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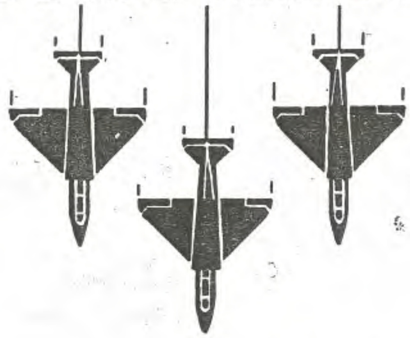
Report of the Defense Science Board Task Force



Volume II
BASIC REPORT

8 May 1968

Office of the Director of Defense Research and Engineering
Washington, D.C.

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Report of the

Defense Science Board Task Force

Volume II: Basic Report

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Office of the Director of Defense Research and Engineering
Washington, D. C.

MEMBERSHIP

of

DEFENSE SCIENCE BOARD TASK FORCE

on

FIGHTER AIRCRAFT

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Dr. Thomas Amlie	U. S. Naval Weapons Center
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Dr. Andrew Longacre	Syracuse University
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single missile can perform both functions, at a somewhat greater cost per missile but with increased effectiveness and perhaps reduced overall cost because of the reduced force-mix type of problems. As the development program proceeds, it should be possible to decide between a single missile and two missiles for this task.

3. The report mentions the importance of ECM and other counters to the surface-to-air missile, and the Board wishes especially to stress the critical nature of this problem. In addition, the air battle between a number of our fighters and a number of enemy fighters cannot be effectively handled from individual aircraft, and adequate communications, AWACS, other theater control and IFF are of great import.

With these comments, the DSB forwards the attached report.

Robert L. Sproull

Robert L. Sproull
Chairman,
Defense Science Board

OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D. C. 20301

14 May 1968

MEMORANDUM TO CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the DSB Task Force on Fighter Aircraft

As chairman of the DSB Task Force on Fighter Aircraft, I have the honor of submitting the Final Task Force Report (SECRET), as well as an Executive Summary (CONFIDENTIAL). The report is concerned largely with the next generation of fighter aircraft for the Air Force and the Navy. The report concludes that aircraft with the recommended avionics and ordnance, together with new high-performance engines and airframes, can provide reasonably stable superiority over the expected Soviet fighter threat of the mid 1970s.

The chief recommendations of the Task Force, as taken from the report are:

1. That a development program, following the basic approach of prototype procurement and testing, be initiated now for a new fighter aircraft. An IOC for the early 1970s—i. e., before 1975—should be sought. Competitive prototype demonstration flight programs should be pursued separately for avionics, for airframes, and for engines.

2. The fighter should be designed for both air-to-air and air-to-ground operations, with the primary design emphasis on air-to-air capability. The air-to-air capability should include close-in combat capability. The air-to-ground capability should be for primarily visual weapon delivery with homing or area ordnance insofar as autonomous aircraft operations are concerned.

3. Guided (i. e., steerable) guns and highly-agile missiles should be provided for forward-hemisphere firing, unless flight tests reveal basic flaws in the concept. Missile seeker, propulsion, airframe and target designation should provide for firing missiles at large angles off the aircraft nose. Rear-hemisphere ordnance should be investigated, tested, and incorporated in the design if found desirable on grounds of utility and performance tradeoffs.

4. Head-coupled sights and display should be used to eliminate the gunsight, radar display, TV display, heads-up display, etc. and provide at the same time flexible all-angle TV viewing and target designation.

5. The avionics should incorporate a pulse-doppler radar with low-PRF mode for ground map, but without either electronically-scanned phased-array or separate terrain-following radars. A redundant central digital computer should couple the displays to the weapons, manage stores and do the computations required for flexible weapons delivery.

6. DDR&E should review those development concept papers for systems which might be available before or about 1975 to provide planning guidelines for synergistic systems rather than to allow each 7-year advanced system to assume the environment as it was at the beginning of the development cycle.

7. Urgent development commitments should be made to:

a. navigation systems providing terrain avoidance by navigation

b. single-frame TV for remote target designation and homing

c. simple hitting surface-to-surface cruise missiles

d. artillery-emplaced, ground and airborne target designating schemes for homing bombs.

e. directed, unmanned reconnaissance and target designation

f. effective and flexible air-to-ground ordnance, such as proximity-fuzed air-opening dispenser munitions, cost-reduced bomblet land mines, etc.

8. Development should proceed immediately on a turbofan engine of the 20,000 pound thrust class, with bypass ratio and other design features to be jointly determined by the Navy and the Air Force.

The key to this fighter capability is the head-coupled avionics and flexible ordnance system discussed throughout the report. Detailed examples of its use are found in Appendix C of the main report.

I want to call to your attention also the extent to which our capability and the effectiveness of even these aircraft can be enhanced by the provision of non-fighterborne systems such as:

- adequate theater control and IFF (via AWACS),
- theater-range cheap surface-to-surface target-hitting cruise missiles,
- navigation and communication aids, such as satellite systems or LORAN,
- adequate target-designating systems, such as laser target designators or artillery-emplaced beacons.

I personally wish to emphasize the critical threat that surface-to-air missiles will pose and the necessity for an intensive and enlightened program on penetration aids and tactics in order to counter these missiles.

The Task Force is pleased to have had the opportunity to contribute by its efforts.

Richard L. Garwin
Chairman,
DSB Task Force on
Fighter Aircraft

PREFACE

This report of the Defense Science Board's Task Force on Tactical Aircraft is written in response to a request (see Appendix A) from the Director of Defense Research and Engineering for the Defense Science Board to examine the tactical air-to-air missions and air-to-ground missions for the Navy and the Air Force. As a consequence of the indication that the air-to-air problem should receive priority, the Task Force initially submitted a draft report on this mission area October 1967. Air-to-ground missions were the subject of a further draft added 3 February 1968. The present report supplants the previous drafts, without, for the most part, major changes in conclusions or recommendations.

One note of caution—the Task Force has not drawn any overall judgment as to the attrition that Soviet missiles of the 1975-1985 time frame might cause to tactical aircraft nor as to the corresponding tactics and hardware that must be adopted by tactical aircraft if they are to survive in an environment of advanced surface-to-air missiles. Furthermore, the Task Force has addressed only the characteristics of and the program to obtain an optimum fighter aircraft for the 1975+ period—the necessary number of such aircraft may be affected by strategic and even political considerations.

A brief Executive Summary of this material is issued separately as Volume I of this report. Both the Executive Summary and this basic report were accepted by the Defense Science Board on 8 May 1968.

Since the effectiveness as a fighter is the most stringent condition for the aircraft, implications of this role on system design and development programs are treated first.

CONTENTS

UNCLASSIFIED SECRET

CONTENTS (continued)

SECRET UNCLASSIFIED

1. TASK DEFINITION

In his directive memorandum defining the work of the Defense Science Board (DSB) Task Force on tactical Aircraft, the Director of Defense Research and Engineering put the primary question for air-to-air operations in the following terms:

> which is the route of greater promise for achieving superiority over the Soviet Union in air-to-air combat—a) emphasis on speed and maneuverability in the aircraft, or b) emphasis on maneuverability and firepower in the missile? Consideration should also be given to the identification problem, type(s) of weapons and avionics, development costs and risks for alternative approaches, and the stability of any solution against Soviet growth.

In examining these questions and in making its recommendations thereon, the Task Force has also reviewed the principal missions of the tactical air forces of the United States and the extent to which these differing missions make different performance demands upon the aircraft and upon the weapons. It is possible that the missions are sufficiently different (and separable) so that separate aircraft designs should be optimized for each. It will be of interest also to note in what particulars, if any, the Task Force recommendations differ from the Services' proposals for FX and VFAX aircraft (the next generation fighter aircraft proposed for the Air Force and the Navy respectively).

1.1 Mission of the United States' Tactical Air Forces

The missions of the Navy and Air Force tactical air forces derive from the U.S. commitment to a policy of collective security with its allies throughout the world. These same missions would be required in any unilateral intervention as well. To meet these global responsibilities, there is required an ability for quick deployment, followed by sustained operations, anywhere in the world.

It is generally accepted that the principal missions of the tactical air forces in a theater of operations are counterair operations, interdiction and close air aupport, the objectives of these missions usually being stated in terms such as these:

The objective of counterair operations is to attain and maintain air superiority by elimination of interference by the opposing air forces.

. The objective of interdiction is to reduce support for the enemy's military forces by destruction or disruption of lines of supply and communication.

The objective of close air support operations is to provide fire support to friendly ground forces that are engaging the enemy.

Attainment of the second and third objectives—and even the survival of our entire deployed force—may depend on the prior and continuing attainment of air superiority. By far the most efficient way to destroy enemy aircraft is generally to strike them at the air base, but we recognize the need for an air-to-air combat capability superior to that of the expected threat in order that the opposing air power may be rapidly suppressed even if political constraints prevent our striking enemy air bases, or in case active and passive defenses make such attacks unprofitable. It should be evident that the possibility of these constraints requires us to build much larger air forces than would be required for strikes at airfields; and it is important to note that the enemy controls the rate of encounters and thus the rate of destruction of his own air force, even if we have air superiority.

1.2 Air-to-Air Combat

A responsible reply to the air-to-air question requires careful assessment of the probability of success of existing and achievable U. S. aircraft and air-to-air weapons for the time period of concern, namely, 1975-80+. Air-to-air combat tactics, present and extrapolated, provide the frame for this assessment, and the experiences of Korea and Southeast Asia provide useful data which any reasonable evaluation procedure must consider.

Air-to-air combat may be "close in" or at relatively long range, depending upon the circumstances of detection, identification and the characteristics of the weapons. It is important to know whether close-in combat could be ruled out for this time period, since a large fraction of the program cost for a new fighter aircraft could be due to provisions for close-in combat. This is because combat with the medium-range air-to-air weapons at aircraft separations of 10 to 20 miles does not require the same high degree of aircraft and ordnance agility demanded by close-in air-to-air combat.

The Task Force's study of aircraft performance, weapons performance, air-combat tactics and experience data from the war in Southeast Asia and from other wars has led to the conclusion that a need for both a close-in and midrange (i. e., within visual and beyond visual range) air fighting capability will exist during the foreseeable future of tactical air combat.

Even though the preferred method of destroying enemy air power may continue to be attacking aircraft on the ground, we cannot be confident that airfield attacks will always be feasible or adequate. Airfields may enjoy politically established sanctuary in certain future wars, as has been the case in current and past wars. Furthermore, it appears technologically and economically feasible for a nation to protect its aircraft on the ground by various combinations of active and passive defenses and aircraft design (e. g., V/STOL) to such an extent that attacks against them would be less profitable. Recent experience in attacks against prepared enemy bases in North Vietnam appears to indicate a trend in this direction.

Surface-based missiles and even guns will play an important and perhaps dominant role in destroying aircraft in the air, but fighter aircraft will continue to retain such advantages as all-altitude capability, wide area coverage, rapidity of deployment, suitability for escort and sweeps over enemy territory, and protection of support aircraft—e. g., tankers and large transports—that are operating over sea or land areas outside of surface-based weapon range.

A close-in fighting capability will be needed for several reasons. Among them are the need (in some circumstances) for visual identification, the need to discriminate between closely spaced friendly and enemy aircraft, and the need to fight at times from an initial position of disadvantage. In many possible battle situations it will be necessary to identify aerial targets positively before attempting to destroy them. It will be necessary to distinguish enemy aircraft from neutral as well as from friendly aircraft. This may be of critical importance in a limited war in which commercial aircraft or military aircraft of nonbelligerent powers may be using the battle air space. The problem may be complicated by large numbers of aircraft from all four air services of the United States and, in some cases, aircraft from one or more Services of one or more nations allied to the U. S. taking part in operations in the battle area. To date no fully satisfactory IFF equipment has been adopted to perform positive identification securely and reliably, and our overall air-superiority effectiveness is much diminished by this lack. The ideal system should be difficult to jam, spoof, deceive or copy. It should be passive to permit its use in situations where emissions (such as radar transmissions) could be used by the enemy to detect and track our aircraft. We believe that continued research on IFF systems, including such visual aids as stabilized optical systems, must be pursued vigorously. However, we stress that much could be done to install less than ideal, but still effective equipment. We also conclude that approach to within visual ranges,[1] for identification purposes, will be required in many cases throughout the operational life of the next generation of aircraft. (This is an observation, not a statement of predestination.)

Even though identification may be made at ranges beyond visual range, it may sometimes be necessary to hold fire until close in to avoid hitting friendly aircraft flying near the target.

A large fraction of tactical air engagements begin with a surprise attack from the rear. If the attack is detected in time to avoid destruction, or if the attack fails for some other reason, the airplane that is under attack is very likely to become involved in a hard-maneuvering engagement, parts of which may be at close quarters. Surprise attacks and resulting close-in combat are by no means confined to environments where one side has the advantage of warning and GCI (ground-controlled intercept), however, they are especially likely to occur in such environments. Thus, when our fighters are operating over enemy territory, their encounters with enemy fighters are likely to begin with the enemy positioned for a closing, rear-hemisphere attack.

For reasons such as those listed above, closure to within a few miles of the target will be necessary to press an attack or it may be forced on our planes by the enemy. Once closure to within visual identification range has been made, a close-in air combat capability is essential.

A capability for midrange combat[2] will also be needed as an integral part of the fighter system design. The midrange ordnance will be essential in situations where satisfactory identification can be accomplished at radar line-of-sight ranges and where the enemy is

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[1]Generally speaking, less than 5 miles.

[2]Combat at greater than visual ranges, out to, say, 20 miles. We are referring to a range capability like that of Sparrow III, and not that of longer range missiles such as the AIM-47 and AIM-54 (GAR-9 and Phoenix).

equipped with medium-range ordnance. The maximum range for medium-range ordnance should exceed the enemy's estimated tactical air-to-air missile range.

1.3 Multimission Capability

1.3.1 Roles: In determining the appropriate role for a new fighter aircraft, the main consideration should be to achieve a force structure with sufficient air-to-ground and air-to-air capability to meet the expected enemy threat. On this basis, the major gap in the approved force program for both the Navy and the Air Force appears to be in the area of air-to-air combat, although some skepticism may be in order also as to the current effectiveness of the air-to-ground operations. The 1975 approved program for the U.S. Air Force shows about 800 ground-attack aircraft (F-111A and A-7) plus over 900 multipurpose aircraft (F-4C/D and F-4E). The F-4Es are expected to constitute an excellent air-to-air weapon by the standards of the late 1960s. They are likely to be outclassed by enemy fighters in the mid-1970s, particularly in close-in combat. The approved Navy program for 1975 shows a total of over 700 attack aircraft (A-4, A-6, A-7) plus about 150 air-to-air fighters (F-8 and F-111B). Both of the latter two types of fighters would probably be noncompetitive with Soviet fighters of the mid-1970s in close-in tactical air combat.

The conclusion is inescapable that the new fighter aircraft should provide a capability for air-to-air combat in quality and in quantity sufficient to meet the enemy threat of the mid-1970s. The air-to-air capability should include, but not be restricted to, close-in fighting ability superior to that of the best enemy tactical fighters.

Conceptually, the air-to-air combat task can be handled by an aircraft designed as a multipurpose, i.e., ground attack plus air fighting, airplane. In practice, one mission or the other must dominate the design. It is instructive to note that our most successful air fighting machines have been designed primarily for air combat, though in some cases they later proved to have a useful air-to-ground ability. The F-51, F-86 and F-4 exemplify this point.

The Task Force believes that the new airplane should be designed primarily for air-to-air combat. This will naturally result in a less efficient air-to-ground capability, but proper attention to this point can give a very good attack performance without impairment of the primary mission.

1.3.2 Stated Service Requirements: The Navy and the Air Force have stated somewhat different requirements for a new fighter. The Navy has initially placed more emphasis on the ground-attack mission, the Air Force more emphasis on close-in air-to-air combat. The Navy sees a necessity for a close-in air-to-air capability competitive with mid-1970s enemy fighters, but argues that the need to exercise this ability is not continuous. They visualize an initial period of contested air superiority, followed by decreasing air-to-air activity and increasing U.S. air-to-ground activity. Because there is an absolute limit on the space available for aircraft aboard a carrier, the Navy argues that it cannot afford to allocate space to aircraft specialized for air combat. Instead, it must have multipurpose fighters that can be used in air combat on some occasions and in air-to-ground missions on others, and the Navy comments that they will in any case so use even a specialized air-to-air machine. The air-to-ground requirement is stated not only in terms of a considerable range-payload capability, but in terms of a sophisticated avionics package that is supposed to provide a first-class all-weather ground-attack capability. The ground-attack radius requirement is stated to be 600 nautical miles (with a 4000-pound payload), this radius being based on a survey of required carrier standoff distances and land-target positions.

The Air Force requirement has been stated in terms of a primary air-to-air capability. Range requirements appear to be a 200-nautical mile radius for high-altitude cruise, plus a 70-nautical mile dash radius at 10,000 feet at Mach = 0.85 and 3 minutes of combat at 10,000 feet and Mach = 1.0. The equivalent air-to-ground mission range/payload ability appears to be somewhat less than that asked for by the Navy. However, the Air Force requirement also calls for an all-weather air-to-ground capability.

On examination, it is difficult to see why there should be basic differences in the requirements of the Navy and the Air Force. Both Services would like to have a multipurpose fighter, provided that it would do the air-to-air task adequately. Both would like to reduce the number of aircraft types. Although the Air Force does not have an acute problem in providing parking space as does the Navy, smaller aircraft would help relieve congestion on some crowded Air Force tactical bases and would be easier to shield in covered revetments. (The Task Force is unanimous in the opinion that shelters are needed at forward tactical bases, but discussion of this subject lies beyond the scope of this report.) And, of course, the overall capability within a given budget may be greater if every aircraft can be effective in both air-to-air and air-to-ground even if fewer aircraft are purchased, than if a somewhat larger number of smaller aircraft could be used only air-to-air or only air-to-ground.

The Navy's need for air-to-ground ability is not clearly different from that of the Air Force. The basic purpose of military aircraft is to influence the ground battle; in tactical operations, the primary requirement for fighter/attack aircraft is for weapon delivery against ground targets. Both Services would like to improve their all-weather bombing capability. However, if a supplement to the programed all-weather ground attack capability for the Air Force and Navy is needed, it is hard to see why that capability should be met with an airframe capable of Mach 2.3 or higher speed and with a high maneuvering and acceleration potential.

The argument for a multipurpose aircraft, with air-to-air characteristics somewhat degraded by the requirements for the air-to-ground mission, on the basis of a time-phased need for air-to-air combat is open to serious question. One of the important questions is: whether an aircraft compromised in its air-to-air ability by demands for the air-to-ground mission, might be unable to hold its own against specialized high-performance enemy fighters, so that the air-superiority battle might go badly for the multipurpose airplane—or, at best, might be prolonged? Also, the timing and severity of the need for air-to-air combat are quite dependent on the "scenario." The air-superiority battle may be fought briefly in the first days of the war, as in the case of the German attack on Poland or the Israeli attack on Egypt. Or it may be a long, continuing battle as in the Battle of Britain, the defense of Malta, the Allied air offensive against Germany, the Korean War, or the war in Vietnam.

1.3.3 Could One Aircraft Do the Job? The requirements stated by the Navy and Air Force are sufficiently different that it does not appear desirable—or perhaps even feasible—to attempt to build one aircraft to meet both requirements. Informal opinions expressed by government and contractor personnel are that an aircraft possessing all the mission capabilities asked for by both Services would weigh upwards of 65,000 pounds. An aircraft of this size would probably fail to meet the Navy's expressed need for a small spotting factor and would be undesirably large, i.e., too easy to see and to hit, for close-in air combat. It would surely be unnecessarily expensive. However, if the Task Force argument stated above regarding the similarity of actual needs for Air Force and Navy forces is correct, then one aircraft could indeed do the job—the job being to provide a first-class air-to-air combat capability, including close-in combat ability, plus a good visual delivery air-to-ground capability, which could, however, be very effective with modern homing and area weapons, e.g., Walleye and CBU-24, respectively. If range capability adequate to provide fighter escort and sweep operations out to the limit of ground attack[3] operations is built into the fighters, there should be an excellent "fallout" capability for visual ground attack with very little compromise to the air fighting characteristics of the airplane. Section 4.3.2 suggests techniques for obtaining all-weather delivery capability without dependence on a complex radar.

1.3.4 Crew Size: For the mission described above, a single-place airplane would be preferable to a two-place airplane, provided that the best available techniques in controls, switching and display are incorporated in the design. The feasibility of a one-man aircraft should be established by the program recommended in the next section, 1.4, one of our chief concerns being the desirability of training a single crew—especially, a single man to do both the air-to-air and an air-to-ground job as contrasted with the better performance and survivability which might be obtained from specialized air-to-air and air-to-ground crews.

1.4 Is a New Tactical Fighter Needed by the Air Force and/or Navy to be Operational in the Early 1970s?

As of 1975 the only aircraft programed to be in the Air Force or Navy inventory (except for 24 F-8s) capable of maneuvering combat within visual detection and identification ranges will be the F-4. The F-4 appears to be competitive with the Fishbed and indeed, superior to the Fishbed C/E models as judged on the basis of combat result against aircraft flown by North Vietnamese pilots. On the other hand, approximate theoretical analyses of the acceleration and turning ability of the F-4 indicate that it is inferior in those respects to both Fishbed and Fitter throughout most of the flight envelope. However, it is clear from recent data that the Fishbed C/E models suffer from major limitations in cockpit layout, switchology, engine power response, visibility from the cockpit, and handling characteristics during maneuvering flight. The F-4's capability against later models of the Fishbed flown by more highly skilled pilots than the North Vietnamese is still open to question. The ordnance carried by the F-4—in particular, the F-4E with an internal M-61 gun—appears somewhat superior to that of the Fishbed and Fitter, and might counberbalance whatever edge in airframe performance may be possessed by the latest versions of those Soviet fighters.

[3] Using external fuel prior to combat.

U.S. intelligence organizations have estimated that the Soviets will deploy considerably more advanced tactical fighters by the early 1970s. Their technical capability to do so was evidenced at the 1967 Domodedovo air show. It appears likely that the F-4, an airplane representing the technology of the mid-1950s—first flight was in 1958—will be seriously outclassed in maneuvering combat against the Soviet Union's tactical fighters deployed as follow-ons to the current generation. On this basis, we conclude that a new tactical fighter with superior close-in air-to-air performance to the to the F-4 is needed by the U.S. Air Force and U.S. Navy. In addition, the effectiveness of the F-4 even at medium and long range, combat is far less than can be obtained with the avionics suit and ordnance proposed here.

2. FIGHTER SYSTEM DESIGN IMPLICATIONS OF THE AIR-TO-AIR MISSION

2.1 Ordnance-Avionics Implications

Implicit in the air-superiority role of the proposed fighter aircraft is the necessity of a forward-hemisphere capability to detect, identify and successfully attack hostile aircraft. The identification function must distinguish friend from nonfriend in a "guns-free" environment and distinguish hostiles from other nonfriends in a "guns-not-free" environment. The forward-firing air-to-air ordnance for these respective environments must include improved medium-range missiles (over 5 miles) as well as improved short-range ordnance (under 5 miles) of both missile and gun types.

SEA (Southeast Asia) experience bears out the obvious deduction that a fighter so formidably equipped to cope with hostile aircraft in the forward hemisphere will itself most often be the object of surprise attacks from the unprotected rear. Therefore, these proposed aircraft must also have the ability to detect, identify and, if possible, attack successfully such rear-hemisphere hostile intruders.

The route of greatest promise in achieving air superiority over the Soviet air-to-air threat appears to be the provision of greater agility of the ordnance and improved performance of the associated avionics as compared to the respective existing capabilities. Because of the intimate dependence of ordnance effectiveness upon the avionic and human elements of the system, automation techniques should be exploited to the maximum feasible extent to gain the tactical advantage of increased system agility.

The Task Force believes it technically feasible to provide the same suit of avionics for Air Force and Navy fighters except that, if one of those aircraft should be found to require more complex avionics than the other, then the simpler avionics suit should be derived from the more complex one by deletions.

With respect to the ordnance suit and ordnance-related portions of avionics, the Task Force recommends that the elements and capabilities designated as Head-Coupled Avionics/Weapons System be investigated with sufficient intensity that they be available for incorporation into the new generation of fighters. Examples of the use of these systems are illustrated in detail in Appendix C.

The ordnance systems will be discussed first.

2.2 Ordnance Systems

2.2.1 Guns: The aircraft should have an integral forward-firing gun system. The Task Force feels that a major tactical advantage in air-to-air gun attack can be achieved if the gun is automatically directed by computer-generated aiming signals based on input sensor data including radar-derived range. It seems desirable to use an electro-optical tracker to assure very accurate target-angle inputs for the computation. The gun guided by the computer aiming signals should be trainable from about -2 degrees to +18 degrees in elevation and ±2 degrees in yaw.

Whereas a fixed gun must be aimed by maneuvering the aircraft to satisfy the computed lead-angle solution, the guided gun is aimed automatically anywhere within its trainable limits and thus will substantially reduce the combat time required to bring the gun into firing position. Consequently, many opportunities for gunfire that would be lost with a fixed gun can become effective attacks with the guided gun.

A guided gun is now under consideration for an Air Force test program. The Task Force strongly recommends that sufficient resources be allocated to establish the feasibility and utility of a guided gun by flight testing during this calendar year, using primarily off-the-shelf components to provide a fully operating system for the test.

The guided gun, directed by the head-coupled sight described in section 2.3.2 should give these aircraft clear superiority against similar modern high-performance aircraft, but it is imperative that the particular version of this system to be specified for the aircraft be determined by actual flight test of a fully operating demonstration system to establish its feasibility and utility. In section 3, we prescribe a program which we hope will accomplish this.

2.2.2 Missiles: The missiles being used by U.S. forces in SEA are essentially of a 1949 design and without exception were originally designed for attacks against nonmaneuvering subsonic bombers. The AIM-9 was first put in operational service in 1956, and the Sparrow III, at approximately the same time. These missiles have gone through various modifications which greatly improved their reliability and performance, but they are essentially obsolescent ordnance designed for another purpose. The Sparrow III was bought as a long-range head-on point interceptor missile. The fact that it has some effectiveness in close-in air combat is a tribute to the aircrews using it. The AIM-9 was also designed as a bomber killer, and the limited success it has had against maneuvering targets is, again, a result of the training and self-discipline of the users under extreme stress. These two missiles, as well as the recently introduced AIM-4, have severe limitations when fired against strongly maneuvering targets. They are simply not designed for this task.

The Task Force feels strongly that a new missile is required to cope with the short-range, highly maneuvering target. (Short range will arbitrarily be taken as less than 5 miles at altitude.) The Task Force is not doctrinaire as to choice of guidance, which could be infrared (IR), electro-optical (E-O) or radar, the consensus being that any of these is feasible. The short-range missile must be optimized for quick-reaction firing and for shooting at targets which are at large angles off the nose of the fighter—these specifications are at least as important as any other characteristics of the missile. The most capable system would seem to incorporate a short-range semiactive radar-homing missile, together with either an E-O or IR missile in case of countermeasures. But we stress later the changes which must be incorporated in the weapons control system in order to launch flexibly at short ranges. The Sparrow has been designed and optimized for the long-range head-on intercept role and could be retained for that mission. It should also be modified with an adaptive control system so that the transfer functions can be made variable to provide both long range, which requires low induced drag, and also to take care of the maneuvering or jinking target, which requires quick missile response near the end of its intercept path. Modification to incorporate a closed hydraulic system also appears desirable, and this missile, too, should benefit from our later recommendations to improve the flexibility of launch.

2.2.3 Rearward-Firing Ordnance: Rearward-firing ordnance would provide a great increase in capability against the now prevalent enemy attacks from the unprotected rear. The Task Force recommends strongly that sufficient resources be allocated to ensure a vigorous investigation of the feasibility and design characteristics of a rearward-firing gun and/or a rearward-firing missile. The associated rear-hemisphere detection, identification and weapons control are discussed in connection with avionics systems.

2.3 Avionics

2.3.1 Display and Control: The Air Force aircraft is envisioned as a one-man air-superiority fighter. Because of the intimate dependence of ordnance effectiveness upon the avionic and human elements of the system, the displays and controls must be simplified and integrated to a very high degree to reduce the pilot's work load, particularly in times of combat. Automation techniques should be exploited to the maximum feasible extent to gain the tactical advantage of increased overall agility during close-in air combat. It appears that incorporation of the head-coupled display techniques, as discussed in section 2.3.2, would make a major contribution to such a program.

2.3.2 Head-Coupled Electro-optical Techniques: The Task Force was very favorably impressed by the reported status and promise of electro-optical techniques. In particular, the Army and other programs on helmet-mounted, or head-coupled, sights and displays are impressive.

The Task Force believes that these techniques could be applied in the proposed fighter aircraft with important tactical advantages, in that many fleeting opportunities to acquire targets that would be lost if conventional head-in-cockpit acquisition techniques were used (in either a one-man or two-man aircraft) could instead become effective gunfire or missile attacks. It also seems clear that a one-man aircraft could be effective for missions otherwise necessitating a two-man design; short-range missile attacks could be effected without interrupting radar search, and the pilot's work load could be greatly reduced.

Incorporation of these techniques by means of a head-coupled display (HCD) would result in an integrated "head-coupled avionics and weapons system." For this system, the Task Force envisions advantageous uses in air-to-air and air-to-ground operations, as described below, all in a head-up manner. (Illustrated examples are given in Appendix C.):

For guided-gun attacks:

- The optical sight function of the head-coupled display would be used to point the radar antenna for automatic lock onto a hostile aircraft seen visually by the pilot but not yet seen by the radar.

- Concurrently, either the coupling signals of the HCD or the autotrack output signals of the radar would direct a video contrast tracker for automatic lock onto the aircraft to obtain very accurate angle data for the guided gun aiming computation.

- The CRT display function of the HCD would then be used to present the pilot's steering portion of the gun attack solution.

For short-range missile attacks:

- The optical sight function of the HCD would point the radar antenna for automatic lock-on just as in the gun attack case, whereupon the autotrack output signals would point the missile seeker for lock onto the hostile aircraft.

- Alternatively, the HCD coupling signals would be applied directly to point the missile seeker.

- Commands for the pilot, if any, for completion of the missile attack solution would then be presented via the CRT display function of the HCD.

For midrange missile attacks:

- The CRT display function of the HCD would be used for viewing air-intercept-radar video in a "vertical situation" type of presentation stabilized relative to the aircraft and for checking the IFF reply status of detected airborne targets. (For viewing all radar- and TV-type video, a shutter would be positioned automatically, or by a push button, to preclude interference by light coming through the combining glass of the HCD.)

- In a guns-free environment, while viewing the stabilized vertical-situation display, the pilot's head motion would initiate radar autotrack lock-on by positioning a target-designation symbol on the radar target of a hostile aircraft as seen in the HCD. The autotrack output signals of the radar would point the seeker of the midrange antiaircraft missile (e.g., Sparrow) for lock onto the radar illumination reflected from the target aircraft.

- In a guns-not-free environment (where visual recognition must be relied on to distinguish hostiles from other nonfriends), upon initiating autotrack radar lock-on as described above, the output signals would point a high-magnification forward-looking TV unit toward the same aircraft. The CRT display function of the HCD would then be used to view the video output of the TV unit, thereby distinguishing hostiles from other nonfriends at ranges up to 10 times that possible by the unaided eye.

For standoff air-to-ground attack (e. g., Walleye):

- The CRT display function of the HCD would be used to view the stabilized-TV-type weapon video, and the pilot's head motion would position the weapon tracking gate for lock onto a selected target. Thereafter, the HCD would be used to monitor the weapon video if required.

For routine and GCI flight control:

- The CRT display function of the HCD would give the pilot the same HUD-type presentation as is provided by conventional head-up displays. It would display vectoring and warning information from AWACS or from other GCI facilities.

It seems clear that the HCD could become the primary display of these fighter aircraft providing for all normal uses the head-up, vertical-situation, horizontal-situation, and multisensor display presentations. Although one head-in-cockpit unit might be retained as a multipurpose backup display, the helmet-mounted display weighs only a few ounces and operating spares could be carried in the cockpit.

The Task Force believes that the head-coupled system can contribute greatly in making possible an effective one-man air-superiority aircraft. It strongly recommends that the services allocate sufficient resources—and initiate competitive contracts as soon as possible—to intensively investigate this head-coupled concept and to establish its feasibility and utility for the proposed new fighters by actual flight test in a fully operating demonstration system.

2.3.3 Radar: To avoid very serious penalties in performance, weight and reliability, the radar—as well as other avionics systems—should represent a fresh start, not a modification of some existing radar system such as the APG-59 or the ASG-18. As such, the radar should take advantage of the new components and techniques available, such as the availability of head-coupled CRT displays, to reduce weight and bulk and to provide more flexible aid to the human. Lightweight, simplicity of operation, low maintenance cost and reliability are important considerations in the tradeoffs that must be made in any system. Given these desiderata, the radar must in all likelihood have a 30-inch aperture, four-lobe monopulse, at least 1 kilowatt of average radiated power, and a substantial look-down capability (which implies coherent processing). The radar must have a high degree of automation in acquisition, both in the long-range search mode and the close-in mode, wherein the antenna is pointed in angle by the pilot using the head-coupled sight system. The radar must provide suitable illumination for use with the Sparrow III missile and for any other semiactive radar-guided missile. The Task Force feels that X band is a more suitable frequency than Ku for this system and that, for the mission of this aircraft, the increased weight, complexity and high cost of an electronically scanned antenna would make it an unwise choice (albeit feasible and capable). This question is discussed further in section 4.3.1, in connection with the air-to-ground operations.

In connection with the VFAX program, the Navy proposed a hybrid radar which combined mechanical and electronic steering. The antenna provides two beams, one for the radar and one for the CW Sparrow illuminators. The radar beam is scanned electronically in elevation and mechanically in azimuth and is horizontally polarized. The illuminator beam is scanned electronically in azimuth and mechanically in elevation and is vertically polarized. The concept is superficially appealing, in that the number of phase shifters required is greatly reduced from the number required for a full-phased array. On the other hand, the system has limitations and drawbacks that seriously impair its usefulness.

Although the radar and illuminator beam can in principle be steered independently up to 60 degrees from each other, this independence is severely restricted by the necessity for the radar to supply steering information for the illuminator. Further, the system requires linear polarization in order to create two beams, which precludes the use of circular polarization to combat precipitation return. When we consider that the scanning motion of the radar beam is still limited by mechanical effects, that it compounds the losses involved in the rotating -joint hardware (4 channels) with the losses and power-handling limitation of high-power phase shifters, the added benefit of the electronic scan seems marginal at best. The Task Force is unanimous in the opinion that the radar does not represent a desirable line of approach.

The Air Force proposes a full-phased-array radar. This is a K-band radar using a reflecting array with about 3800 elements. Using full phase-phase steering it is capable of quite versatile multimode operation on a pulse-to-pulse sequential basis. (The radar details are outlined in a Raytheon document.) The Task Force is convinced that a radar of this type can be made to perform approximately as indicated.

Further, we believe that the full-phased-array radar is the most promising approach toward providing the full multipurpose capability that would be needed in an airplane that does such diverse missions as night interdiction of fleeting targets, using radar terrain avoidance or terrain following, and air-to-air combat. On the other hand, we are not convinced that it is the best solution for a fighter aircraft in which the prime mission is air-to-air combat and in which the air-to-ground capability is limited to the type of mission that can be efficiently performed by a single-man crew.

It is not possible at the present time to provide an exact estimate of the weight and cost involved in providing true multipurpose capability of the type provided by the phased-array radar, but we believe that they would be of considerable proportions. In the pure air-to-air role, this capability is not needed. Assuming flight times of the order of 10 to 15 seconds for a Sparrow-type missile, there is little penalty involved in interrupting the search scan for this period. Consequently, we believe that a simple dish-type radar would be quite adequate. Further, there is a substantial spectrum of air-to-ground missions for which the more sophisticated radar capability is not required. These include such things as daytime strafing, dive bombing, etc., as well as the delivery of weapons such as Walleye in which the sophistication is aboard the missile. For attack on fixed targets an accurate navigation system and for attack on moving targets a simpler radar may do as well.

We recommend that the radar for an aircraft optimized for the air-to-air role should not be required to provide terrain avoidance, terrain following, synthetic aperture, and other sophisticated air-to-ground modes. We do feel that a simple ground-mapping function should be provided, which would preclude a radar having only a high-PRF pulsed doppler mode. No low-PRF radar equipped with airborne MTI has yet proved to be adequate. Such a radar would also preclude the recognition of turbine-blade signatures and may provide less probability of detection under certain conditions. At present, both high and low PRF seem required. In either case, we feel that a simple dish-type antenna would be adequate for the air-to-air role and for these air-to-ground missions such as strafing, dive bombing, and delivery of Walleye-type missiles that do not put sophisticated demands on the airplane's avionics.

Our investigation of the air-to-ground problem shows that a flexible navigation system and computer can perform many of the functions normally considered as belonging to a radar.

2.3.4 Other Avionics: The other subsystems incorporated in the aircraft follow the precepts of light weight and simplicity of operation and maintenance. The voice link should utilize spread-spectrum techniques to make it secure and relatively immune to jamming. For clear-weather operation, it seems at first sight that the navigation system need only be adequate to bring the aircraft to within a couple of miles of a point to be attacked and then to return it to the general direction of its base. However, it may be that clear-weather operations can be extended to a much larger portion of the day and night by improvements in navigation, and this is addressed in the air-to-ground section 4 which follows. Instrument landing capability is required. The Task Force does not feel that solution of the IFF problem is a part of its charter, but recognizes that the utility of the midrange missile depends heavily on the availability of an adequate system. ECM equipment and penetration aids should be installed so that they can be easily changed as the requirements change, and the present ECM programs must be further intensified in order to handle the threat.

ECM: Surface-to-air missiles are a determining fact of life in Vietnam, Korea and most of the rest of the world. With money, hard experience, and luck, we have continued to fly (although in a highly-constrained manner) through SA-2 territory. A home-on-jam monopulse seeker could change all this, and both self-contained and stand-off ECM must be given continuing high priority for the 1975+ period, for air-to-air as well as for air-to-ground missions.

Integrated Communication, Navigation, Identification (ICNI): The multiplicity of antennas, knobs and black boxes in current aircraft for these functions is a reflection of the gradual growth of these functions as independent elements and subelements. Clearly it is past time for an intensive conceptual and system design effort, not limited to the airborne equipment, to obtain a proper return on the investment in frequency spectrum, cockpit space, and pilot work load represented by the CNI functions. We are most concerned that drive and resources toward this end be made available now so that an informed decision may be made several years hence as to what form the ICNI and associated nonaircraft systems should take. Among the latter, for instance are communication-satellite facilities, satellite navigation and air-traffic control, AWACS data link, voice encryption, etc., and it is urgent to have a broad plan, at least at the development concept paper (DCP), stage to achieve this infrastructure by the time the aircraft is operational. Still, the cost of introducing these systems should not be borne entirely by the new fighter, since the benefits will be widely shared with other new and old aircraft. On the other hand, if a new fighter is committed without an ICNI and its infrastructure, great difficulties will arise in deploying such an advanced system—which at its inception will benefit no important group of aircraft.

Navigation for Air-to-Air: Although accurate navigation may not seem important for air-to-air combat, this is misleading in at least one aspect. The aircraft that can maneuver in three dimensions near the ground—even in partial cloud—without fear of collision with the terrain has a real advantage over his opponent. A digitally stored terrain map, together with a computer-directed or computer-performed pullout, can provide this advantage even during hard-maneuvering combat. Further, the operational advantages offered by such a system, which can bring the aircraft back all the way to the landing pattern without requiring a change to local navigation or control, simplify the pilot's job.

2.4 Airframe

As discussed in section 3 on development strategy, it appears desirable to defer decision on details of airframe design pending the results of further study and prototype testing. It is particularly, the pilot's reactions to various capabilities which are needed from such tests; open questions being the utility of maneuvering flaps, the combat effectiveness of a guided gun, the relative desirability of various head-coupled displays. The guided gun and the head-coupled avionics can be tested in current aircraft, but sizing of maneuvering flaps, sizing engines vs. fuel flow, reduction of trim drag, and, most important, a choice between equally plausible configurations on the basis of demonstrated handling properties calls for a competitive prototype program. The design characteristics outlined in the present section are only intended to indicate what are currently considered to be trends and likely areas of choice for various portions of the system. We have tried to indicate where there may be important feedback from tests, studies and subsystem development that have major effects on the total system.

2.4.1 Airframe and Propulsion Performances: T/W, W/S, Size, Handling, Range/Payload: The airframe and propulsion system should produce a high acceleration and maneuvering capability and excellent handling characteristics. For maximum maneuverability, thrust-to-weight ratio (T/W) should be high, and wing loading (W/S), low. The specific values of T/W and W/S should be the object of intensive study and testing prior to the final decision on airframe design. In order to maintain equal maneuverability, for each additional pound of armamant the takeoff gross weight must increase by a factor that may range from 5 to 11 as the required maintained "specific excess power" increases from 800 to 1000 feet per second.[4] Tentatively, an airframe/propulsion-system combination with a T/W of the order of 0.9 (maximum thrust, sea-level static condition at design takeoff gross weight) and a W/S of the order of 80 pounds per square foot appears desirable for a platform launching ordnance like that currently available (i.e., fixed guns and missiles of the Sidewinder/ Falcon/ Sparrow generation); but the optimum W/S may well be higher for the improved ordnance discussed here. An aircraft in the 40,000- to 45,000-pound size range would appear suitable to meet Navy and Air Force requirements for radius, spotting factor and performance.

Since the agility required of the airplane in combat maneuvering is, to some extent, a function of the agility and field of fire of the ordnance, and since beyond a certain point increased agility becomes very costly, the study of aircraft performance requirements should take into consideration the performance attainable with advanced design guns, missiles and fire-control systems. It is important to recognize that the added system agility provided by flexible ordnance may be a supplement to, rather than a replacement for, airframe agility. Considerable agility is necessary to close on an enemy or to avoid dangerous positions with respect to enemy fighters. However, the flexible ordnance and fire-control system we propose will create an aircraft whose tactical superiority is much more stable against the growth of Soviet air-to-air capabilities than would be an aircraft using normal displays and armaments. It will be difficult to match the maneuvering capability of a short-range Soviet fighter in a U.S. fighter that must fight at a distance of hundreds of miles from home base. However, the maximum practical degree of aircraft agility that can be achieved in an aircraft of the proposed size should be sought, both to provide a suitable launch platform for offensive ordnance and to permit successful defensive maneuvering when under attack by enemy weapons. Final determination of the desired airframe and propulsion performance should be based on overall system performance in both offensive and defensive situations.

Among the most highly desired characteristic of a close-in air-to-air fighter is high turning rate at low speed. Since low wing loading induces penalties in range and maximum speed, we feel that intensive effort should be placed on maneuvering flaps, rapidly deployable during combat, to permit the aircraft to benefit from high agility but not to suffer, to the normal extent, a low wing-loading configuration at all times.

[4] At 10,000 feet altitude, 1 g, and Mach 0.9.

The ability of a combat aircraft to fully exploit its acceleration and maneuver potential in combat is critically dependent on its handling characteristics. Unfortunately, trying to ensure good handling characteristics involves much more than selecting between features which can be specified by thrust-to-weight ratios or wing loadings or by the type of data presented in preliminary designs or proposals. Importance must be attached to the past performance of design organizations in this connection. In addition, it is important that the iterative sequence of design, wind-tunnel testing, flight testing, and final design freezing allow for maximum handling performance to be achieved.

Range/payload performance should be based on the required radius for fighter sweep and escort mission in an air-to-air combat configuration.[5] An unrefueled radius of 400 nautical miles on such missions is a minimum; a longer radius would be desirable. The mission radius required for air-to-ground operations by other fighter-bombers or attack aircraft should provide the basis for determining mission radius for this fighter, but there should be no design requirement for any specific air-to-ground mission radius for the fighter itself. The appropriate time allowance for fuel consumption at maximum thrust during combat should be an object of detailed study, along with the study of aircraft and ordnance system performance.

2.4.2 Airframe and Propulsion Performance: V_{max}: A V_{max} capability of Mach 2.3 would most likely be adequate for all tactical air combat situations. Speeds higher than this in fighter aircraft can only be achieved at altitudes greater than 35,000 to 40,000 feet. Once combat is joined in a close-in encounter, speed and altitude tend to decrease rapidly to transonic or high-subsonic speed and altitude, below 20,000 feet. However, a higher speed of, say, Mach 2.8, could be useful in situations where it is desired either to force an engagement on, or to disengage from, an enemy at high altitude. This is particularly true if the enemy has a V_{max} of Mach 2.7 or 2.8, as has been forecast by the Defense Intelligence Agency for advanced Soviet tactical fighters.

Starting with a design possessing high maneuvering and accelerating potential at speeds between Mach 1.5 and 2.0 the changes required to raise the top speed to Mach 2.5 to 3.0 might not represent a large relative increase in the total system cost—provided that only the aerodynamic and propulsion capability for sustained flight at the higher speed range were added. Of the total combat sorties flown, only a

[5]It would appear appropriate to base radius-performance calculations on the assumption that external fuel is used prior to combat.

small fraction might be required to spend significant time at maximum velocity this fraction might then rely on refueling support. It would not be necessary or desirable to design the structure for a high limit load factor at top speed, nor to design engine inlets of the size and sophistication required for efficient cruise at top speed.

A high V_{max} should not be sought at the expense of features desirable for close-in combat at speeds around Mach 1.0 and less. Such features as cockpit visibility and maneuvering potential at lower speeds, for example, should not be sacrificed. Nor should the frontal area required for adequate radar antenna size and flexible gun installation be compromised. On the other hand, it would be reasonable to accept poor cruise efficiency and a lower limit load factor at V_{max}. It would be useful to have a study of the practicability and total system costs—including possible credits for increased corrosion and fatigue resistance of titanium structure over aluminum—of a fighter designed for efficient air combat operation up to Mach 2.3 but with an emergency capability for higher speed operation.

2.4.3 <u>Other Airframe Characteristics</u>: The airplane should have excellent visibility from the cockpit, should incorporate vulnerability-reducing measures such as armor, backup control systems, and fire-suppressant material and the general design with regard to component arrangement and materials should be guided by considerations of survivability. Provisions for in-flight refueling and low-drag carriage of external stores should be included.

2.4.4 <u>Propulsion System</u>: Studies by the Air Force, Navy and industry appear to have agreed that engine development is one of the pacing items for the overall system. They also agree, within a fairly close range, as to the major engine characteristics desirable, namely, an engine with about 20,000 pounds of thrust and a bypass ratio of about 0.9 to 1.25. The Task Force recognized that some risk of obtaining a nonoptimum engine is attendant upon starting engine development prior to airframe finalization, but feels that the risk is acceptably low and the penalties for nonoptimum design would be acceptable. Therefore, the Task Force recommends that development proceed immediately on a turbofan engine of the 20,000 pound thrust class, with bypass ratio and other design features to be jointly determined by the Air Force and the Navy within a time period that will not cause delay in engine preliminary flight rating test (PFRT).

2.4.5 <u>General Design Philosophy</u>. The design should be oriented toward simplicity of operation and maintenance. This does not necessarily mean simplicity in design or construction. On the contrary, a great deal of sophistication should be employed in the design of controls, switching arrangements, and displays to aid the pilot in his tasks of flying and fighting; and all subsystems should be carefully engineered for survivability and for ease of maintenance, test, replacements, and repair in the field. The Department of Defense would be making a tragic mistake if it did not recognize that new weapons and a new type of avionics integration are essential to the success of a new fighter.

A systems designer always has to balance the desire for some residual weapons effectiveness, when some damage or failure has been suffered by the aircraft or its system, against the difficulty of training the crew to operate in all kinds of degraded modes. The Task Force recommends that no provision be made for mission completion in the case of failure of the total computer system, or of other major damage, but that great care be given to incorporate the ability to "get home" safely in case of almost any single (and most double) failures. The aim is for the aircraft functionally to appear the same to the pilot, so long as he is expected to complete the mission, and for him to abort the mission in case of failure, rather than to continue with diminished effectiveness.

2.5 Command and Control

It is likely that no completely adequate IFF will be available for these fighters at IOC. Experience in North Vietnam shows the tremendous advantage occurring to the side with adequate IFF and GCI. If AWACS is to be committed to full-scale development, the new fighter must be equipped with convenient, secure voice and data link in order to make use of the new capability of theater control and to recover some of the advantage which is provided to the enemy by his ground-based radars and GCI. It is difficult to overstate the increase in capability which AWACS could provide in the absence of effective jamming, not only as a result of its own radar but also by virtue of its serving as a tactical intelligence and communication center. Granted that the new fighters will sometimes operate independently of AWACS, they should be equipped to make good use of its availability.

3. STRUCTURE AND MANAGEMENT OF THE DEVELOPMENT PROGRAM

In order to minimize program costs and to have a high assurance of meeting schedules and requirements, the Task Force recommends a considerable departure from recent aircraft development procedures. In brief, we recommend the initiation of two or more competitive airframe demonstration programs, each of which is intended to result, after 18 to 24 months, in the existence of three demonstration aircraft. The Task Force notes that these aircraft would have government-furnished present-generation engines which could be heavier and larger than VFAX/FX production engines; the airframes could be made with "soft" tooling and would thus have a heavier structure than a production-tooled airframe, but aerodynamically they could serve as a baseline for small projections by the contractor as to the performance of a full-production new-generation fighter.[6] Engine/airframe matching is a considerable problem in new aircraft, but the use of podded engine designs can reduce this to manageable proportions.

The Services should also fund three competitive full head-coupled avionics and weapons demonstration programs using government-furnished present-generation aircraft so that a baseline of technology and of contractor capability may be established. After some 30 months, the full development and procurement selection may be made among the airframe and among the avionics contractors, for separate Air Force and Navy fighters or for a single aircraft in two variants; but this selection would be made on the basis of demonstrated performance and slight extrapolation, and not on the basis of a paper proposal.

Assuming a reasonably competent selection mechanism, this procedure has the further advantage of:

> The contractors know that a full development and procurement contract is likely to be awarded on the basis of demonstrated

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[6]People with extensive aircraft experience have objected to the Task Force that an airframe prototype cannot usefully be flown with an engine different from the one it eventually will carry. We still do not understand how, on the contrary, it is possible to design and produce airframes to work with only the specifications of the new engine and also how such airframes then can accept much different, improved engines. On the other hand, equally experienced people have supported the thesis that airframe prototype development and test can be done very profitably with current-generation engines.

in air performance and not on the basis of either radical promises or extreme conservatism in the paper proposal. Thus, the contractors will make every effort to demonstrate their performance within schedule and to build the very best system they can during the 2-year period. They may understate their costs; but, even so, should themselves have a sound idea of the cost of the full-scale program on which they will then bid.

We emphasize that we do not believe that the usual 6- to 9-month contract-definition phases give the contractors time to demonstrate with any confidence, even to themselves, what they will be able to do and an honest contractor will bid an unduly conservative system because of this ignorance. If this period is to require an airframe contractor as prime to obtain commitments from avionics and weapons contractors to a level of assurance and detail sufficient for the prime to commit himself to the government, then no improvement in avionics and ordnance capability can be expected, although there is in fact much feasible with high assurance on a 1974-1975 IOC time scale.

SUGGESTED STRUCTURE OF PROPOSED

FIGHTER DEMONSTRATION AND DEVELOPMENT PROGRAM

	July 1968	June 1970 to March 1971	June 1971	January 1974
Airframe	Let two or more contracts, each for three flight demonstration aircraft.	Test demonstration aircraft. Prepare specifications and bids.	Award airframe contracts.	Production aircraft available.
Engines	Let two contracts for common engine.			Full production engines available.
Avionics	Let three contracts for full avionics flight demonstration suits.	Test-fly avionics. Prepare specifications and bids	Award avionics contracts.	Early avionics available. Full production in twentieth aircraft, June 1974.

The proposed "fly-before-buy" program is economical, because it allows iteration, modification and improvement of the airframe in the soft-tooled rather than in the high-production phase. It combines technical and management aggressiveness on the part of the contractors with assurance for the government, since the program is a failure only if all three of the airframe or all three of the avionics programs miss their targets, e.g., an assurance of 89 percent if a single airframe—avionics—engine contractor were chosen from the beginning.[7]

Further, we firmly believe that in this type of competitive demonstration program the contractor will keep his best people on the job, and the evaluation will be easier and more reliable than for a paper proposal.

The airframe demonstration programs could cost $60 million per contractor, and the avionics demonstration programs, perhaps $30 million each, although these estimates are at best a guess. The contractors not selected for production will in any case prove to be a resource for the future, but even if the effectiveness of the aircraft built is increased only 3 percent by this procedure, or its cost reduced 3 percent, the demonstration expenditures will have been fully recovered.

Until CY 1970, there seems to be no fundamental reason to require separate Air Force and Navy system project offices (SPOs), but we frankly cannot see a mechanism to enable the Navy and the Air Force to work effectively together. It will cost more but probably give better results to have two airframes and two avionics demonstration contracts from each Service—with, however, the possibility of production for any Service by any contractor.

If the program initiation must be delayed because either lack of funds or lack of understanding of the place of new fighter aircraft in the force structure, we plead the urgency to begin the avionics/ordnance competitive demonstrations, since this is the most critical item and since improvements here could also be available to existing aircraft programs.

There is a serious question regarding the integration of the airframe, avionics and engine full-scale development programs. Three possibilities are evident: prime responsibility for such integration might vest with the government, with the airframe or with the avionics

[7]Assuming engine development programs with 80% (each probability of success).

contractor. Probably the government is not a realistic possibility, and choice between giving integration responsibility to airframe contractor or avionics contractor could be made on the basis of their bids on a separate integration contract.

4. THE NEW FIGHTER IN AIR-TO-GROUND OPERATIONS

4.1 The Spectrum of Targets for Attack by Air

Experience shows that a new fighter, like most other types of aircraft in the past, will be used to deliver ordnance on ground targets. The risks to aircraft in this role and the resulting attrition make it worthwhile–if only even just for the preservation of our air-to-air forces—to invest as much money as is useful in air-to-ground capability for these aircraft, provided that the overall air-to-air effectiveness is not significantly reduced. Still, there is no reason to waste a very expensive fighter aircraft on a ground target which with some foresight can better be attacked by other means. A surprisingly large fraction of the targets do fall in this category, for example:

1. Fixed, prebriefed targets—these can be attacked by a low-altitude cruise missile with accurate navigation and remote optical terminal guidance.

2. Close-support targets—where the ground troops have more accurate knowledge of enemy positions than does the pilot, these can best be struck by a bomb or unguided rocket delivered into a several-mile acquisition "basket" at high altitude; the weapon then homes to hit either a laser-illuminated spot or an artillery-emplaced microwave beacon.

A per sortie attrition rate of 1.7 percent—such as we are experiencing in attacks on Hanoi and Haiphong—on a $3-million aircraft, including attrition on its perhaps $5 million 10 year O&M in case attrition aircraft are bought and maintained is some $130,000 per sortie, so that an advanced weapon like Walleye could be well worth its cost in reduced attrition even if it required as many sorties for target destruction as do iron bombs. Thus, an important part of the air-to-ground effectiveness of a new fighter will come from the foresight to include adequate displays, pylon wiring, etc., to use the most effective existing ordnance and to provide flexibility to incorporate new ordnance as it is developed during the life of the aircraft. The inaccuracy of gravity bombs is a classical problem: Level bombing from high altitude requires good navigation and a knowledge of ballistic wind; low-altitude level bombing requires good target location (especially altitude), and is limited by the need to remain ∿ 2,000 feet above the target to avoid bomb blast; the use of low-altitude retarded bombs reintroduces wind errors and at present constrains the attack altitude; dive bombing is limited by the necessity to release at long slant ranges in order that the aircraft achieve in 2,000-foot separation from the target (e.g., at 500 knots, 3-g pullout, a slant range of more than 4,500 feet is necessary), thus introducing dispersion due to angular misalignments, etc. A missile guided to impact has no such long free-fall time to magnify the initial errors, and for this reason we put great stress on such homed missiles or bombs.

4.2 Other Urgent Developments

With regard to the FAX air-to-ground performance it is most important to recognize (and act accordingly) that the 7 years or more which are required to obtain this new aircraft are adequate at the same time to develop and produce those missiles and marking techniques and systems that would provide alternatives of lower cost and greater effectiveness than would be possible with conventional aircraft attack. These items can also contribute to the capability of the fighter itself. These systems should be committed now and include:

1. A general-purpose low-cost accurate navigation system—either range-range satellite or LORAN, self-contained or retransmission for external computation—suitable for high-accuracy cruise-missile attack.

2. Single-frame long-range TV relay from missile to directing craft or center to allow a further unique target designation within the few-hundred-foot accuracy obtainable from a high accuracy navigation approach. With an accurate navigation system, 500 to 1000 lines of TV resolution is ample for target recognition and designation.

3. A hitting, nonreusable cruise missile taking advantage of (1) and (2) and with emphasis on low cost and simplicity of use. The World War II V-1's propulsion should be considered among others.

4. A line of artillery-emplaced microwave beacons, ground and airborne laser target designators should be committed to development and production, as well as a compatible set of bomb-mounted sensors, guidance fins and flexible proximity fuzes to be attached to existing and new bomb bodies as they enter the inventory.

5. Directed, unmanned reconnaissance and target designation: Starting with the present Navy SNOOPY (DASH conversion),

a lighter and cheaper helicopter platform mounting TV, single-frame camera and laser target designator would immensely increase the security and effectiveness of our ground forces and their aerial support.

In addition, there will always be a demand for more kill effectiveness per sortie, and expanded development effort will be necessary, e.g., on proximity-fuzed, air-opening dispensers for use with beacon- or laser-homed guidance; on cost-reduced bomblet land mines for interdiction that effectively convert the vulnerable area of a truck on a road from a few square meters to a strip a few meters wide by a hundred meters long; etc.

The Task Force urges that these developments be committed. Our recommendations of the air-to-ground capabilities for a new fighter and for its employment are based on the assumption that such alternative systems will exist and be used by the U. S. in the 1975 time period. Realistic, and vigorous tactical testing to guide development and improvement is necessary in all these programs. Particularly when there must be interaction among different elements, as between ground forces and air support in "direct air support" or between reconnaissance and strike in prebriefed target attack, this link must be realistically exercised and its performance monitored from a higher level if the capability is really to exist in fact when it is needed.

4.3 On-Board Equipment

4.3.1 Radar: At present it seems that a high- and low-PRF radar is necessary for good MTI in the air-to-air role, but the cost, weight and complexity of electronic scan hardly seems warranted for air-to-air alone, compared with a monopulse tin-dish, mechanically scanned radar. However, if the aircraft is to survive in a SAM hostile environment and if it hopes to be undetected at night, it must be equipped to fly at low, and ground-conforming altitude. Naturally, MTI in Soviet ground radars will become much more common in 1975+, and terrain masking may be the only benefit of low flight. Terrain following is now done with success by the A-6A and the F-111A, in the latter by the use of two identical redundant radars. We recommend that the new air-superiority fighter not be equipped with a terrain-following function. If the new fighter is even so, to have terrain-following radar, the Task Force agrees that this mode should be obtained, together with the air-to-air and air-to-ground modes, from a single electronically scanned radar (probably phase-phase) which might, however, still be mounted in gimbals to achieve a cheap bias or larger look (not scan) angle, or greater gain at large off angles, than is possible with an electronically scanned flat-plate array fixed to the airframe.

However, terrain following radar is in our opinion neither the only nor the best terrain following means, and we propose that the new aircraft programs consider the following system—a redundant, high-accuracy radio-inertial navigation system (Loran C-D for one radio element and a satellite range-range system for the other), together with a stored terrain map of the entire theater of operations. At low altitudes the sequence of radio-altimeter readings, together with the terrain map, provides either confirmation or a third high-accuracy navigation system (like TERCOM), but the key point is that terrain following can now be done passively—except for the radio altimeter, which itself is not necessary with a satellite navigation system giving accurate altitude as well as position—and without the weight, space, cost and ECM penalties of terrain-following radars. Considering reasonable (say, 2-g) acceleration limitations in terrain following, as well as navigation accuracies $\sim$ 200 feet, an adequate terrain map could well consist of the maximum altitude in every 1,000 square feet, i.e., 36 altitudes per square nautical mile, or on the order of 2×10^6 numbers for a country the size of Vietnam. Such a system would lend a great deal more confidence than the terrain-following radars, and the pilot would have continuing verification of its correctness but, it would, of course, have to be supplemented by an adequate capability for satelliteborne or airborne radar terrain-mapping—an effort that seems well worth the investment and could be completed on the same (1975-) time scale.

In sum, we recommend for a new fighter a monopulse, low-high-PRF, mechanically scanned tin-dish radar, with terrain-following implemented via the combination of stored terrain map, redundant radio-inertial navigation system and radio altimeter. If, on the contrary, terrain following by radar is chosen, then we believe it would be preferable to go to an electronically scanned array without separate terrain-following radars.

As for the choice of radar frequency between X and K_u bands, there is much more to gain by appropriate pulse compression and doppler processing than by a simple drive toward shorter wavelength. In any case, cross- or reverse-circular polarization is necessary to combat precipitation return—and especially so in K-band. We note, however, that the ground-map resolution usually desired is redundant to good navigation and target-location accuracy, and that these resources can probably better be put into improved standoff (synthetic-aperture, side-looking radar) reconnaissance sensors, either satelliteborne or high-altitude airborne, than into fighterborne equipment that repeatedly verifies that the mountains or coastline have not moved. We are further led to comment that, in the search for improved MTI against either ground or aerial targets, pulse compression seems to have been somewhat neglected as a tool, yet pulse-compression ratios of 100 to 300 or so are easily and cheaply available and result in an improvement in subclutter visibility by some 20 db or more in comparison with the uncompressed pulse. Naturally, this narrower effective pulse width requires more storage in the MTI filter bank, but such storage is less expensive now.

4.3.2 Navigation for Air-to-Ground: As previously discussed under Radar, an accurate radio-inertial navigation system allows automatic terrain following of a quality previously unknown and at little additional cost. The terrain-avoidance feature, of course, permits flying automatically on a prebriefed flight plan and leaves the pilot free and alert for reconnaissance, self-defense or emergencies. Further, the navigation computer-control system can begin a "pop-up" and even complete a blind delivery against a prebriefed target, or against one designated on radar, or by a flexible, probably helmet- or eyeglass-mounted, sight allowing blind delivery accuracy of a few hundred feet, with gravity bombs but, more importantly, putting the aircraft and the pilot in a position to better define the target, to take precise navigation fixes, or to launch homing weapons upon it. It is no simple matter in combat to time a pull-up and descent so that there is any proper release point in the pullout; and a computer-directed or -performed maneuver will make more sorties count, and with less time in the target area.

The radio-inertial navigation system proposed for the terrain following role would have the accuracy and flexibility to do these jobs.

4.3.3 Weapons-Delivery Computer: The functions to be performed by a weapons-delivery computer seem not to be sufficiently different from those needed in the navigation control computer to require a separate computer or program. In the air-to-air case the computer will have to guide the gun to an aim point calculated from the navigation system and the tracking radar or optical tracking data. It would store and use ballistics data for air-to-ground attack, compute missile firing envelopes and guide the pilot to a position within the envelope if he finds himself outside it. There seems no requirement for a separate stores-management system.

However, it would be foolhardy, to rely entirely on a single, nonredundant computer. Mean time before failure (MTBF) is surely not an adequate measure of probability of perfect performance in a single mission, since internal redundancy, on-line spares and other concepts can give a single computer with an MTBF of 1 year much greater than the simple 99.7-percent probability of finishing its first day without failure. Still, a prudent course would be to plan to install two identical computers, one as a backup, with high reliability in each, until such a point in the program at which it is demonstrated that a single computer, and its associated maintenance plan, will provide adequate assurance.

The computer will also be required to serve as a flexible exchange between various tracking and slaving systems—else n such systems will require n^2 interconnections, rather than the n necessary if a central exchange is used. For instance, helmet- or eyeglass-sight angles will have to be accepted by the computer and used to aim guns, direct the radar, aim a TV recognition system, or simply update a navigation system.

4.3.4 Displays: The Task Force notes the continual conflict between field of view and resolution, and observes that this conflict is eased if one has only a single such display, which can then be made larger in subtended angle of the pilot's vision. This display must then be switchable rapidly, with memory of preset adjustments among its various sensors and functions. Clearly, at least a scan converter is required, but a single display presents vulnerability and reliability problems and still does not provide the natural vision combination of large field of view (at least ±60 degrees), good resolution (probably 1/2 milliradian in the fovea), and convenient scan. As discussed under the air-to-air mission, the head-mounted display and coupler–if it can be made sufficiently convenient–will provide the resolution, peripheral vision and convenient target designation which are needed in a high-performance aircraft. Large display tubes can then be eliminated from the cockpit, and spare helmet-mountable displays carried in order to eliminate the possibility of loss of display.

In the air-to-ground role, the display can be used with the high-accuracy navigation system, the computer, and the TV recognition system slaved to the briefed target position to allow the pilot to see the target at greater ranges and with more magnification and contrast than would be possible with the eye. For night attack, a low-light-level TV can supplement the TV recognition system; the navigation-computer drive allows compensation of aircraft forward speed in the expected region of the target and so reduces image smear and loss of contrast.

In general, this air-to-air fighter could be a very considerable air-to-ground machine for day and night work. It could fall short of the ideal air-to-ground aircraft because of the substantially greater cost per pound of the highest performance aircraft and the penalty in performance—hence, weight growth at constant performance—that would be caused by the addition of frontal armor, etc., to reduce attrition from small-arms fire.

5. SUMMARY

If the new fighters are designed with imagination and foresight, the incorporation of an excellent penetration and air-to-ground delivery capability will cost very little beyond what is required for what we regard as necessary for best air-to-air effectiveness. However, homing missiles, target-designation beacons, new area munitions, effective land mines, etc., should compose the payload, since even an 0.5-percent attrition on the aircraft would be extremely painful, especially if its average sortie did no effective damage. Further, serious commitment must be made to a head-coupled avionics system and display, if it proves feasible, and to advanced weapons to go with it for the air-to-air role, if we are to achieve real air superiority over enemy fighters.

A real problem we see in dual utility of the aircraft arises from our feeling that air-to-air training is a full-time job for the crew; and they either slight air-to-ground or they are not so superior air-to-air as they might be against an enemy who cannot afford to train as much as we can. We regard this as a very serious problem, which would be eased by the devices proposed here.

The elements of the avionics and weapons system that the Task Force proposes fall into two categories:

A. Programs that we regard as already demonstrated in hardware or by analysis to such an extent that we believe that firm planning can proceed to incorporate them into the fighter system. In this category fall:

A-1. The head-coupled sight, to which can be slaved both the radar illuminator for the semi-active missiles and the missile seekers themselves, radar, infrared or electro-optical.

A-2. Flexible missiles, locked-on at large off-angles before launch and not so simple that they boost to maximum speed before guiding.

Other systems and questions fall into Category B:

B. Programs that have a less firm foundation in hardware demonstration or analysis, but that we believe are feasible on the new fighter-development time scale and that will increase the system effectiveness by factors of 2 or more. Among these programs are:

B-1. A forward-firing guided gun, slaved via a computer to the radar tracker or, as desired, to the head-coupled sight, or to the electro-optically tracking TV system. This gun, guided in elevation to $\sim +20$ degrees and in azimuth perhaps ± 2 degrees, could double the effective maneuverability of the fighter in offensive air-to-air operations.

B-2. A stabilized, electro-optically tracking 2- to 10-power TV recognition system, initially slaved to the radar tracker, in order to do visual identification at longer range and over a wider solid angle than is possible with the unaided eye.

B-3. The combat utility of V_{max} = 2.8 Mach rather than 2.3 or 1.8.

B-4. The tradeoffs involved in the incorporation of transsonic maneuvering flaps.

B-5. The optimum time allowance for combat at military power or in afterburner, taking into account the expected performance of the avionics/weapons system proposed.

B-6. Full head-coupled display, replacing head-up display radar indicator, TV display, horizontal and vertical situation display and perhaps some flight-instrument indicators.

B-7. Rearward-firing guided guns.

B-8. Rearward-firing self-defense missiles.

B-9. Rearward-looking warning and tracking radar to allow antimissile and antifighter action.

B-10. A full investigation of the feasibility of high-quality terrain following by precision LORAN-inertial or satellite radio-inertial navigation, coupled with a digitally stored terrain map of the theater of operations.

In addition to these fighterborne equipments, the other urgent non-aircraft programs of section 4 must be funded on the same time scale.

6. OVERALL PROGRAM RECOMMENDATIONS

1. It is recommended that a development program, following the basic approach of prototype procurement and testing, be initiated now for a new fighter aircraft. An IOC for the early 1970s—i.e., before 1975—should be sought. Competitive prototype flight programs should be pursued separately for avionics, for airframes and for engines.

2. The fighter should be designed for both air-to-air and air-to-ground operations, with the primary design emphasis on air-to-air capability. The air-to-air capability should include close-in combat capability. The air-to-ground capability should be for primarily visual weapon delivery with homing or area ordnance insofar as autonomous aircraft operations are concerned.

3. Guided (i.e., steerable) guns and highly agile missiles should be provided for forward-hemisphere firing, unless flight tests reveal basic flaws in the concept. Missile seeker, propulsion, airframe and target designation should provide for firing missiles at large angles off the aircraft nose. Rear-hemisphere ordnance should be investigated, tested, and incorporated in the design if found desirable on grounds of utility and performance tradeoffs.

4. Head-coupled sights and display should be used to eliminate the gunsight, radar display, TV display, heads-up display, etc., and to provide at the same time flexible all-angle TV viewing and target designation.

5. The avionics should incorporate a pulse-doppler radar with low-PRF mode for ground map, but without either electronically scanned phased-array or separate terrain-following radars. A redundant central digital computer should couple the displays to the weapons, manage stores, and do the computations required for flexible weapons delivery.

6. DDR&E should review those development concept papers for systems that might be available before or about 1975, to provide planning guidelines for synergistic systems rather than to allow each 7-year advanced system to assume the environment as it was at the beginning of the development cycle.

7. Urgent development commitments should be made to:

a. navigation systems providing terrain avoidance by navigation,

b. single-frame TV for remote target designation and homing,

c. simple, hitting, surface-to-surface cruise missiles,

d. artillery-emplaced ground and airborne target-designating schemes for homing bombs,

e. directed, unmanned reconnaissance and target-designation

f. effective and flexible air-to-ground ordnance, as described in section 4.2.

8. Development should proceed immediately on a turbofan engine of the 20,000-pound thrust class, with bypass ratio and other design features to be jointly determined by the Navy and the Air Force.

APPENDIX A

DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D. C. 20301

17 May 1967

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Defense Science Board Task Force: Tactical Aircraft

Both the Navy and the Air Force have expressed a need for new tactical aircraft to meet the postulated threat and to fill existing gaps in the force structure relating to air superiority by air-to-air combat and to the air-to-ground attack mission.

It would be of value for the Board to examine both the air-to-air and the air-to-ground missions. Some specific questions and comments are given below, but the Board should not feel limited by them. The air-to-air problem should receive priority.

1. Air-to-Air: The air-to-air question might be simply stated as follows: which is the route of greater promise for achieving superiority over the Soviet Union in air-to-air combat— a) emphasis on speed and maneuverability in the aircraft, or b) emphasis on maneuverability and firepower in the missile? Consideration should also be given to the identification problem, type(s) of weapons and avionics, development costs and risks for alternative approaches, and the stability of any solution against Soviet growth.

2. Air-to-Ground: Means of improving the air-to-ground mission effectiveness should be considered. Of particular interest is the balance between use of a sophisticated delivery system for conventional ordnance and use of guided weapons. The study should include analysis of the spectrum of ground targets to be attacked and the most appropriate weapon to counter them. In this regard it will be useful to have a brief analysis of the achievements of our air-to-ground operations in Viet Nam. The recommendations should include a rough division of development and procurement costs between avionics, airframe, propulsion and weapons.

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Consideration should be given the requirements for one man or two men to accomplish both missions.

These problems are urgent and I would appreciate as rapid a response as practical. To be most useful your report should be submitted by 15 September 1967.

I have asked Mr. Fowler to be the cognizant deputy, and he will make available whatever staff support is necessary.

/s/

John S. Foster, Jr.

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APPENDIX B

Meeting Schedules of DSB Task Force on Fighter Aircraft

13-14 June 1967

Date	Time	Subject	Responsible
13 June 1967	0900-0945	Executive Session	
	0945-1045	Air-to-Air and Ground-to-Air Threat	Navy
	1045-1145	Tactical Aircraft Force Structure	Navy
	1145-1245	Lunch	
	1245-1345	Air-to-Air and Air-to-Ground Requirements	Navy
	1345-1445	Advanced/ Engineering Development Programs/ Test Programs	Navy
	1445-1545	Study Subjects	Navy
	1545-1645	Air-to-Air and Ground-to-Air Threat	Air Force
14 June 1967	0900-1000	Tactical Aircraft Force Structure	Air Force
	1000-1100	Air-to-Air and Air-to-Ground Requirements	Air Force
	1100-1200	Advanced/ Engineering Development Programs/ Test Programs	Air Force
	1200-1300	Lunch	
	1300-1400	Study Subjects	Air Force
	1400-1600	Executive Session	

11-12 July 1967

Date	Time	Subject	Responsible
11 July 1967	0800-0900	Reference material made available	ODDR&E
	0900-1000	Executive Session	
	1000-1100	Tactical Aircraft	Air Force, Dr. Flax
	1100-1200	One-Man vs. Two-Men Concepts	Air Force
	1200-1300	Lunch	

Meeting Schedules (continued)

Date	Time	Subject	Responsible
11 July 1967 (continued)	1300-1400	Performance of FX/ VFAX/ AX	NASA
	1400-1445	Engine Performance	General Electric
	1445-1530	Engine Performance	Pratt and Whitney
	1530-1630	Tactical Missiles	Navy and Air Force
	1630-1730	Air-to-Air IFF Review	DSB, Navy and Air Force
12 July 1967	0800-0900	Reference material made available	ODDR&E
	0900-1100	Radar/ Avionics Review	Navy and Air Force, Mr. Longbrake & Mr. Francis
	1100-1200	Air-to-Air and Air-to-Ground Missiles	Hughes Aircraft Company
	1200-1300	Lunch	
	1300-1400	Tactical Aircraft	Navy, Dr. Frosch
	1400-1500	Air-to-Air and Air-to-Ground Missiles	Raytheon Co.
	1500-1600	Discussion of material presented	
	1600-1700	Planning for next meeting	

17-18 August 1967

Date	Time	Subject	Responsible
17 Aug 1967	0800-0900	Executive Session to discuss study reports	
	0900-0930	NATO/ Warsaw Pact Study	OASD (Systems Analysis), Mr. Sprey
	0930-1030	Lesson Learned from A-6A	Syracuse Univ. Research Corp., Mr. J. Rodens
	1030-1130	Project "Red Baron"	WSEG
	1130-1215	Aircraft Vulnerability Study	The RAND Corp., Mr. R. Johnson

Meeting Schedules (continued)

Date	Time	Subject	Responsible
17 Aug 1967	1215-1300	Lunch	
	1300-1400	VFAX/ FX Design Study Results	Lockheed and LTV
	1400-1500	VFAX/ FX Design Study Results	North American Aviation, Los Angeles and Columbus
	1500-1600	VFAX/ FX Design Study Results	Boeing
	1600-1700	VFAX/ FX Design Study Results	Grumman
	1700-1800	VFAX/ FX Design Study Results	McDonnell
	1800-1830	Justification and Character of the Fighter Airplane	Aerocounsel, Mr. Myers
18 Aug 1967	0800-0900	Planning for next meeting	
	0900-1000	Fighter-Pilot Panel	Navy and Air Force
	1000-1030	Status Report on Project "Combat Hassle"	Air Force
	1030-1115	Electrooptical Systems	Army
	1115-1200	Electrooptical Systems	Navy
	1200-1245	Lunch	
	1245-1330	Electrooptical Systems	Air Force
	1330-1430	VFAX/ FX Avionics	Navy and Air Force
	1430-1530	U.S./F.R.G. V/STOL	Air Force and Navy
	1530-1600	One-Man vs. Two-Men Study	Air Force

25-26 September 1967

25 Sept 1967	0800-1230	Review Draft Report
	1230-1330	Lunch
	1330-1500	Discussion with Dr. Laidlaw
	1500-1800	Review Draft Report

Meeting Schedules (continued)

Date	Time	Subject	Responsible
26 Sept 1967	0800-1200	Review Draft Report	
	1200-1300	Lunch	
	1300-1400	Review Draft Report	
	1400-1530	Discussion with Mr. Fowler, Dr. Flax and Dr. Frosch	
	1530-1800	Review Draft Report	
		24-25 October 1967	
24 Oct 1967	0800-0900	Executive Session	
	0900-1030	Current/Future Air-to-Ground Weapons	Navy
	1030-1200	Current/Future Air-to-Ground Weapons	Air Force
	1200-1300	Lunch	
	1300-1345	Current/Future Navigation Systems	Navy
	1345-1430	Current/Future Navigation Systems	Air Force
	1430-1515	Current/Future Designation Systems	Navy
	1515-1600	Current/Future Designation Systems	Air Force
	1600-1645	Current/Future Aircraft Sensors	Navy
	1645-1730	Executive Session	
25 Oct 1967	0800-0830	Executive Session	
	0830-0915	Current/Future Aircraft Sensors	Air Force
	0915-1000	Current/Future Displays and Computers	Navy
	1000-1045	Current/Future Displays and Computers	Air Force
	1045-1130	VFAX Air-to-Ground Systems	Navy
	1130-1215	FX Air-to-Ground Systems	Air Force
	1215-1315	Lunch	
	1315-1345	Tactical Command and the Hostile Environment	Navy
	1345-1600	Executive Session	

Meeting Schedules (continued)

28-29 November 1967

Date	Time	Subject	Responsible
28 Nov 1967	0800-1000	TAC Views on FX/AX/ U.S.-F.R.G. V/STOL	TAC, Maj. Gen. Graham
	1000-1100	F-111A Mark I Results	Air Force
	1100-1215	Mark II Avionics	Air Force
	1215-1315	Lunch	
	1315-1430	AX Study Results	Air Force
	1430-1615	U.S.-F.R.G. V/STOL Phase II Results	Air Force
29 Nov 1967	0800-0900	Executive Session	
	0900-1030	Executive Session with Mr. Fowler	
	1030-1200	Executive Session	
	1200-1300	Lunch	
	1300-1600	Executive Session	

5-6 January 1968

Date	Time	Subject	Responsible
5 Jan 1968	0830-1100	Executive Session	
	1100-1230	Research and Development for Southeast Asia	Air Force
	1230-1300	Lunch	
	1300-1430	Use of Drones	All Military Services, ODDR&E
	1430-1530	Discussion of SNOOPY	Navy
	1530-1630	Executive Session	
	1630-1730	Defense of Europe	OASD(SA)
6 Jan 1968	0830-1000	Multisensor Aircraft	All Military Services, ODDR&E
	1000-1030	Executive Session	
	1030-1130	LIT Program	Air Force

Meeting Schedules (continued)

28-29 February 1968

Date	Time	Subject	Responsible
28 Feb 1968	0900-1230	Executive Session to review and revise report	
	1230-1330	Lunch	
	1330-1600	Executive Session to review and revise report	
29 Feb 1968	0900-1230	Executive Session to review and revise report	
	1230-1330	Lunch	
	1330-1600	Executive Session to review and revise report	

10 April 1968

Date	Time	Subject	Responsible
10 Apr 1968	0900-1230	Executive Session with selected DSB members to discuss Task Force report	
	1230-1400	Luncheon with members of ODDR&E staff	
	1400-1600	Executive Session with selected DSB members to discuss Task Force report	

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APPENDIX C

DESCRIPTIVE SUPPLEMENT:

ILLUSTRATED EXAMPLES OF USE OF SYSTEMS PROPOSED

BY THE

DEFENSE SCIENCE BOARD TASK FORCE

ON

FIGHTER AIRCRAFT

29 March 1968

Contributed by

Homer Tasker

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CONTENTS

Table I. GUIDE TO WEAPONS AND SYSTEM ELEMENTS AND THE TACTICAL PARAMETERS OF EXAMPLES

System Example	Initial Target Position Data*	Tactical Environment	Fig. No.	Applicable Head-Coupled Techniques**	
Fixed-gun attack	Visual	Close-in air combat	3	HCS	HCD
			4	HCS	HCD
			5		HCD
Guided-gun attack	Visual	Close-in air combat	6	HCS	HCD
			7		HCD
Agile missile attack	Visual	Close-in air combat	***	HCS	HCD
	VIsual		***		HCD
Radar target attack designation	Radar	Long-range air-to-air guns free	8		HCD
Optically augmented recognition	Radar	Long-range air-to-air not guns free	9		HCD
			10		HCD
			11		HCD
Advanced homing air-to-ground weapon (e.g., Walleye)	Radar/ Missile TV	Ground attack	12		HCD

Notes:

*Visual: Aircraft position is seen visually, and target designation for attack is effected visually, i.e., without reference to a radar display.

Radar: Aircraft position is seen as a radar blip and target designation for attack or recognition is effected by means of the radar data, i.e., by reference to the radar display only.

**HCS: Head-coupled sight, i.e., optically projected reticle but no CRT display.

HCD: Same as head-coupled sight plus CRT display capability.

***Not separately illustrated; similar in essence to Figures 6 and 7.

SUMMARY

This appendix describes in somewhat greater detail than was feasible in the main body of the report the following systems, as proposed by the Task Force:

- Guided gun and control system
- Agile missile and launch system
- Optically augmented recognition system
- Head-coupled sight and display system

The discussion deals with these systems in an integrated combintion comprising the Task Force recommended head-coupled avionics and weapon system.

The wide range of applications envisioned by the Task Force for these head-coupled techniques is discussed. Descriptions of specific uses are primarily in the form of illustrated examples. A condensed guide to the weapons and system elements and the tactical parameters of these examples appears in Table I.

We realize that, in the process of implementing a workable system, many of the details will be modified as more experience is gained with the human-engineering aspects. Nevertheless, the examples given will illustrate the potential of such systems.

1. Task Force's Observation of Head-Coupled Sights and Displays

The Task Force was very favorably impressed by the progress reported by the Army and others in the development of head-coupled sights and displays and by the tactical advantages that appear to be attainable by incorporating such techniques into a head-coupled avionics and weapons system.

It seems clear that, with the head-coupled techniques, many fleeting opportunities to acquire targets that would be lost if conventional head-in-cockpit acquisition techniques were used could instead become effective opportunities for gun or missile attack. It also seems clear that head-coupled techniques would greatly reduce the pilot's work load.

Among the advantageous uses envisioned in air-to-air and air-to-ground operations, all in a head-up manner, would be the following:

- Directing a video contrast tracker for automatic lock-onto an aircraft seen visually by the pilot (whether or not seen by the radar) for such functions as aiming a guided gun.
- Directing the seeker of a short-range air-to-air missile (infrared or video contrast) for automatic lock-onto an aircraft seen visually by the pilot whether or not seen by the radar
- Pointing the radar antenna for automatic lock-onto an aircraft seen visually by the pilot but not yet seen by the radar.
- Viewing through high-magnification forward-looking (and perhaps rearward-looking) TV units to identify targets visually.
- Viewing air-intercept-radar video, and making attack designation of a selected target.
- Viewing video ground-mapping presentations.
- Viewing Walleye or other missile video presentations, and directing the missile tracking gate for lock-onto a selected target.

Viewing in a manner virtually identical to that of conventional head-up displays any of its usual presentations, including gyro horizon, heading and other flight-control data, during ground-controlled intercepts, air-to-air gun or missile attacks, etc.

As the discussion proceeds, it should become apparent that head-coupled techniques offer very wide latitude to the system designer. The particular embodiments illustrated, while not optimized, should give a general indication of the effectiveness of such techniques, both in tactical advantages gained and in reduced pilot work load reduced.

2. Technical Description of Head-Coupled Avionics and Weapon System

"Head-coupled avionics and weapon system" means the provision of a lightweight, helmet-mounted CRT display, plus devices to sense helmet orientation. Thus, the pilot's head movements are translated into coupling signals suitable for radar antenna pointing, missile-seeker aiming, designation-cursor positioning, etc.

These coupling signals may be applied to the helmet-mounted CRT in such a way that information presented by the CRT display may be positioned in accordance with the pilot's head movements so as to be realistically superimposed on his central field of vision as he looks in various directions through the combining glass and windshield. Because of such coupling from head and helmet to avionics and back to the helmet-mounted display, the latter is referred to as a head-coupled display, or HCD, during most of this discussion.

To describe the operation of the proposed head-coupled display, a comparison with the conventional head-up display (HUD) may be useful. Figures 1 and 2 illustrate the same presentation on a conventional head-up display and on the head-coupled display, respectively.[1] The subject matter chosen for this comparison consists of basic flight data (i.e., pitch, roll, heading, speed and altitude) plus data-link command flight data for a ground-controlled intercept and computer-derived "steering cursors" to facilitate flying the command data. Both HUD and HCD presentations are superimposed directly on the pilot's forward view, and both are held fixed with respect to the airframe but by quite different techniques.

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[1] A viewing distance of about 8 inches gives the proper scale to these illustrations.

The conventional head-up display (Figure 1A) effects presentation in the pilot's forward line of sight by means of optical projection from a very high-intensity cathode-ray tube onto a combining glass. This latter is mounted just above the instrument panel in the pilot's central field of vision as he looks directly forward through the windshield. In the F-111 Mark II avionics, the combining glass is large enough to subtend horizontal and vertical angles of approximately 10 degrees at the pilot's viewing distance of approximately 26 inches, or roughly one-half of that depicted in Figure 1A.

For the most part, the display symbology of these and subsequent illustrations has been adapted from Autonetics' report, One Man Crew Effectiveness Study for F-X, Contract F33657-68-C-0167. The symbology of Figure 1A can be considered representative of flight data displayed on a conventional head-up display[2] during a ground-controlled intercept.

The proposed head-coupled display, as illustrated in Figure 2, is capable of functioning in place of a conventional HUD presenting

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[2]For those unfamiliar with this symbology, Figure 1B identifies the principal elements. The central W-shaped symbol is the aircraft reference symbol. It remains in a fixed position on the combining glass independently of aircraft pitch or bank. The horizon bars, on the other hand, are aligned with the true horizon at all times and move relative to the aircraft reference symbol to register pitch and bank. Thus, in Figure 1A the horizon bars indicate straight and level flight, whereas in Figure 1B they indicate a moderate up-pitch and left-bank attitude. Two computer-generated steering cursor bars provide steering guidance for flying GCI flight commands received via data link. At the bottom of the display is an expanded heading scale. The present heading (216 degrees) appears opposite a triangular heading reference symbol, while command heading (209 degrees) is represented by a rectangular "bug" positioned by the GCI data link. In like manner, calibrated airspeed and altitude data are presented on the scales at left and right. The heading data require a left turn of 216-209 = 7 degrees from the present heading. In agreement, therewith, the vertical steering cursor bar in Figure 1A calls for a left bank. Similarly, command altitude requires a climb of 800 feet and the horizontal steering cursor bar of Figure 1A corresponds by calling for a moderate up pitch. In Figure 1B, the aircraft now has approximately the desired left bank and up pitch. When the resulting left turn and climb have brought the command-heading bug under the present-heading triangle and command-altitude bug opposite the present-altitude triangle, the steering cursor bars will be centered on the aircraft reference symbol.

exactly the same flight data in exactly the same position. In this case, however, the combining glass, the optics and the CRT are all of small size and lightweight and are supported by the helmet. The optics effectively focus the view screen of the CRT in the pilot's far field of vision as seen through the combining glass, and thus the flight data are superimposed on his forward view. The combining glass, being mounted at an angle, may be made oval in shape so as to present to the pilot's eye a circular aperture of the desired magnitude, and the optics may be designed so that this aperture closely matches the CRT view-screen area. The large circle of Figure 2 represents an aperture on the order of 40 degrees.

The coupling signals corresponding to the pilot's head movements are employed to make the presentation of Figure 2, like that of Figure 1A, appear fixed, or "stationary" with respect to the aircraft. Therefore, a small head movement such as that shown by the dashed circle in Figure 2 makes no change in the presentation.

Assume now that the pilot turns his head still farther away--for example, to get a quick glance at another aircraft. Part of the presentation will momentarily disappear from his view but will reappear when he looks back. It is as though the CRT view screen were a round window through which the flight data are fully seen when centered, or nearly centered, but are partly occluded as the window moves farther off center. If we now imagine a small circle to be fixed in the center of the round window so as to move with the window, and if, by head movement, we superimpose the small circle on an aircraft as seen by either eye (or both), the resulting helmet-coupling signals will provide a capability to initiate gun or close-in missile attacks on an aircraft seen visually by the pilot, whether or not it is seen by the radar.

This concept, as implemented by the head-coupled avionics and weapon system, can have a great tactical advantage. Several examples of its use are illustrated in section 3 of this appendix. In Figures 2 through 12, substitution of the HCD for the conventional HUD is assumed, and the usual vertical situation display is shown uppermost on the instrument panel in these figures. Actual flight experience with the HCD will allow a decision as to whether the vertical situation display and certain other instruments might be replaced by the HCD. The HCD itself is small enough that several can be carried for redundancy.

3. Tactical Applications of Head-Coupled Avionics and Weapon System

3.1 Attack Designation of Visual Targets

Situations of the type illustrated in Figure 3 frequently occur during a dogfight type of air-to-air combat, viz., wherein a hostile aircraft is seen by the pilot, although it is not presently seen by the radar. Accurate aiming of an air-to-air gun requires a director-type solution in which the computer inputs include very accurate range and angle coordinates of the hostile aircraft. While more accurate angle data can be obtained by a video contrast tracker, the range data must be radar derived, and radar angle data can be valuable for positioning a video contrast tracker prior to lock-on.

Unfortunately, in existing tactical aircraft, crucially important time (on the order of 10 to 20 seconds) can be lost by the head-in-cockpit techniques of radar-antenna scan switching and slewing to get a "search" radar presentation of the hostile target before attack designation can be made, acquisition and tracking initiated, and computing of the gun-attack solution begun. In fact, the hostile aircraft may often be lost in the process; the pilot may not be able to reacquire it visually, and thus the attack opportunity may be lost.

In marked contrast, the pilot using the head-coupled display does not lose the target aircraft because he keeps his eye glued on it; he does not miss a maneuver, because his head is out of the cockpit; and he loses very little crucial time because his whole operation of attack target designation and initiation of automatic tracking (whether radar or video contrast, or both) takes a second or two at most.

Examples of HCD Attack Designation of Visual Target

Case I—Designation and Computer Solution for Fixed-Gun Attack (Figures 3, 4 and 5): Referring to Figure 3, assume that the pilot has just caught sight of the MIG at upper left in his peripheral vision field but has not yet turned his head to look directly at the MIG. Assume that he selects the gun attack mode on his weapons-control panel because of the evidently close range of the hostile aircraft. The pilot then makes the attack target designation in two simple steps as follows:

1. Momentarily Looks Directly at the Hostile Aircraft. The pilot's gun mode selection has caused a dashed circle to appear which remains centered in his head-coupled display regardless of head motion. His natural head movement in looking directly at the aircraft enables him in a quick and almost effortless

manner to superimpose the dashed circle on all or a portion of the hostile aircraft, as illustrated in Figure 4. The diameter of the dashed circle corresponds to the acquisition area of the video contrast or radar tracker, as the case may be. The coupling signals from the pilot's helmet have slewed the radar (and the video contrast tracker, if provided) to the dashed-circle position; hence, they are ready for automatic acquisition and tracking as soon as step 2 has occurred.

2. Presses the TRACK Button. In response to this action (which can be concurrent with step 1), the logic circuitry initiates automatic acquisition and tracking of the hostile aircraft. Track initiation is confirmed to the pilot by a square designation symbol surrounding the target, which is also shown in Figure 4. Immediately thereafter, the computer supplies a fixed-gun attack solution in the head-coupled display.

The estimated time is:

Pilot effort—less than 1 second

Overall time to appearance of attack solution—1 to 3 seconds

A powerful new means of presenting a gun attack solution is provided by the head-coupled display. Instead of having to glance back and forth between the synthetic target position on a conventional HUD (or VSD) and the real aircraft in space, the pilot can now keep his eye continuously on the real aircraft and the attack solution can be brought conveniently to him.

One form of such a presentation is illustrated in Figure 5. Radar boresight has superimposed the synthetic target position (viz., the small circle at the intersection of the two steering cursor bars) solidly on the real aircraft as observed in space by the pilot's eyes. The computer steering solution places the aircraft reference symbol in the proper position relative to the steering cursor bars. Thus, the correct initial pilot response in this Case I, as illustrated in Figure 5, is to left bank and up pitch.

Case II—Designation and Computer Solution for Guided-Gun Attack (Figures 6 and 7): The pilot, even with the superior display of the fixed-gun attack solution (as just described in Case I), has a very substantial remaining task—to maneuver his aircraft into the proper lead-firing position as directed by the displayed attack solution. To achieve this firing position typically requires much maneuvering and many seconds at 1000 pounds or more of fuel per minute. Even with very high pilot skills, firing position will often not be achieved before exhaustion of the combat fuel reserve. Therefore, the guided gun, as recommended by the Task Force, provides a major tactical advantage in air-superiority operations as compared to fixed guns. In the particular combat situation of Case I, it would greatly reduce the excess fuel consumed, the time elapsed and the test of pilot skills, as will be made evident by this Case II example, which applies the guided gun to the Case I situation.

The gun is assumed to be trainable through ±2 degrees in azimuth and from -2 degrees to +18 degrees in elevation. The pilot effects attack designation of the hostile aircraft exactly as in Case I. However, the computer-generated gun attack solution, as illustrated in Figure 6, is much different. Instead of the very small steering cursor circle of Figure 5, there is now a large, rectangular allowable steering error "symbol." It is only necessary that the pilot bring the hostile aircraft, or its radar blip, within this rectangle. The obvious maneuver (shown also by the computer-generated steering cursors in this figure) is a bank to the left of about 45 degrees. Completion of this maneuver, displayed to the pilot as in Figure 7, can bring the hostile aircraft within the allowable-steering-error symbol in an overall time of 2 to 4 seconds. The guided gun will fire automatically whenever it is on target.

Case III–Designation and Computer Solution for Short-Range Air-to-Air Missile Attack: The same sort of tactical advantages obtainable via the guided gun, as compared to fixed guns, should be attained in close-in "dogfight" IR missiles as a result of planned improvement programs.

Whereas, Air Force launchings of Sidewinder in Southeast Asia have required boresight steering of the aircraft almost as rigorous as that for fixed guns, the future configurations of short-range air-to-air missiles will permit seeker lock-on at gimbal angles as high as 50 degrees off boresight.

The launching system must be capable of providing target-angle signals to align the seeker. If obtained from the radar with present display techniques, the same crucial time loss of 10 to 20 seconds of head-in-cockpit techniques is imposed upon the pilot. The head-coupled display employed as in Cases I and II, removes this limitation by quick pointing of the radar. It can go further and provide missile-seeker alignment on the target aircraft without use of the radar—for example, while maintaining radar surveillance of another sector of space. For this purpose, the pilot's procedure would be unchanged, but the helmet-coupled signals would be applied directly for missile-seeker alignment without intervention of the radar.

The computer-generated attack solution for these missiles will include an even larger allowable-steering-error symbol than that of the guided gun (shown in Figures 6 and 7).

3.2 Attack Designation of Radar Targets (Figure 8)

An aircraft whose radar replies have sufficient amplitude may be automatically detected by the computer, be interrogated for IFF response, and, if selected criteria are met, can be called to the pilot's attention by an audible alert, typically while still beyond visual range. Its radar reply, or blip, may appear on the head-coupled display as either synthetic or standardized radar video.

Assume that the solid dot at far right in Figure 8 is such a target, determined to be hostile for lack of IFF response in a gunsfree environment. The pilot may quickly make attack designation of this target using the same procedure as in Case I, II or III, respectively, except that now his head movement will superimpose the dashed circle on the radar blip of the hostile aircraft as seen in the HCD rather than on the aircraft itself as seen visually in space in the previous examples.

In case the detected aircraft coordinates are beyond the angular coverage of the HCD when the computer gives the audible alert, it can provide a special symbol, such as the open circle and arrow seen near the solid dot in Figure 8. This informs the pilot that, upon swinging his head to the right, the target in question will come into view.

3.3 Optically Augmented Visual Recognition

The Task Force has observed that a crucial identification gap exists in air-to-air operations when a gunsfree condition does not exist. Despite the values of existing IFF and the long-range detection capability of airborne-intercept radars, hostiles cannot be distinguished from other "nonfriends" until they come within visual identification range. Due to limitations of the unaided eye, visual identification of a hostile will usually occur at such short ranges that the potential advantage of long-range air-to-air missile attack is lost and the friendly aircraft is seriously disadvantaged in the ensuing combat. Therefore, the Task Force recommends incorporation of a system for visual recognition that will increase the range of visual identification to 5 or 10 times beyond that of the unaided eye. One possible implementation of such a system might be based on ATARS. The system would then comprise:

- TV camera, plus gimbaled high-magnification optics,
- video contrast-tracking circuitry for on-target stability, and
- pilot's TV display.

Whereas the small field of view of the ATARS precludes its use for general search and target acquisition, the intercept radar readily supplies the deficiency, and the head-mounted display readily provides the pilot's TV display, plus coupling interface, as may be seen in the following illustrated example:

Example of Augmented Visual Identification (Figures 9, 10, 11): Assume that the radar blip shown high and to the right in Figure 9 is a new nonfriend target that has been detected just as in the preceding example, except that a gunsfree environment does not exist. Visual identification is then necessary to classify the target as neutral or hostile. Frequently the range of the target when first detected by radar will be too great for unaided-eye identification, or even detection. In all such cases, the pilot can activate the ATARS in two simple steps as follows:

1. Momentarily Looks Directly at One of the Targets. As in the attack designation of a radar target, the pilot's natural head movement in looking directly at the selected target enables him quickly and easily to superimpose the dashed circle on all or part of that target, as illustrated in Figure 10. As before, the coupling signals from the pilot's helmet concurrently slew the radar antenna boresight with the dashed circle in readiness for automatic acquisition and tracking per step 2.

2. Presses the TRACK Button. In response to this action (which can be concurrent with step 1), the logic circuitry activates automatic acquisition and tracking of the selected radar target. As in previous examples, track initiation is confirmed to the pilot by the solid square surrounding the target, as shown in Figure 10.

In this case, however, the logic circuitry activates a video-contrast search-and-track feature of the ATARS to scan the small area representing radar coordinates uncertainty. As soon as lock-on has occurred, the pilot's display will automatically switch to the ATARS video presentation.[3] To prevent deterioration of this view by light coming through the combining glass, a small shutter is automatically positioned.

The estimated time is:

Pilot effort—less than 1 second

Overall time to appearance of ATARS picture—1 to 4 seconds. (This assumes adequate slew rates for the ATARS gimbals.)

The resulting ATARS presentation is illustrated by an example in Figure 11 showing a MIG at 5.5 miles, which illustrates approximately the quality of image obtainable from as few as 12 lines of the TV raster. By this means, visual identification can be effected at ranges up to 10 times the unaided eye's range. Meanwhile the radar can return to its previous search-scan condition, since the video contrast tracking circuitry of the ATARS will hold the TV camera optics on target until released by the pilot.

The head-coupled display can function in like manner with the recommended tail-warning radar and a rearward-looking ATARS. A zoom feature should be evaluated for ATARS, the amount of zoom possibly being controlled by radar range, when available.

3.4 Attack Designation of Ground Targets for Advanced Homing Weapon—e.g., Walleye (Figure 12)

Whereas all of the radar presentations discussed above are produced by TV rasters obtained from scan converters (such as those employed in the F-111 Mark II avionics system), the target-viewing signals of the Walleye missile (like those of ATARS) are already in TV raster form. Hence, they may be applied directly to the head-coupled display without scan conversion. In this case, as with ATARS, a small shutter is automatically positioned to preclude interference by light coming through the combining glass.

As illustrated in Figure 12, target designation for missiles of this type consists of placing a tracking gate symbol on the selected target as seen in the TV picture. Essentially, the symbol consists of a square tracking gate, or designation cursor, with extensions of the

[3] The head-coupled display can accept TV raster data directly.

sides of the square to aid the pilot in following its motion. When the pilot turns the selector switch to display Walleye-missile video in the HCD, the logic circuitry will cause this cursor to follow the pilot's head motion as he views the picture and then looks directly at a selected target point. When he has thus positioned the designation cursor, he presses the TRACK button. This activates the Walleye tracking circuitry. He may continue to monitor its operation by viewing the Walleye TV presentation.

4. Navigation-Update Designation Functions

In making a navigation update, the pilot must designate the coordinates of a checkpoint to the computer. The "slew stick" or "designation stick" function of positioning cursors on the checkpoint in the navigation display can be performed even more effectively by the head-coupled display. The techniques are essentially the same as those described in connection with Figures 8, 10 and 12. The general applicability of these techniques is evident.

5. Radar and TV Video Viewing

In connection with viewing ATARS and Walleye presentations, it was noted that a small shutter could be automatically positioned to preclude interference by light coming through the combining glass. Alternately, the shutter could be push-button controlled by the pilot. Whether activated automatically or manually, it should also be beneficial during daylight operations when making attack-target designation in a vertical situation radar presentation such as Figure 8, when viewing ground map video and in like applications.

6. Approach and Landing

There is evidence of much current interest in a head-up presentation of flight data during approach and landing. For this application the head-coupled display is well suited. On the other hand, for approaches during semidark conditions, it may be desirable not only to turn off the flight-data presentation but even to remove the combining glass of the HCD, being much smaller than that of the conventional HUD, can easily be tilted out of the way under push-button control.

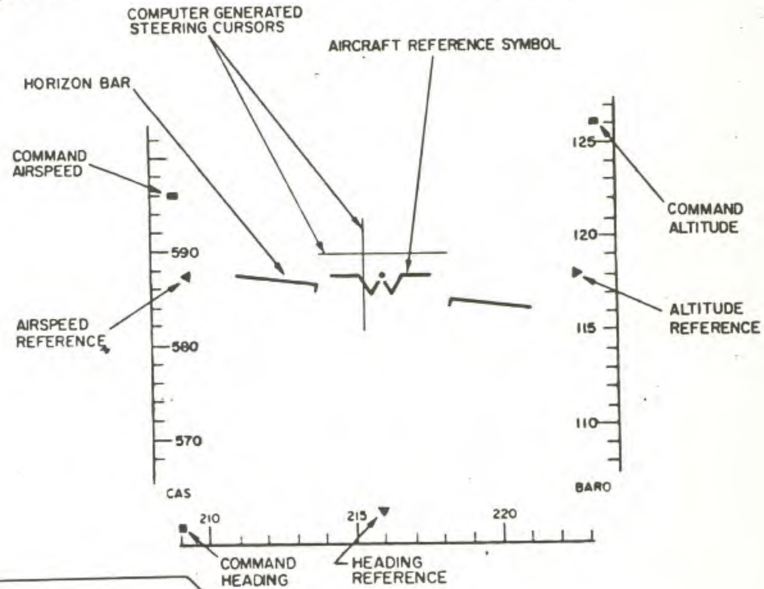

Figure 1B

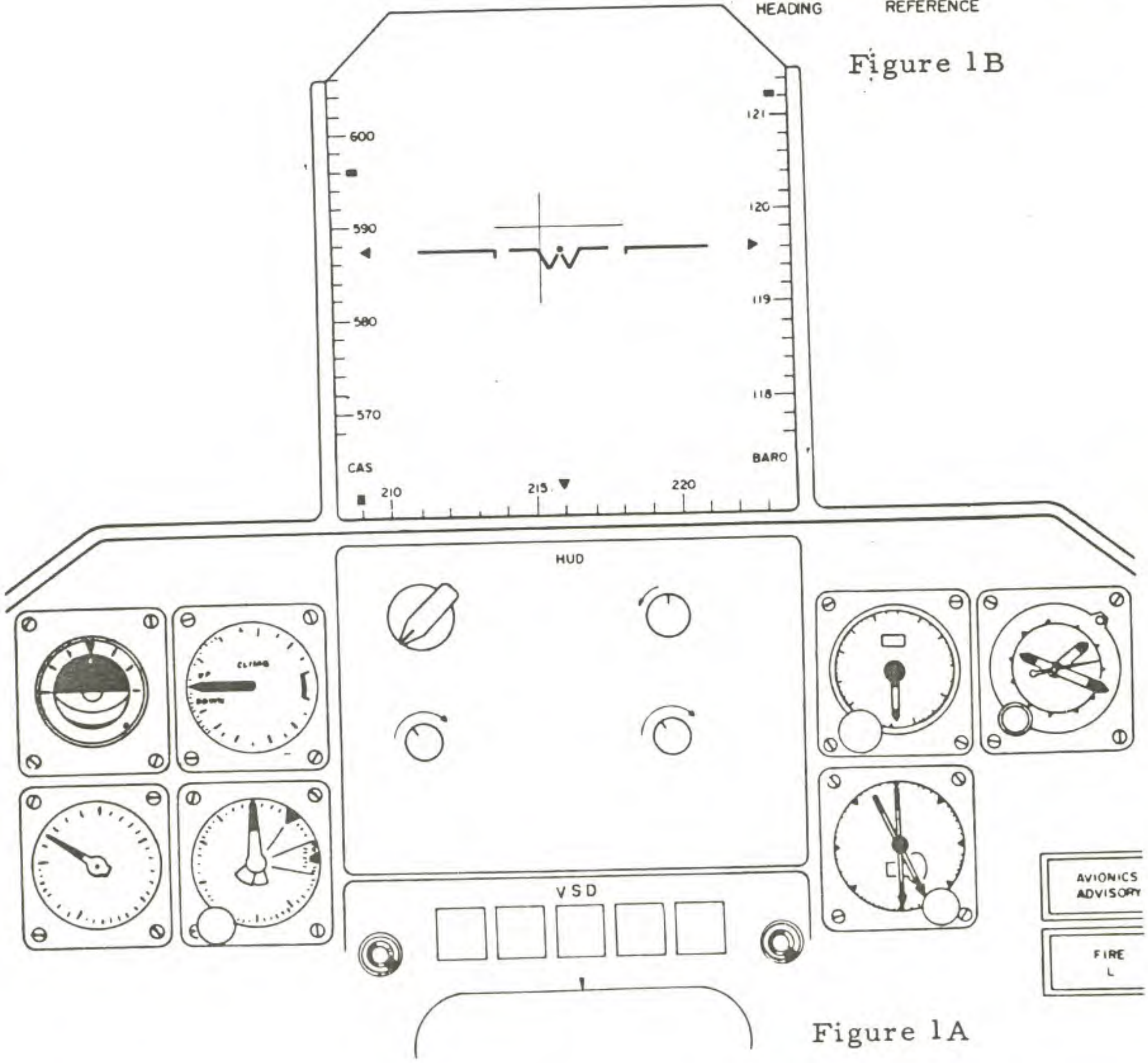

Figure 1A

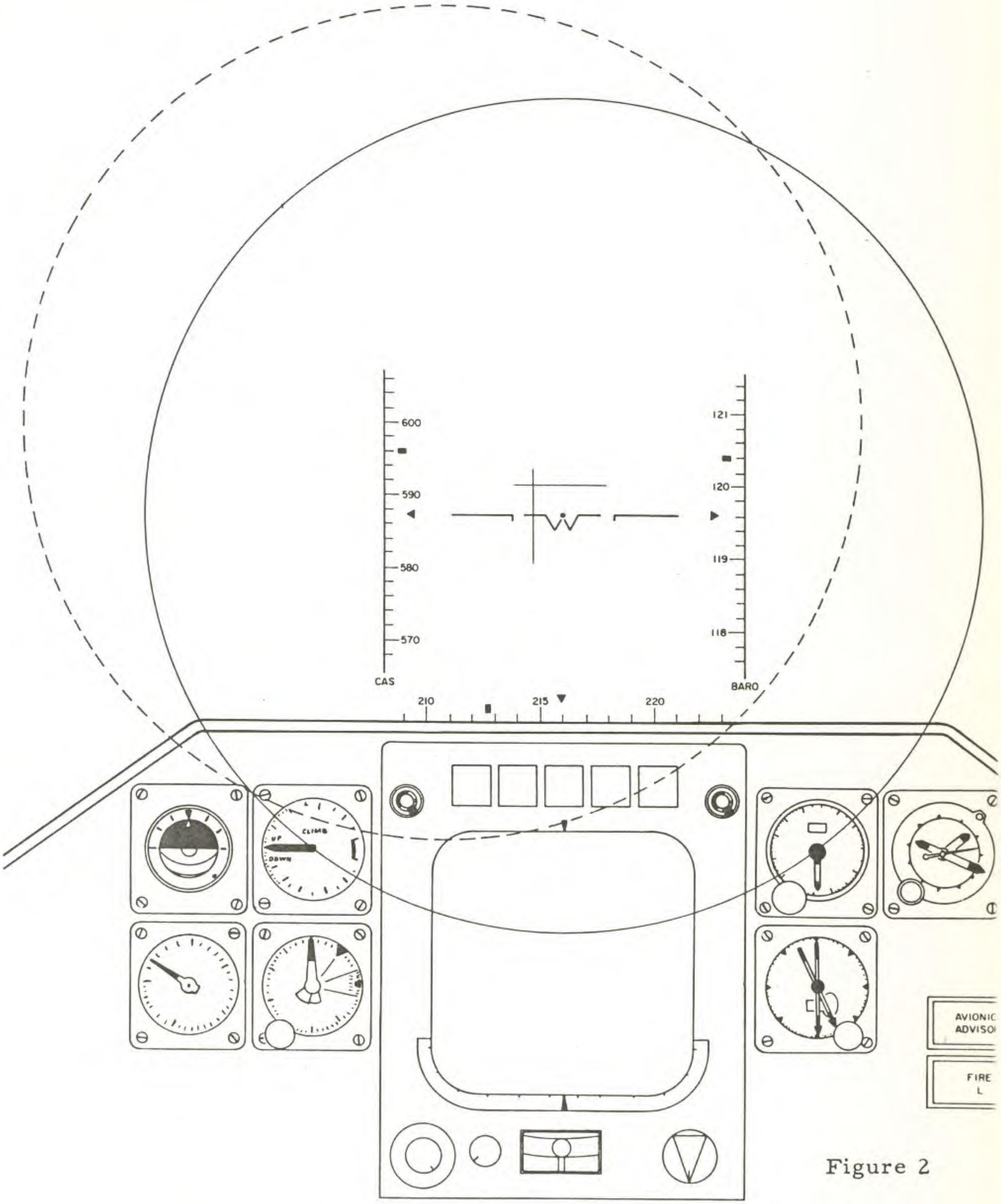
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Figure 2

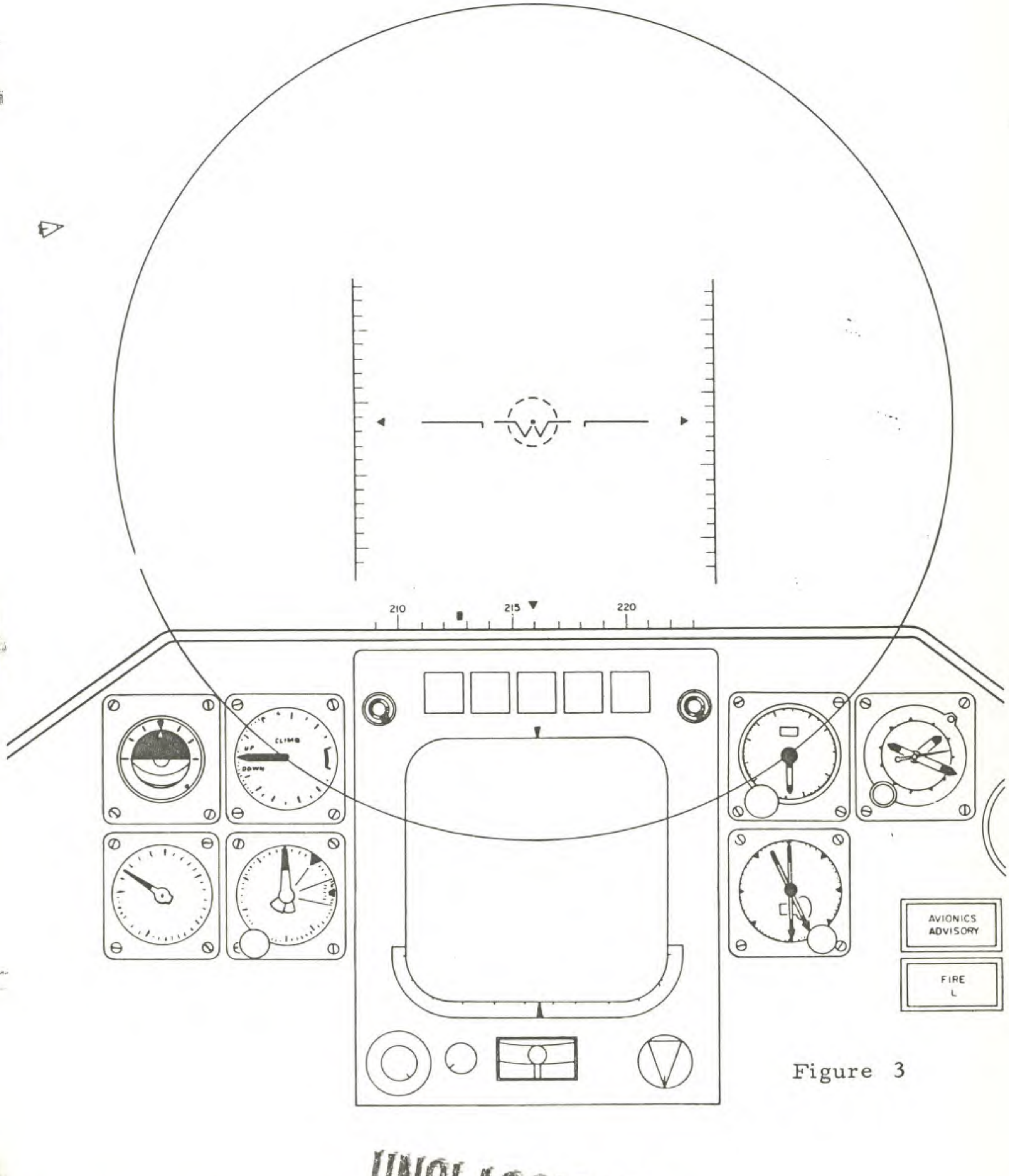

Figure 3

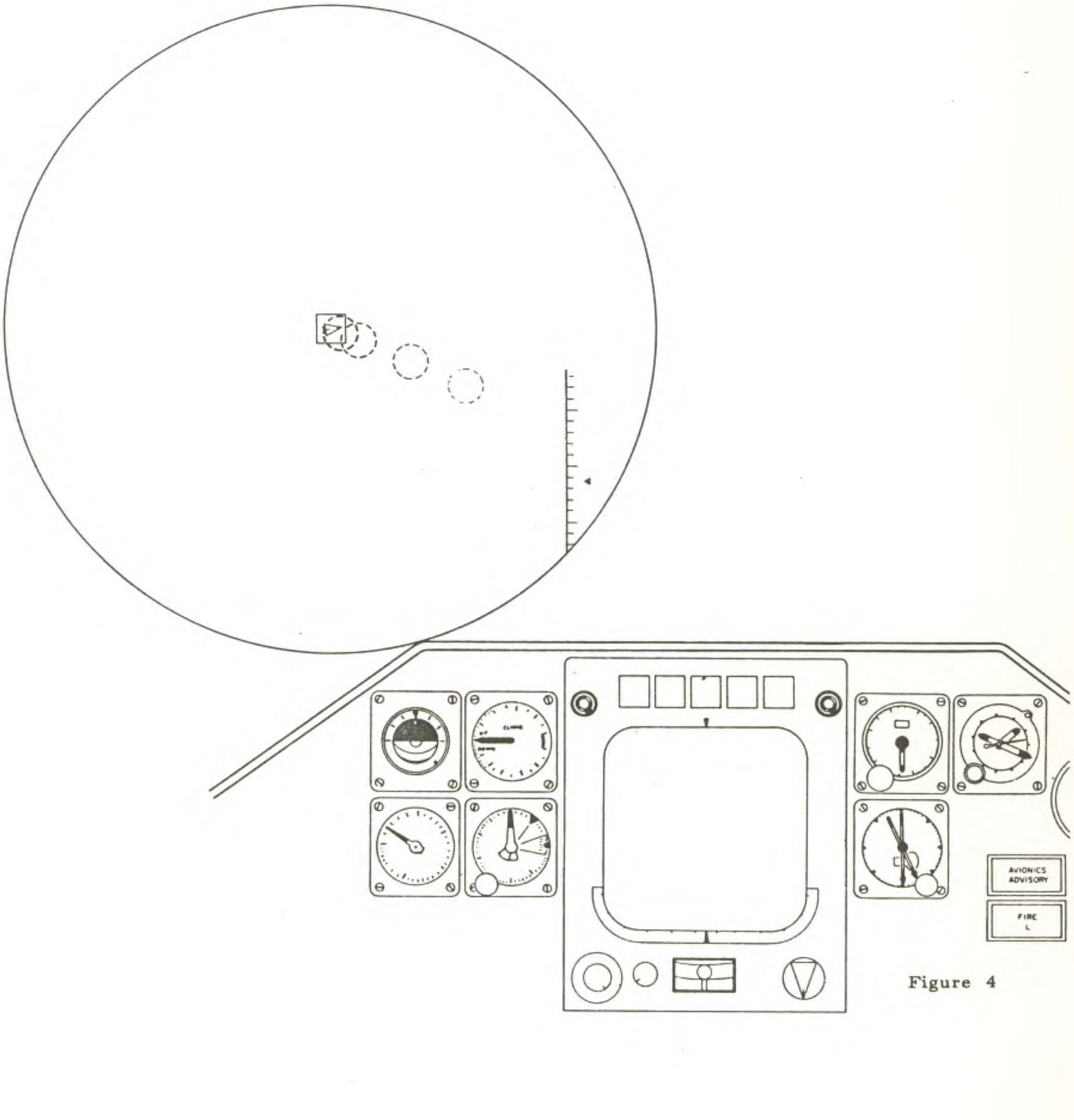

Figure 4

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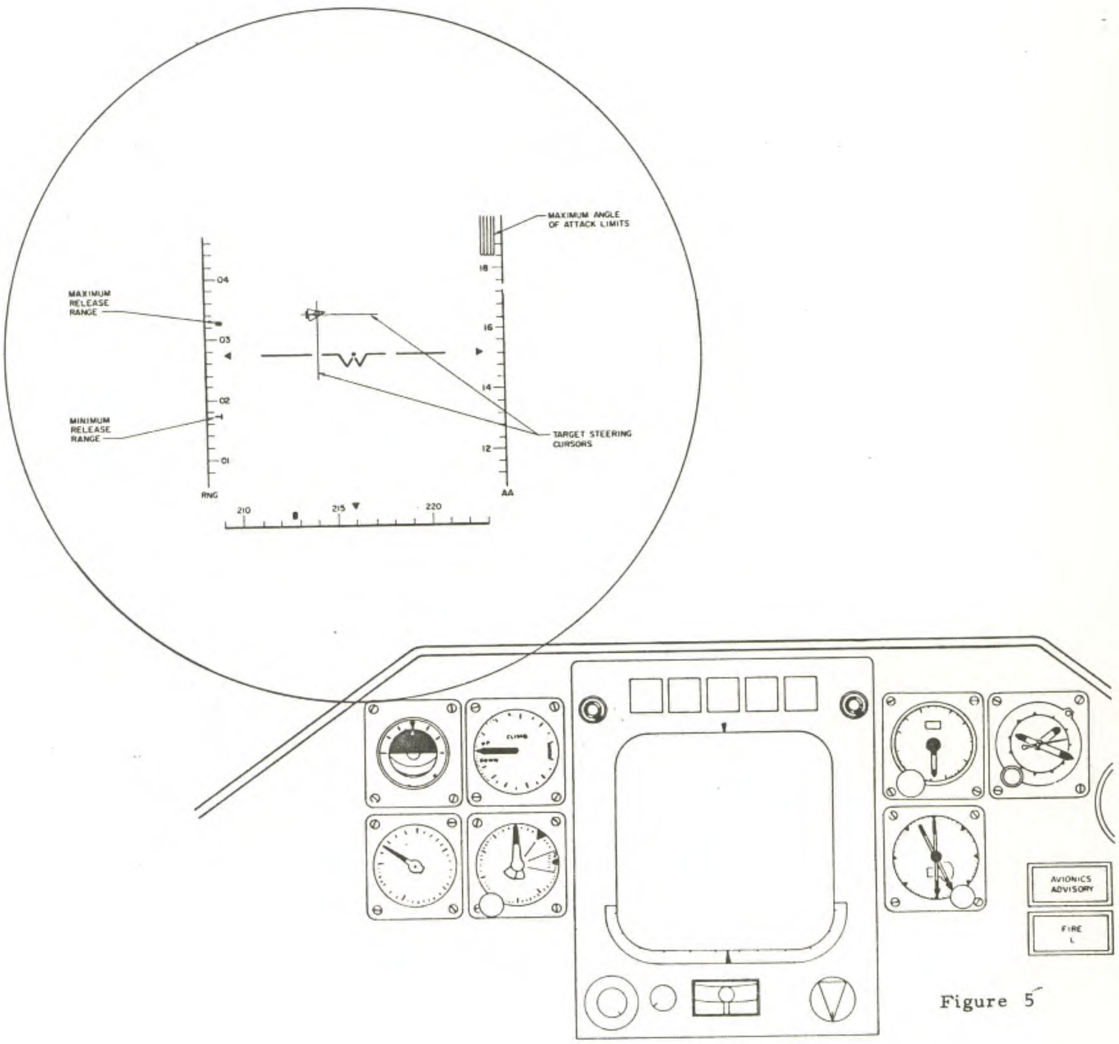

Figure 5

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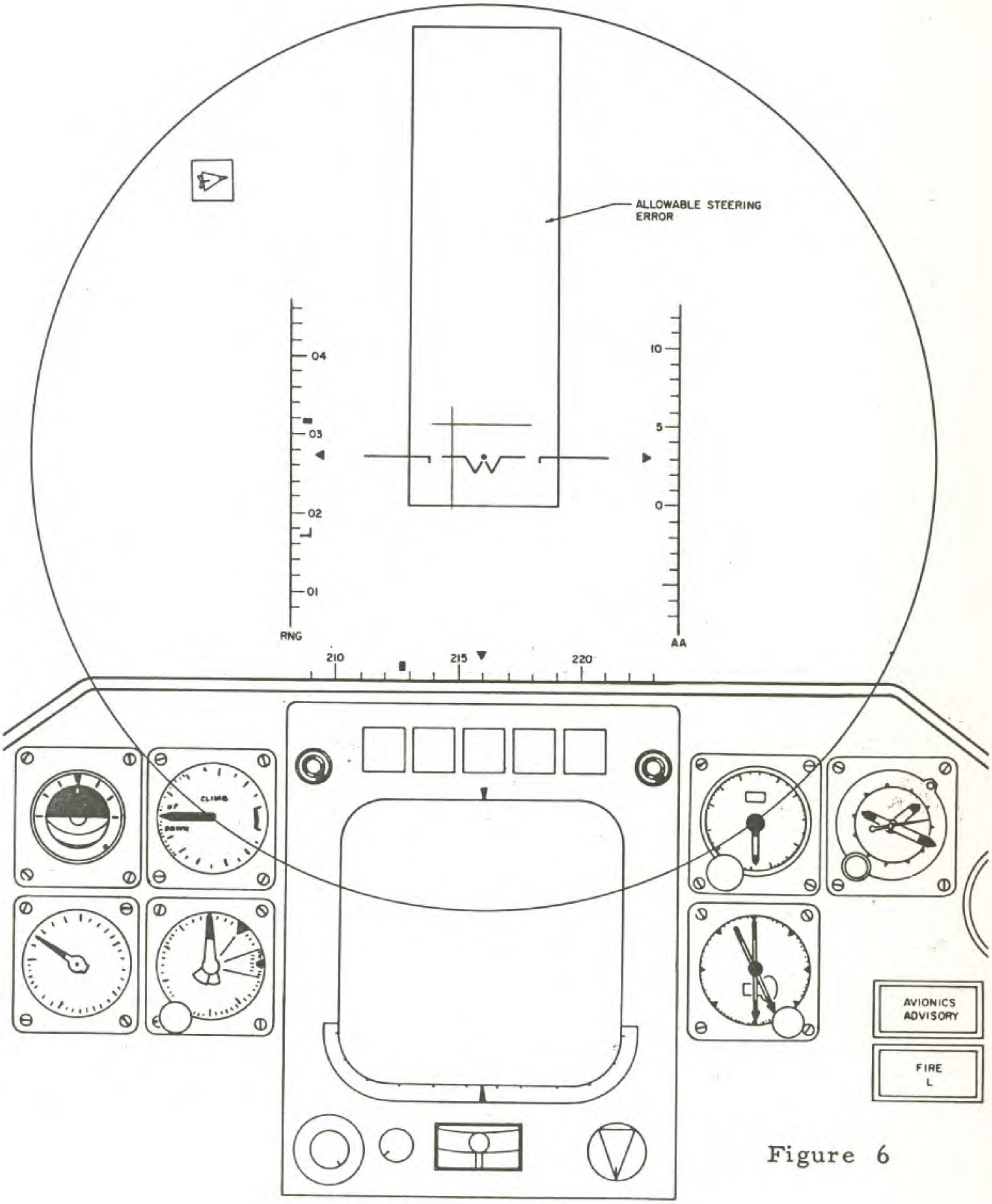
ALLOWABLE STEERING ERROR
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Figure 6

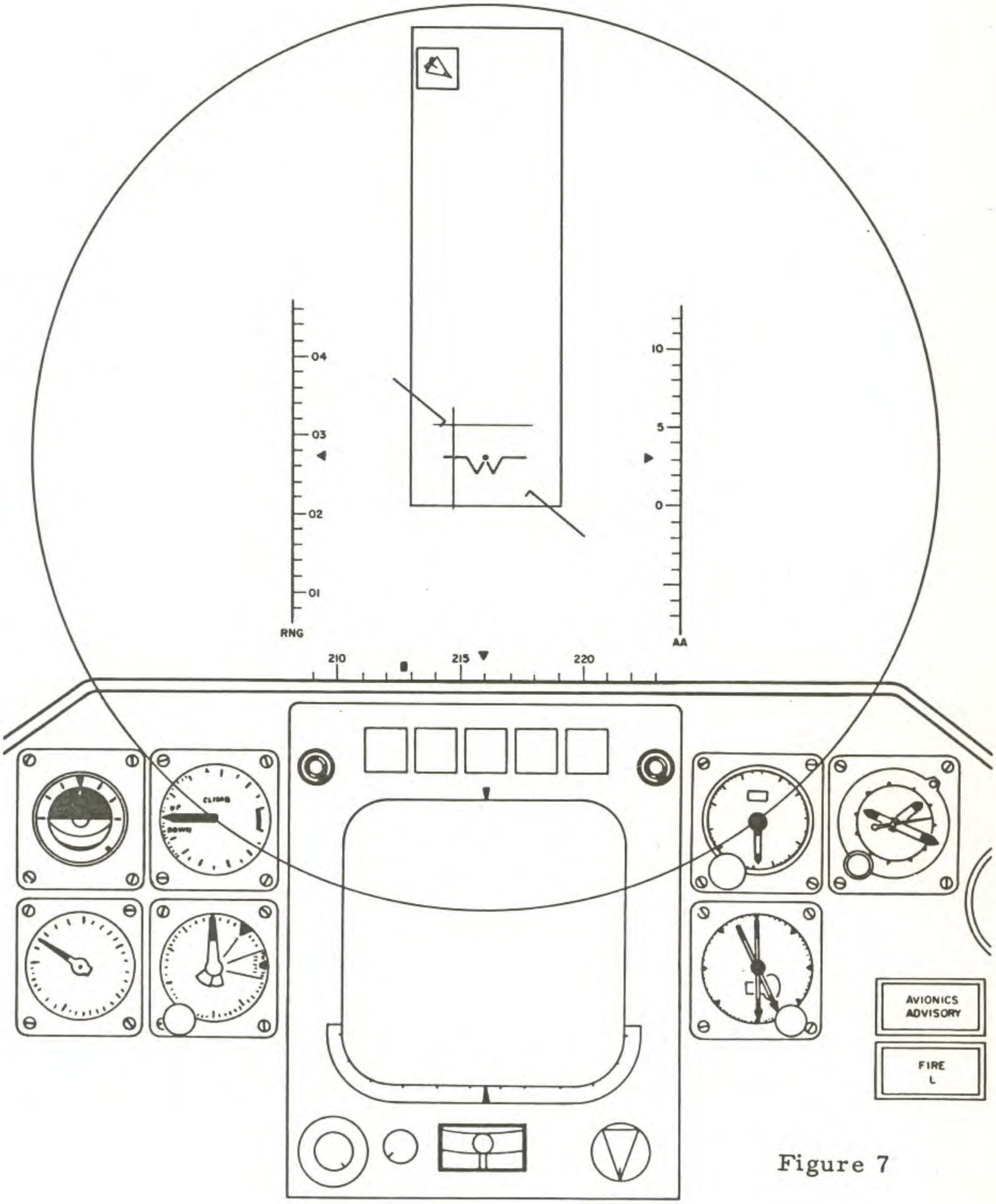
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Figure 7

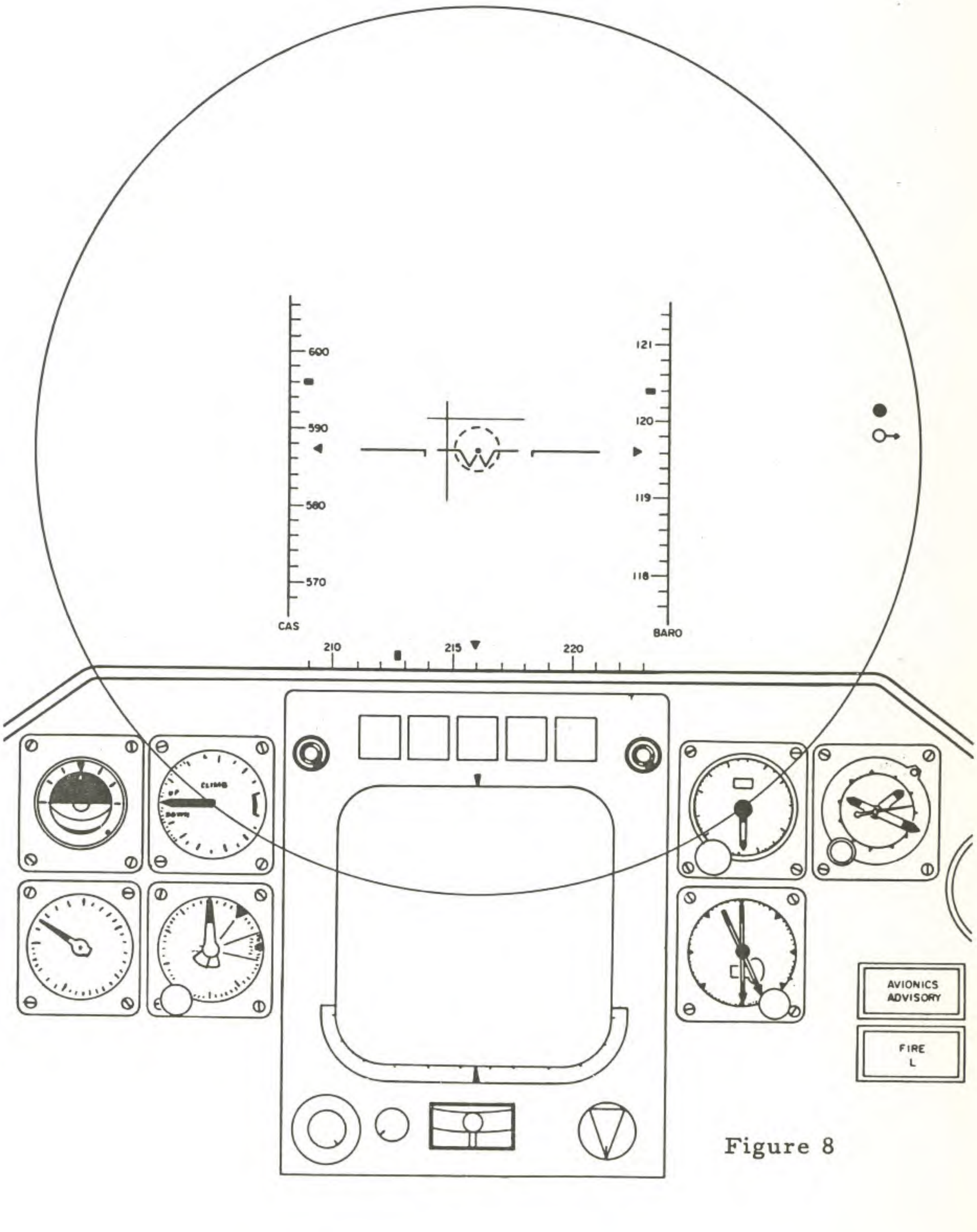
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Figure 8

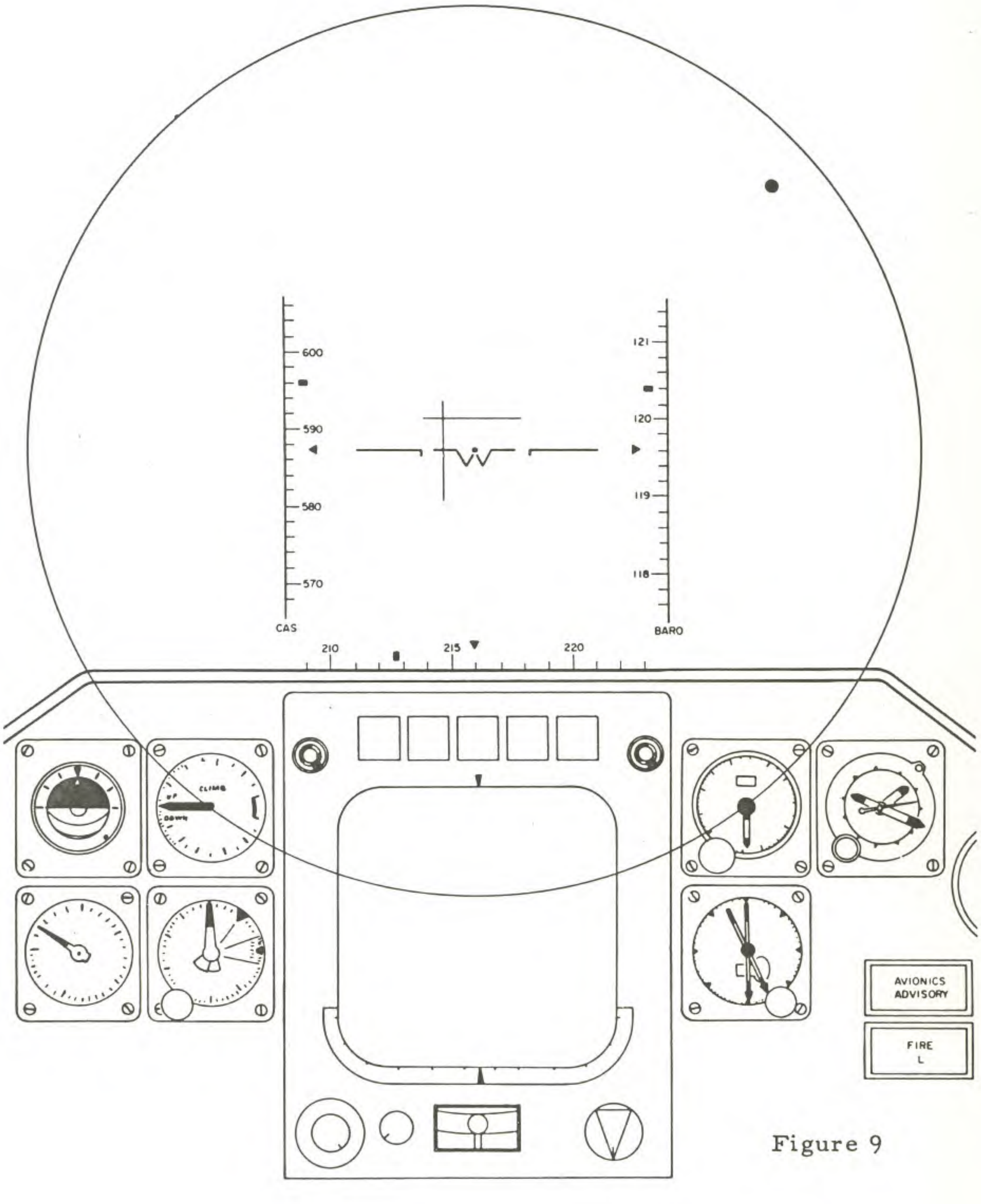
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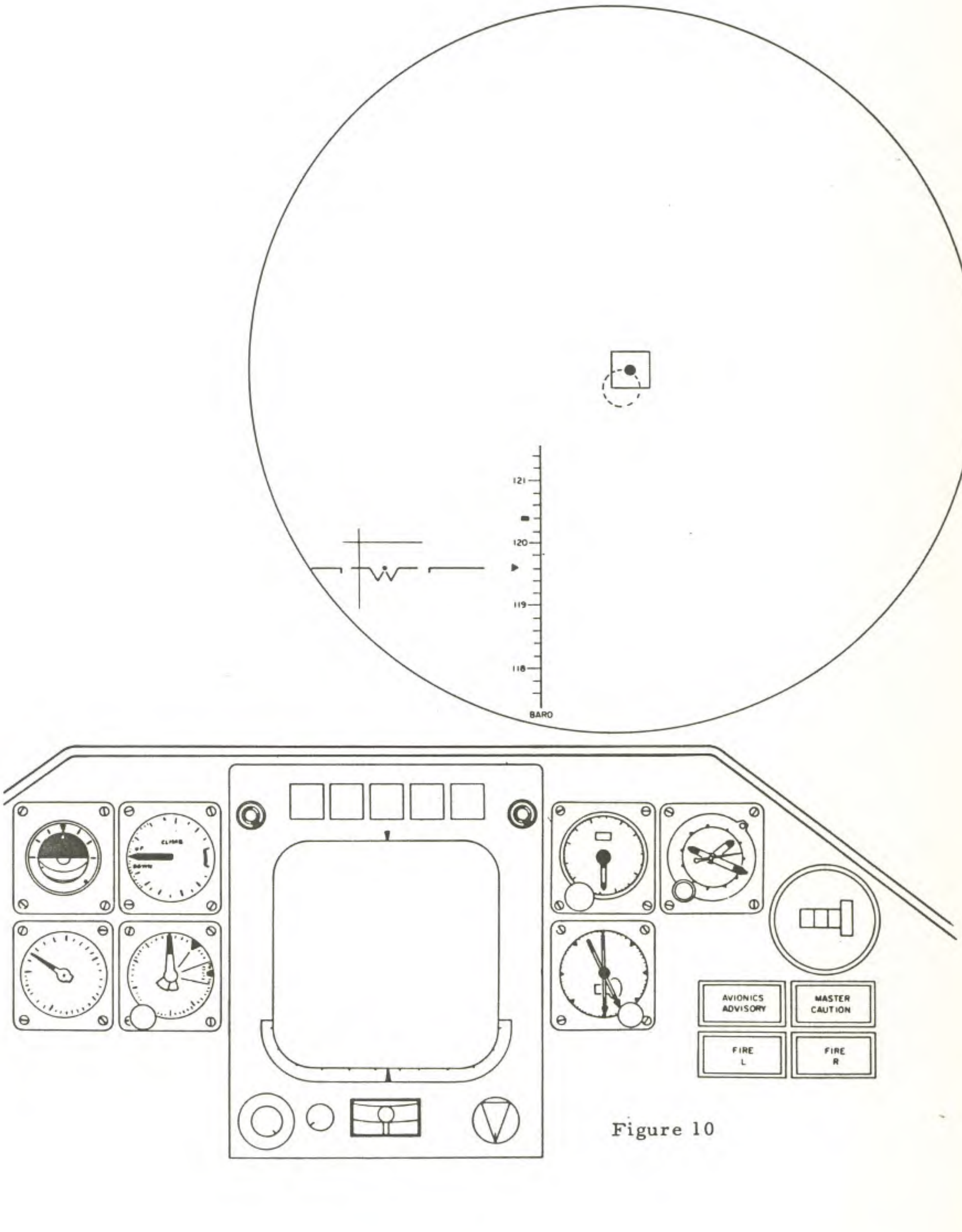
Figure 9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AVIONICS ADVISORY
MASTER CAUTION
FIRE L
FIRE R

Figure 10

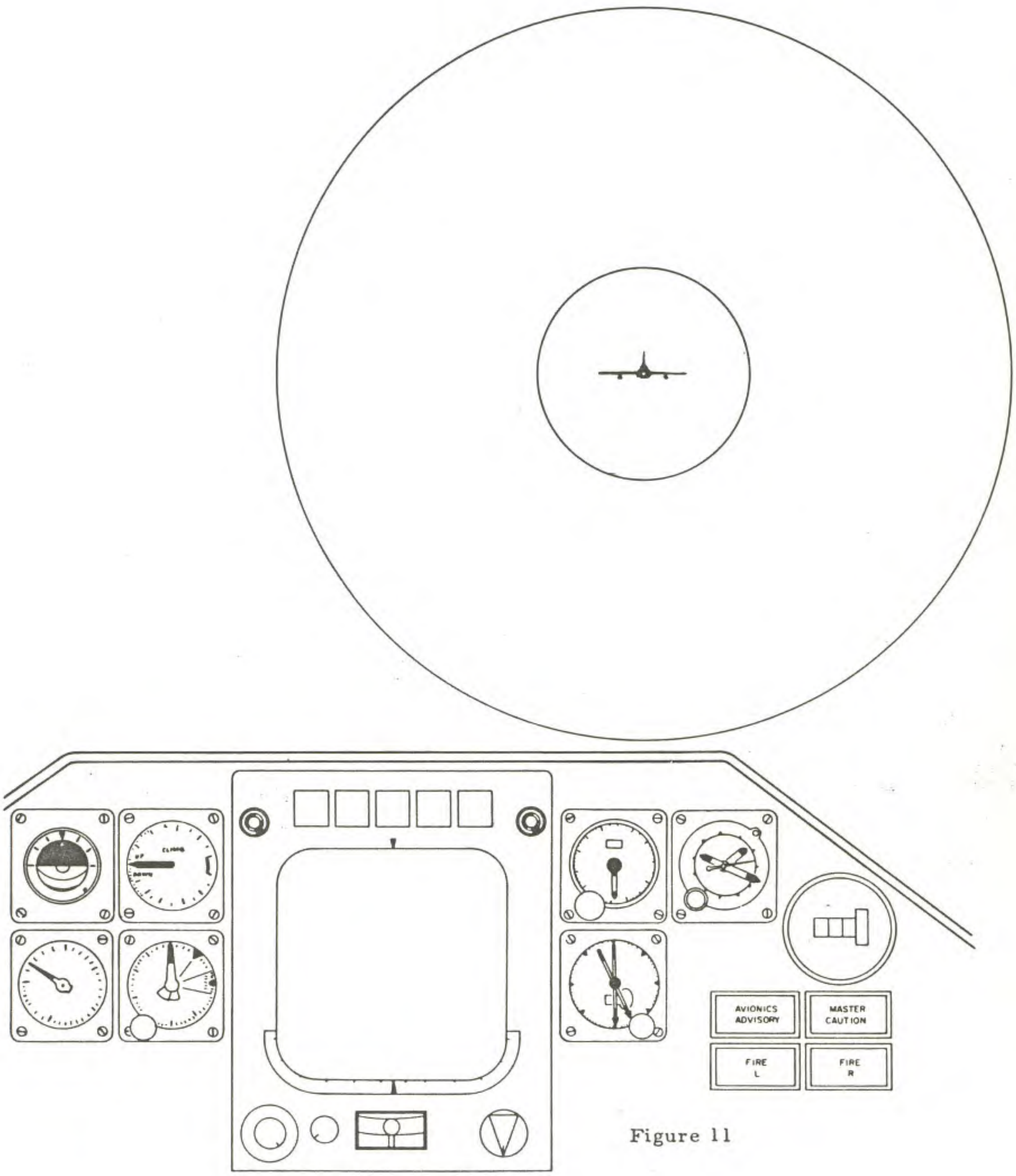
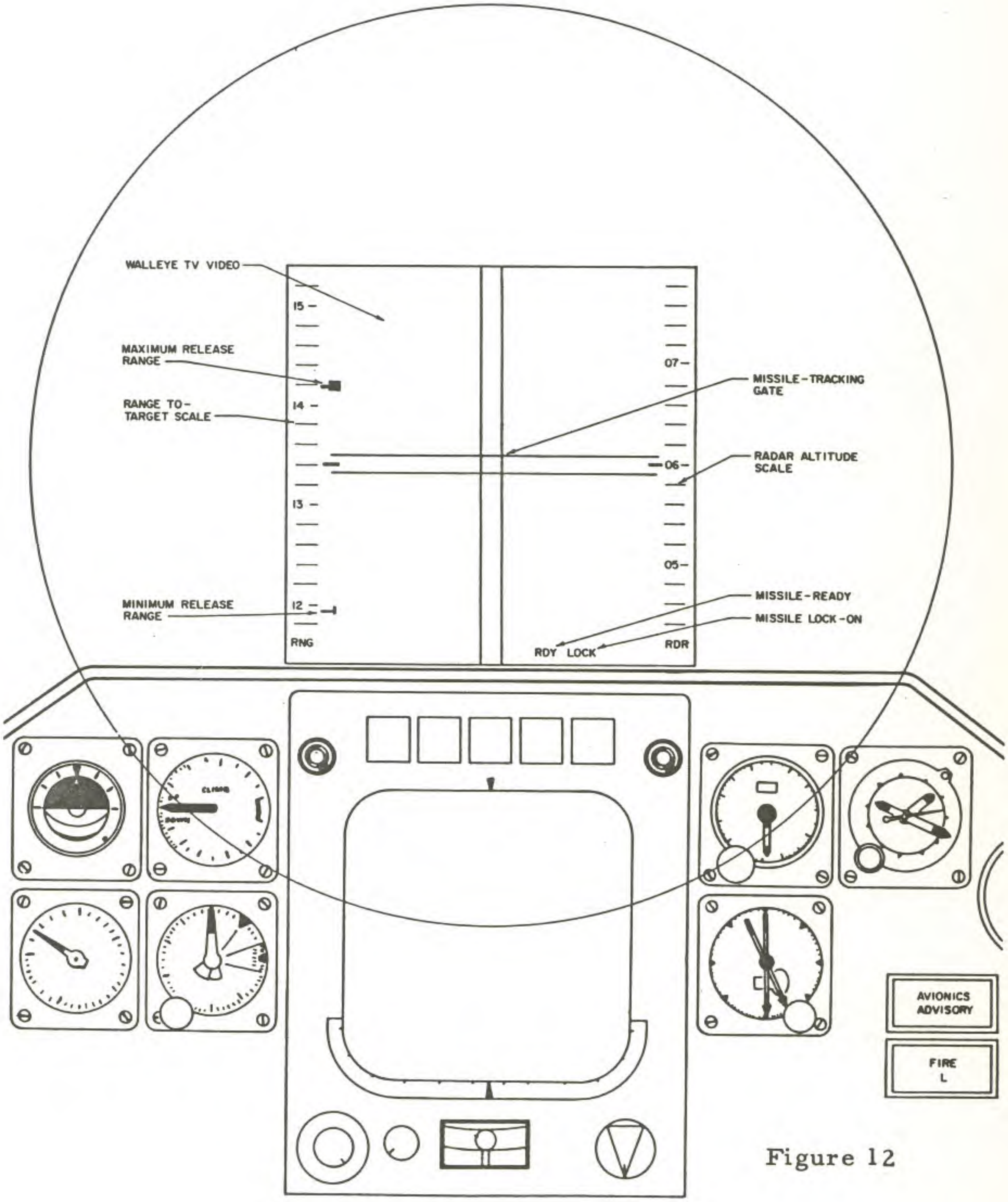


Figure 11


WALLEYE TV VIDEO
MAXIMUM RELEASE RANGE
RANGE TO-TARGET SCALE
MINIMUM RELEASE RANGE
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14
13
12
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07
06
05
RDR
RDY LOCK
MISSILE-TRACKING GATE
RADAR ALTITUDE SCALE
MISSILE-READY
MISSILE LOCK-ON
AVIONICS ADVISORY
FIRE L

Figure 12