-performance radar to be mounted. On the other hand, a radar which will provide indications of targets rapidly closing in the rear hemisphere, out to a range equal to ones own altitude, would seem very much worthwhile. A scanned fan beam, with elevation determination by monopulse is one approach, but one might also use four-lobe monopulse at VHF to avoid all scanning. In any case, ranges up to five miles would be quite useful. The rearward-facing radar could then alert the pilot to use low-magnification stabilized optics to look to the rear, thus allowing him to take evasive action or perhaps to use a rearward-facing missile, if one were provided. (U) The linkage among the helmet-mounted sight, the steering commands to the pilot, the optical tracker, and the gun pointing itself is provided by the central digital computer which can perform a second-order lead-angle prediction. Thus, steering commands will be provided to the pilot to maneuver in roll (which he can do very easily and quickly), while the gun itself provides most of the motion in pitch. Of course, fine tracking in pitch can be performed by the gun with fractional-second time constants, as compared with the 2-second settling time of the normal sight.

Computer

(U) A redundant central digital computer can carry out navigation computations, weapon delivery computations, guidance, display generation, and can provide a flexible interface among the multiple sub-systems of avionics and ordnance. Presently-demonstrated computers seem adequate for this task, but the fact that the entire programming package can be installed in an aircraft in a minute or less should not be used as an excuse to delay the development of the software. In fact, experience shows that the schedule and quality control of software development is every bit as demanding as that of hardware, perhaps because there has been less extensive experience with software development. Many of the functions of the computer demanded here are routine, the major exception being the proposal to use an accurate navigation system together with stored terrain information for high-performance terrain following. Here it will suffice to note that adequate terrain following can be probably be obtained by storing the maximum ground elevation for every 1000-foot square in the theatre. Thus, if operations are being conducted in a region 200 miles by 500 miles, some $4x10^6$ numbers need be stored, each of some 5 bits accuracy. There is clearly no difficulty in storing this amount of information on standard computer tape or probably for this purpose more conveniently in digital form on chips of photographic film.

Navigation System

(U) A LORAN-inertial system can give accuracy adequate for the fighter role. In such navigation systems, the LORAN signals continuously received is used to up date the inertial system, while the inertial system adjusts filters to track the LORAN signal from the moving and accelerating aircraft. Similar radio-navigation updating of inertial systems can be done with satellite constellations, and it would be shortsighted not to include such provisions in an advanced air-to-air system laid down now. An accurate radio-inertial navigation system of this type, coupled with a stored terrain map, can enable a fighter to use the ground offensively against an enemey fighter not so equipped. A pilot confident of a computer indication to roll and pull out can keep his mind on combat, while his opponent must be ever fearful of getting too close to the ground. A reliable, accurate navigation system can also be very valuable in planning and carrying out productive missions, with consequent transformation of fuel load to payload.

III. Preferred System and Summary

(U) From the foregoing discussion, it is evident that a coherent system can be built of the following elements:

---Radar

Forward looking high-PRF X-band. Four-lobe monopulse, with ground map mode.

---Navigation System

LORAN inertial, with satellite-inertial provided.

---Stabilized Optics

One to ten power zoom, with 360° visibility and presentation on the head-coupled displays.

---Displays

Head-coupled display for viewing radar, stabilized optics, terrain map, status information, TV and forward-looking infrared. For use also as a gunsight and to point the radar and the missiles.

---Guns

Guided gun with ± 2° in yaw and -5 to +15° travel in pitch.

---Missiles

Semi-active cw homing missiles for short to intermediate range (0.15 to 20 miles), with lock-on at large angles before launch, and with maneuver before boost.

---Computer

Redundant central digital computer to communicate among the sub-systems and to drive the displays.

(U) Much development remains to be done on the concepts outlined here. However, it seems to me that anything less technically aggressive than such a program would not provide the superiority which we need in our future air-to-air systems. Many of the elements of this system, in particular the head-coupled display, have applicability to existing aircraft and could well be developed and fielded for this purpose, before new airframes are avilable.

Challenges

(U) Beyond the system described here, which seems well within the state of the art, there are real needs for systems which will provide an active defense against enemey missiles, and there seem to be opportunities for more advanced head-coupled display systems, along the following lines:

---Lower weight by incorporation into the helment, with provision made for replacement in flight to insure system reliability.

---Higher central field (foveal) resolution to make better use of the sensors, transmission bandwidth, and display system. This can be obtained either by optical or by fiber-optical means.

---Eye tracking. The head-coupled sight requires the pilot to designate by moving his head. It is more natural to designate by moving the eye and several approaches have been demonstrated in the laboratory, but at present no accurate convenient eye tracker is available. Such a device would further improve the utility of the system.

(U) I believe it most important to distinguish between the potential utility of a system and its technical feasibility. Many individuals who are superbly qualified to judge utility do not have the basis for evaluating feasibility. On the other hand, systems have been judged feasible and have sometimes been successfully developed without being useful in meeting real needs. I hope that I have avoided these twin perils, but I would like critics to specify whether they differ with me on the grounds of utility or of feasibility. Finally, I thank my colleagues, both in government and out, for their many contributions to these thoughts.

References

1. Greene, T. E., "Engineering Aspects of a Guided Gun for Fighter Aircraft" (U), (Confidential), Journal of Defense Research--Series B: Tactical Warfare (Spring 1969).