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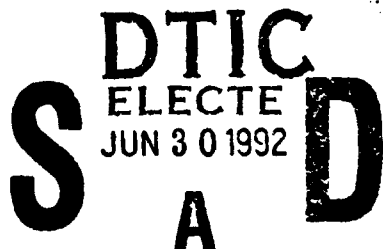
Investigation of the Influence of Air Defense Artillery on Combat Pilot Suppression and Attrition Management Practices

AD-A252 249



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May 1992

92-17003



United States Army
Research Institute for the Behavioral and Social Sciences

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1992, May

Final

Jul 86 - Jun 89

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Performance under combat conditions should equal the best levels achieved under training conditions. However, wartime performance may be degraded by the suppressive (psychological, indirect, or deterrent) effect of enemy weapons. This report examines the effect of air defense artillery (ADA) on air-to-ground missions. The methodology focuses on searches of the stress-and-performance and aviation combat literature, pilot interviews, and analysis of aviation tactics. A definitional framework of the concepts of actual and virtual suppression and attrition is presented. Command-and-control attrition management practices are examined, and examples from recent and past warfare are provided. Suppression was studied from the points of view of the performance-in-dangerous environments literature and cockpit workload. Examples of air-crew reactions to air defense artillery are included, and a summary chart lists pilot and mission characteristics influencing accuracy in weapons delivery. The authors conclude that (a) effective ADA can indirectly affect the otherwise effective firepower of attack aircraft through attrition management--safer attack profiles to preserve pilot and aircraft resources, (b) high cockpit workload in a threat-rich environment can contribute to suppression of (Continued)

Performance (human)	Attrition
Stress (psychology)	Air strikes
Air defense	Weapon delivery

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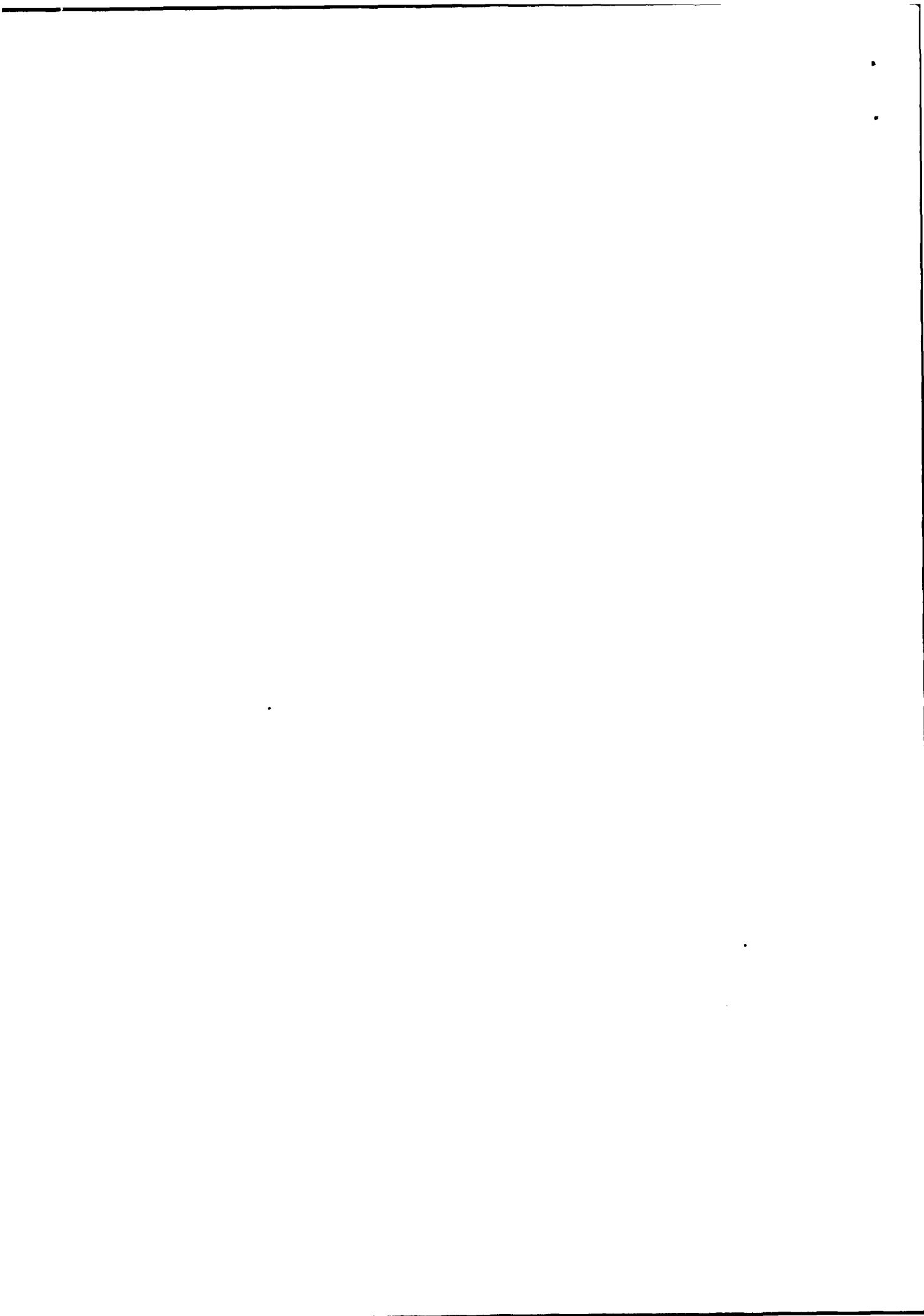
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BLOCK 13. ABSTRACT (Continued)

pilot performance because of task overload, and (c) pilot-induced practices influence pilot performance.

ACKNOWLEDGMENTS

The author would like to thank John E. Stewart II of the U.S. Army Research Institute for the Behavioral and Social Sciences for his role as technical consultant to the project. In addition to his thoughtful comments on an earlier version of this paper, he contributed greatly to the Appendix on pilot workload.

INVESTIGATION OF THE INFLUENCE OF AIR DEFENSE ARTILLERY ON COMBAT PILOT SUPPRESSION AND ATTRITION MANAGEMENT PRACTICES

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INVESTIGATION OF THE INFLUENCE OF AIR DEFENSE ARTILLERY ON COMBAT PILOT SUPPRESSION AND ATTRITION MANAGEMENT PRACTICES

BACKGROUND

The Problem

The use of weaponry under combat conditions hopefully equals the best levels achieved under training conditions. However, performance under the stress of combat may in fact not approach baseline levels. For example, evidence from World War II indicates that infantrymen may not always fire their rifles under warranted circumstances--indeed, the data show that in some infantry companies as few as 25 per cent of combat soldiers fired or continued to fire their rifles when in fact such action would have been clearly warranted (Marshall, 1947). The control of disruptive fear reactions was an important factor in selection and training during WWII (see Stouffer, et al., 1949, Ch. 4). Likewise, the efficacy of much of today's high-tech weaponry depends on the ability of the human operator to function properly, that is, operate the equipment to its full capacity under combat conditions.

The study of the suppressive influence of weapons (also referred to as deterrent, indirect, or psychological effects) has been largely applied to ground warfare--for example, the use of artillery fire, mines, tank rounds, or rifle fire to pin down, harass, or cause the threat to alter movement or tactics. (For an excellent summary, see the articles in Thompson et al., 1990; see also Schechter, Richards, & Romberg, 1989; Gilman, 1990; Dept. of the Army, 1975; & U.S. Army Field Artillery School, 1979.) The issue of interest in this report is whether performance is degraded in air-to-ground missions that are disrupted by air defense threats. Pilots must be aware of and react to surface-to-air missiles and antiaircraft artillery. The stress and cockpit workload of operating in the often dangerous environment around a target area might result in inaccurate or incomplete weapons delivery. Furthermore, heavily defended targets may cause aviation command and control to attack important targets under less risky profiles. This practice may place limits on the otherwise efficacious use of an attack aircraft's firepower.

This report is an expanded version of a presentation prepared for the Forward Area Air Defense System (FAADS) Study Advisory Group, which requested information on pilot reactions to air defense artillery (ADA). A need was identified for adding soldier (i.e., pilot) aspects into attrition computer models that simulate the performance of air defense systems against attacking aircraft. The earlier version was presented before the TRADOC Systems Analysis Activity (10 Sept., 1986, Ft. Bliss, TX), to the US Army Materiel Systems Analysis Activity (29 Sept., 1986, Aberdeen Proving Ground, MD), and at the Virtual Attrition Briefing to the Chief of Staff, Army (Washington., D.C., 31 October, 1986).

Approach

Initial searches of computerized bibliographic data bases revealed that information on the specific topics of the effects of ADA on mission planning, fighter pilot behavior, and weapons-delivery accuracy has not been cohesively

developed. Indeed, the conclusions from the Army Scientific Advisory Panel (Dept. of the Army, 1975) and the Fire Suppression Symposium (US Army Field Artillery School, 1979) on the status of suppression data in general were that there is (1) no adequate quantification of the effects on combat outcomes, (2) no adequate description of the stimuli causing suppressive reactions, and (3) no accepted data on the effects on dismounted troops, mounted troops, or aircraft. As a result, one data collection technique was an examination of accounts of past warfare in an attempt to determine if pilot behavior and combat aviation tactics were affected by ADA weapon systems. Specifically, aviation warfare during World War II, the Korean War, the Vietnam War, the Yom Kippur War, the Falkland Islands War, and the Chad and Afghanistan conflicts were studied. This literature search was combined with these additional approaches:

- Literature search on "performance in dangerous environments" (the psychology of stress and performance)
- Literature search on psychiatric battle casualties
- Interviews with pilots
- Intelligence briefings on aviation tactics and doctrine of Red Force
- Analysis of pilot selection practices
- Analysis of pilot personality characteristics
- Identification and analysis of relevant aviation combat data bases
- Definition of terms

Although this topic has been one of interest for some time (as witness e.g., a 1972 Technical Report entitled "The Effect of Pilot Stress on Delivery Accuracy" (Lovell & Walker)), quantitative operational performance data are in fact hard to come by (see also Youngling, Levine, Mocharnuk, & Weston, 1977, viz. the sparse entries in the "Reaction to Stress" row of Figure 3.2-2, which summarizes studies of aviation combat effectiveness as a function of predictor variables). By necessity, the methods outlined above are essentially descriptive in nature and the information generated from them is intended to serve as a basis for further research in the area. Also out of necessity, the majority of information accessed, analyzed, and presented is from a friendly force perspective, but it is assumed that the general principles outlined in this report will hold for enemy application as well.

Definitions

The four-cell matrix of terms in Table 1 separates "suppression" and "attrition" into categories of "actual" and "virtual." The value of a good air defense system is most dramatically manifested by an actual hit of an aircraft. Whether the aircraft crashes or is damaged to the extent it must abort, actual attrition has occurred (note further that if other aircraft accompany the aborting plane as a safety escort, then from the enemy's point

Table 1

a

Definitions of Terms

	Attrition	Suppression
Actual	Aircraft shot down; mission aborted due to physical damage to the aircraft; wingman escorts a damaged aircraft to base	ADA causes on the spot pilot-induced "prudent practices" that might result in inaccurate weapons delivery due to hurrying, pre-occupation with avoidance of ADA, or high cockpit workload in a threat-rich environment
Virtual	Management procedures ("prudent practices") designed to reduce risk to pilots & aircraft; designated attack profile may therefore be less than desirable	Reduction in efficiency of attack results due to threat per se of ADA (e.g., during mission briefing it is reported that enemy ground troops may have shoulder-launched missiles)

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More examples are given throughout the report (see the sections on Attrition Management; Table 2; Summary of Factors Influencing Suppression; & Summary). The concepts of attrition, suppression, and attrition management have been developed further by Cheever (1986) and in articles by Goodson, Haering, Hardison, and Kramer, which can be found in Payne and Cheever (1987). The term attrition management was first used by Haering.

of view, attrition of these aircraft has been accomplished as well).

The recognition of the threat becomes attrition management (virtual attrition) when command and control chooses different (safer) targets or alters tactics: For example, ordnance is delivered at higher altitudes, time over targets is reduced, single passes only are made, a low-level, pop-up attack profile is decided upon, and the support-to-striker aircraft ratio is increased. These situations are differentiated from suppression.

Suppression is evidenced by pilot behaviors which may result in a degradation in efficiency of the attack. When performance is altered as a result of reaction to ADA, the suppression is actual. Performance decrements might be attributed to high cockpit workload when under fire near the target area. Decrements could be the result of the stress of operating in a dangerous environment, that is, pilot-induced prudent practices over and above the attrition management tactics outlined in the mission briefing. For example, in reacting to ADA the pilot may over control the aircraft (hyperreact), or deliver his ordnance at a less risky attack profile, the net result of which may be reduced bombing accuracy.

When mission efficiency is altered because of the threat of ADA, but in fact no enemy fire is encountered, then the suppression is virtual because the enemy has achieved the same effect as with its ADA weapons without actually firing any ordnance. Attrition management and suppression are the foci of this report and are respectively developed in the following sections.

ATTRITION MANAGEMENT (PRUDENT PRACTICES)

Air defense artillery's role is to hit aircraft, cause disruption of the planned mission which could result in mission abort, or cause inaccurate or incomplete ordnance delivery. The ultimate desired effect, however, would be a decision by the enemy to bypass completely the particular target area. Declaring certain targets as "off limits" would be an attrition management decision, a prudent practice by the aviation command and control to weigh the risk of aircraft and pilot losses against the requirement to gain and maintain air superiority and to effect a certain operating tempo throughout the combat area. Other forms of this practice are represented by (1) the use of stand-off weapons (such as TV- or laser-guided bombs); (2) certain airspace designated as "no fly" zones, and certain ADA weapon systems as "avoid, do not engage"; (3) weapon-delivery attack profiles which sacrifice accuracy for safety; (4) number of target passes limited to one; (5) stand-down procedures, or less risky assignments during a pilot's last few missions; (6) ground-based and air-based suppression of ADA; and (7) ADA countermeasures.

During the Vietnam War the necessity of effective ADA countermeasures became paramount to survival. These measures included (Nordeen, 1985):

- Evasive maneuvering techniques ("jinking" against radar guided missiles)
- Low altitude, "pop-up" attack profiles
- Radar homing-and-warning (RHAW) devices in the cockpit

- Chaff and flare dispensers
- Electronic countermeasures radar-jamming pods
- "SAM killers" (called Wild Weasels or Ironhand) in a strike force: fighters whose role was to attack or suppress threatening SAM (surface-to-air-missile) sites on a given mission, usually just preceding the main strike group's arrival at the target

The use of massed ADA (i.e., both missiles and antiaircraft artillery--AAA) at times made route planning difficult. Low altitude flying (say, 3,000 feet or less) to avoid missile effective ranges subjected an aircraft to AAA and small-arms fire. Flying at higher altitudes to avoid AAA put the aircraft back in the missile's tactical envelope. The technological introduction of equipment such as the RHAW meant that aircraft could fly at higher altitudes to avoid AAA and have sufficient warning of a missile attack to begin evasive maneuvers (Nordeen, 1985, p. 40).

Attrition management is in fact a widely practiced strategy. Examples from various conflicts are provided in Table 2; this historical account represents a sampling of policy decisions made by the "chain of command" to reduce the risks that pilots and their aircraft would be subjected to under various conditions. Again, these management decisions are a balance between risk to pilot, aircraft, and mission, and are reflected in the mission briefing by such details as types of targets to be attacked, desired effects, attack profiles, weapon selection, and procedures upon enemy contact.

THE SUPPRESSION EFFECT

Performance in Dangerous Environments: Background

In order to provide a proper setting for the discussion of operational performance on air-to-ground missions, a section will first be presented on the general topic of performance under stressful conditions. Additional background on relevant stress-and-performance literature is presented as Appendix A.

The effects of battlefield stress on degradation of performance have been of interest as early as WWII when Marshall (1947) remarked on the low percentages of infantrymen who actually fired their rifles in combat (see also Rowland, 1986). The suppressive effect of weaponry on the other side's fire power is one main objective of combat: "Extensive effort is expended in battle in attempting to degrade the performance of the other side--large parts of the effect of artillery fire, small arms and tank fire are expended in the belief that they do have some finite effect" (Rowland, 1986, p. 33). For example, especially fearful to ground troops is area (indirect) artillery shelling accompanied by loud noise, smoke, earth tremor, and debris (see Labuc, 1981 for a summary of the psychological effects of weapons). The assumption is that nonlethal effects of weapons can in fact exert a significant impact on the outcome of a battle because of the perceived dangerousness of them. Thus, "suppression is the degradation of hostile operational capabilities through the employment of military action that has

Table 2

Examples of Attrition Management in Aviation Warfare

General

"While destroying the enemy fighter or attack aircraft is the aim of defensive air warfare, the goal of offensive air power usually is ordnance on target. During the past several decades, a number of countries have investigated means to more accurately deliver weapons, and to do so outside the lethal envelope of short-range antiaircraft fire and surface to-air missiles. Two basic paths have been taken to develop accurate and survivable weapon delivery systems: precision guided weapons and sophisticated aircraft weapon-delivery systems." (Nordeen, 1985, p. 208)

"The Defense Dept., faced with improved Soviet and third nation air defense capabilities, is increasing its emphasis on air-launched standoff weapons by promoting development of an interim Navy long-range ground attack missile and a family of modular standoff weapons to be built within the North Atlantic Treaty Organization".... "Standoff is more attractive because of faster response time, increased survivability of the attacking aircraft and compatibility with stealth aircraft and their operational tactics." (North, 1986, p. 16.)

World War II

"By April 1940, it was clear that losses in day operations were prohibitively high, and the Air Ministry issued a Bombing Directive which switched the strategy of Bomber Command to night attacks on major concentrations of industry." (Reid, 1979, pp. 2-3)

Korean War

"The light bombers were highly effective in low-level operations, but the B-26 crews were finding it difficult to maneuver at low altitudes in the small valleys of Korea. More serious was the fact that hostile small-arms fire was wreaking substantial losses and damages upon the low-flying conventional bombers. By 7 July it was evident that the light bombers had to operate at medium altitudes if they were to survive." (Futrell, 1983, p. 86)

"The horizontal-bombing B-29's operated under severe disadvantages. To escape flak, they had to bomb from altitudes above 18,000 feet, and at such heights the B-29's were inherently unsuited for pinpoint work." (Futrell, 1983, p. 224)

Table 2, cont.

Examples of Attrition Management in Aviation Warfare

Vietnam War

US Air Force had a separate policy for the first and last 10 missions of a pilot's 100-mission tour (they were flown in supposedly relatively benign combat environments; Basel, 1982, pp. 101, 103).

US Navy carrier pilots had a shorter tour (6 months) and were allowed to pick their own targets on the last few missions

"The best way to escape a SAM was to turn into it with a hard diving turn, then make an abrupt four-G rolling pull-up keeping the speed up throughout the maneuver....but since so much altitude was needed for these maneuvers, weather conditions became a critical consideration in our planning for all missions into SAM-defended areas." (Momyer, 1979, p. 127). "During 1965-1968, we sought a 10,000 foot ceiling and no more than 5/10 to 6/10 cloud coverage so that our pilots had both sufficient visibility to see a SAM launch and adequate ceiling for maneuvering to avoid the SAM." (Momyer, 1979, p. 177)

"Pilots in the 1966-1968 campaigns couldn't do much to avoid the SAMs with erratic flight (or "jinking") if they wished to have any hope of getting the bombs on target. But our later bombing systems which compensated automatically for speed, altitude, and a moderate amount of jinking provided pilots much more protection. Also, with the laser weapons used in the 1972 offensive, strike forces had greater freedom of maneuver and could release their weapons from a much higher altitude." (Momyer, 1979, p. 133)

"When ground forces were involved and needed the support, pilots pressed their attacks as low as possible to get the job done. There were, however, occasions when friendly ground forces were not actively involved in the target area or even scheduled to enter the area after an air attack. In those cases, the minimum pull-out altitude for the fighters was raised to 3,500 feet. We simply did not want to risk the life of a pilot and the loss of an aircraft by over-exposure in the danger zone when no friendly ground forces were involved. The pilots, of course, didn't like this, always wanting to go as low as possible for better accuracy." (Momyer, 1979, p. 280)

"With the advent of the jamming pod, F-105D flights could once again penetrate at medium altitude between 12,000 and 15,000 feet where airspeed, range, and maneuverability were all good--above the range of the murderous automatic weapons and without fear of the higher-altitude radar-directed antiaircraft artillery and surface-to-air missiles." (Nordeen, 1985, p. 24)

Table 2, cont.

Examples of Attrition Management in Aviation Warfare

Yom Kippur War (1973)

"To counter the new Arab air defenses, the Israel Defense Force/Air Force modified tactics, employed chaff, installed new U.S. supplied electronic countermeasures equipment, and repeatedly staged extensive defense-suppression attacks"...."All the jammers and deception devices were designed to degrade the effectiveness of search and acquisition radars, antiaircraft fire control radars, and the guidance radars for the SA-2 and SA-3 missiles." (Nordeen, 1985, pp. 165; 147)

Falkland Islands War

The Argentines use of AAA and missiles achieved some air denial: "Whenever the weather permitted, Harriers strafed airfields and radar positions. They had now abandoned low level direct attacks -- the risk of attrition was too great. Instead, they 'toss-bombed', releasing their weapons well short of the target, and turning away at maximum distance from the defences...Harriers lingered over Port Stanley at 20,000 feet, above the ceiling of the enemy's Roland anti aircraft missiles." (Hastings & Jenkins, 1983, p. 157)

"Laydown attacks were successful in hitting runways but in the main our aircraft were vulnerable and damage to the runways was not extensive. On the other hand, high angle and loft deliveries kept aircraft out of the range of ground defenses, but accuracy was poor." (Squire, 1983, p. 100)

"Experience showed that our greatest threat was from ground-to-air weapons which varied from surface-to-air missiles to small arms fire. The two major surface-to-air missile systems were Roland and Tigercat. We had a fair idea where they were located and planned to fly outside or below their engagement zones....The remaining surface-to-air missile threat came from the shoulder launched variety, and these were in plentiful supply. By flying low and fast in the target areas we could negate" this threat. (Squire, 1983, p. 100)

Chad Conflict

Libyan aircraft bombed their captured air base in Chad from as high as 30,000 feet to elude the shoulder-fired Redeye missiles of the Chadian soldiers. (Randal, 1987)

Because the French Air Force had the luxury of time on their side, missions were based on selected criteria: early morning attack, full visibility of target, clear weather, no enemy aircraft in vicinity of target, knowledge of ADA around target, use of sun as a tactical aid, one target pass only. (information from presentation by French pilots to the US Army Air Defense Artillery School, 25 March, 1987, Fort Bliss, Texas)

Table 2, cont.

Examples of Attrition Management in Aviation Warfare

Afghanistan Conflict

Early War: Because of the threat posed by the massed use of SAM-7s by the Afghan rebels, "...Soviet aircraft, primarily MiG-21s, would make their weapons delivery runs from high altitude and release their weapons at 2,000-3,000 ft., in effect sacrificing accuracy for safety" (Gunston, 1984). The Soviets then decided that flares could successfully counteract the SAM-7 threat. Attack altitudes were lowered. Strike fighters operated in pairs: one would fly high-speed, nap-of-the-earth while the other would dispense decoy flares from a higher altitude.

Later War: After the introduction of Stinger shoulder fired missiles into the war, the tactics of the Soviet pilots changed such that fixed wing aircraft flew higher and the hovering tactics of attack helicopters was eliminated:

"The Stinger has forced high-performance Soviet strike aircraft pilots to deliver their weapons from high altitudes, seriously eroding accuracy. It also has forced pilots of Soviet helicopter gunships and tactical strike aircraft, such as the Sukhoi Su-25 Frogfoot, to fly nap-of-the-earth missions and deliver their ordnance on the first pass, making them vulnerable to massed small arms fire and further eroding accuracy"...."It appeared that the pilots involved were putting survival before accuracy"....Their altitude denied "the Stingers a reasonable shot while at the same time sacrificing their own weapon accuracy ..." "Helicopter gunship attacks and missions by Su-25s are apparently assigned only to areas where the Stinger is thought to be absent." (Gunston, 1988, pp. 46, 47, 48)

"The Stingers forced the Soviets to change their tactics in Afghanistan, reducing the number of low-level assaults by Mi-24 Hind helicopters and the Sukhoi-25 Frogfoot close-support aircraft. For months, the Soviets were forced to fly at higher altitudes, out of range of the Stingers. But now Soviet aircraft reportedly are releasing flares to confuse the Stinger's targeting system and serve as cover for surprise low-level assaults." (Dorsey, 1987)

psychological and/or physical effects temporarily impairing the combat performance of enemy forces and personnel who have not themselves been killed or wounded" (Dupuy, 1987).

Whether a person finds himself in a dangerous environment by choice or not by choice, his behavior can be categorized as either non-goal oriented (i.e., he panics, freezes, or tries to remove himself from the noxious stimuli) or goal directed. Performing effectively under conditions of combat stress necessitates not only engaging in goal-directed behavior, but also eliciting responses which are accurately and timely performed (Kern, 1966). That is, a soldier's class of behaviors should be job performance centered. After an initial adaptation period to the unique environment of combat, most soldiers' behavior would be expected to be goal directed. However, over time in combat, perceptions and orientations may change, to the extent that one's stimulus orientation becomes weighted more towards danger cues as opposed to cues which he uses to adapt to his new environment. With further time in a combat zone, attention to environmental signs of danger gradually gives way to preoccupation with anticipatory damage, and behavior is oriented to self-preservation. To summarize this behavioral reaction process (Kern, 1966), after an initial adaptation-to-the-battlefield phase, a soldier can be expected to perform at his best for some period of time before thoughts of danger, then harm, begin more and more to act as distractors (anticipatory fear reaction) to the conduct of efficient, job-oriented behaviors (self focus vs. task focus).

Factors which are important in one's decision to perform in dangerous environments under stress are one's predisposition (trait anxiety, trait arousal), previous exposure to such environments, the perceived assessment of the situation, and one's perceived ability to cope with, or control, the situation (Idzikowski & Baddeley, 1983). Thus, the judged quality of one's training and equipment to perform a particular task or tasks, confidence, and one's sense of competence are crucial ingredients in the quality of performance (Rachman, 1978, 1982).

The stress-and-performance literature suggests that a low to medium arousal state acts by narrowing attention, focusing it on the primary task before the subject (data and theory are summarized in Baddeley, 1972, and Idzikowski & Baddeley, 1983; see also Hockey, 1979; Hockey & Hamilton, 1983). In high arousal states, anxiety acts as a cause of overt distraction. Attention is shared by and shifted between task-relevant variables and self-relevant variables (e.g., self-preservation). In such states, performance degradation is likely on secondary tasks, on tasks requiring manual dexterity, and on sensory-motor tasks such as tracking which require periods of concentration. These effects are especially likely in those who are novice to performing in dangerous environments. Adaptation in the sense of inhibition of anxiety does occur in some individuals after subsequent exposure to stressful stimuli, thus resulting in a lesser degree of performance impairment.

Theoretical frameworks to account for the effects of stress on performance have included arousal theory (for example, the Yerkes-Dodson "inverted U" hypothesis), and capacity (cognitive resource allocation) models (see Hockey, 1979; Hockey & Hamilton, 1983; Idzikowski & Baddeley, 1983; and Sanders, 1983 for summaries). The Yerkes-Dodson Law states that performance

on a given task will decrease when an optimal level of arousal for that task is exceeded. One facet of the hypothesis is that less stress is required to disrupt the performance of a complex task. This postulate would have obvious relevance to the cockpit environment. In capacity models, performance degradation has been explained in such concepts as selectivity in processing of environmental stimuli (i.e., selective attention), divided attention, time sharing, decision making, and perceptual motor load. Thus, the stressed performer of a difficult task, for example one requiring the use of information from many sources (i.e., a high cognitive workload environment) would show a selectivity of inputs as well as responses. Wickens and Flach (1988; see also Wickens, Barnett, Stokes, Davis, & Hyman, 1989) apply capacity concepts to the decision making requirements of the aviator. When a judgment is called for, the experienced pilot will have more reaction repertoires available via direct retrieval from long term memory and will not have to rely so much on working memory. Because stress is postulated to exert its influences more on the resource-limited working memory, an expert should be less prone to making poor judgments under stressful conditions (e.g., scenarios characterized by risk or time pressures).

Stress and Performance in Combat Aviation

Background. The emphasis of this suppression section is on the effects of "chronic intermittent" stress (Burchfield, 1979) on fighter pilot performance in the combat environment--both the appropriateness of the pilot's goal-directed behavior as well as its quality (e.g., weapons delivery accuracy). The intermittent (acute) nature of the stressful environment is based on the operational definition here of the dangerous environment being the mission itself--from time of take off to the return landing. Aviation crews, unlike many ground troops, are in relatively benign environments between missions (see e.g., Grinker & Spiegel, 1945, Ch. 2), and an attempt is made to limit the frequency of missions per unit of time so that fatigue does not become a factor. The chronic nature is the repeated exposure of pilots to combat missions over the length of the tour.

One important aspect of the pilot training program is to teach fighter pilots to perform effectively under stressful operational conditions. By virtue of selection and training, the combat pilot has special aptitudes and acquired skills. Service pilot selection and classification batteries usually include tests of psychomotor skills, personality questionnaires (which include tests of decisiveness and risk taking), and an assessment of a wide range of information-processing capabilities (Kantor & Bordelon, 1985; see also North & Griffin, 1977; Youngling et al., 1977). Upon successful completion of initial and advanced coursework, and selection into the fighter/attack track for specialized training, a close match hopefully exists between those qualities needed for successful combat flying and those possessed by the pilot. By the time combat status has been conferred on a pilot, his training will have exposed him to a number of stressful situations, such as first solo, first night flight, participation in air combat maneuvering training (Burton, Storm, Johnson, & Leverett, 1977), and Red Flag exercises, first spin maneuver, and first aircraft carrier landing (Miller, Rubin, Clark, Crawford, & Arthur, 1970).

The Impact of High-Tech Aircraft and Weaponry on Air-to Ground Delivery Accuracy: Workload. A key concept to the study of successful performance in

an operational aviation environment is that of workload. Part of what makes today's air-to-ground missions potentially stressful is the high demands placed on the operator for constant attention to multiple inputs, rapid decision making and efficient motor responding. That is, pilot performance in high-tech aircraft is contingent upon the ability "to quickly sort, prioritize, and act on a continual stream of visual, auditory, and tactile information" (Kantor & Bordelon, 1985, p. 259). Multi-channel information processing capability, ability to concentrate and filter out irrelevant stimuli (thus, divided as well as selective attention abilities), rapid decision making, memory for procedures, and sensory-motor skill proficiency are indeed all a must. Specifically, the fighter pilot's cognitive workload must be time-shared between the duties of target acquisition, ordnance selection, communications, choice and use of countermeasures, ADA sightings, decision to engage the target, and attack posture to target (to include altitude, speed, maneuver pattern). The issue, then, is the effect of a high degree of sympathetic and central nervous system arousal (e.g., pounding heart, tense muscles, dry mouth, queasy stomach, sensory overload, disrupted attention) on performance of a complex task which must be performed quickly and accurately. Does the required activity in the cockpit actually act as an "anxiety distractor" in keeping the pilot's attention focused on the tasks at hand, or is he so overwhelmed by multiple stimuli and requirements for action that his main duty of weapons delivery is degraded? The stress of operating in a dangerous environment may interact with the high task load of operating a sophisticated aircraft to the extent that a degree of indecisiveness or hesitancy or sensory overload may result in inaccurate weapons delivery accuracy.

Thus, in a high workload environment, stress can act to force the individual to be selective about information input and response output. Although today's air-to-surface weaponry represents sophisticated technology, the sophistication of the attack avionics itself (i.e., the weapons delivery system from the pilot's point of view) must not represent task saturation if accurate delivery is to be achieved. For example, it was mentioned in the "Attrition Management" section that jinking became a widely used and effective technique during the Vietnam War against radar guided weapons. However, altitude, speed, and dive angle must be coordinated at the weapons release point, and during this delivery envelope the aircraft is most vulnerable to ADA. To the extent that ADA results in either a workload "overage" to the pilot and he does not stabilize the aircraft properly for weapons release, the pilot has been suppressed. The operation of some aircraft is so complex that both a pilot and a weapons officer are required to handle all the functions. In single-seat fighters, items such as on-board computers and head-up displays have shared the workload to allow the pilot to attend to all his duties. This topic of pilot workload is developed further in Appendix B.

Air Combat Examples. Examples of air crews' reactions to operating in air space covered by ADA are provided in Table 3. A number of important concepts are contained in the entries. The first panel covers examples from the literature on World War II. The first two entries from the next panel on the Vietnam War illustrate the previously discussed point of ADA affecting workload capacity. The last two entries reflect helicopter combat duty during the IAMSON 719 engagement of that war.

Although certain events of air combat may be perceived as stressful by

Table 3

Examples of Air Crew Reactions to Air Defense Artillery

World War II

Interviews with some 4,500 combat fliers (Shaffer, 1947) upon their return to the United States revealed that the latter missions of one's tour were felt to be more stressful than earlier ones. Part of the trepidation long into the tour was fear of the law of averages catching up on one; the greater fear on the first mission was being a coward, a failure. Additionally, greater stress was felt on preplanned versus on-the-spot missions (possibly due to anticipatory anxiety). Specific fears while in the air included seeing flak or enemy tracers, and not being able to return fire or spot a reported enemy plane. Positive factors were confidence in one's equipment and crew.

The degree of motivation for combat was a function of type of aircraft, the lowest motivation being in heavy bomber crews, followed by medium and light bombers, and fighter pilots (Stouffer et al., 1949, Ch. 8). The differences in feeling were likely due to the perceived controllability over the situation (i.e, the superior speed, maneuverability, and fire power of fighters. (Rachman, 1978, pp. 72, 80-81; Stouffer et al., 1949, pp. 408-409)

Within the Royal Air Force, the cumulative effects of stress as exhibited by neurotic behavior were distributed along a continuum of perceived dangerousness of the type of mission: Thus the incidence of neurosis was greatest on pilots flying night bombing missions, less on fighter pilots, and least on Coastal Command missions. (Symonds & Williams, 1943; Tompkins, 1959)

The German ADA proved effective against the English Bomber Command sorties: "Precision was also adversely affected by the strength of enemy aircraft artillery, for the scatter of bombs round an aiming point was greatest when the target was most heavily defended". (Reid, 1979, p. 3)

The calculation and plotting error of wind vectors by British navigators during night operational sorties increased in and around the target area as compared to safer sections of the route and performance during quasi-operational night training flights. (Reid, 1945)

Bombardiers' ability to guide (track) bombs to their targets showed increasing degradation as a function of intensity of the combat situation versus during training. The more nonsensitive the guided system, the worse the performance under combat. (Walker & Burkhardt, 1966)

Table 3, cont.

Examples of Air Crew Reactions to Air Defense Artillery

Vietnam War

"The missiles and their associated radar threats considerably complicated the task of combat pilots and military mission planners. Pilots, in addition to navigating, flying, searching for, and attacking ground targets or enemy aircraft, now also had to monitor radar homing and warning (RHAW) sensors, listen to transmissions from ships or aircraft radar systems for warnings of approaching MiGs, operate electronic countermeasures equipment, and visually watch out for undetected flying 'telephone poles' or marauding MiGs." (Nordeen, 1985, pp. 208-209)

"North Vietnam's heavy air defenses damaged or downed many aircraft; furthermore, they lessened the effectiveness of those that were untouched by forcing pilots to divide attention among a multitude of tasks. While evading surface-to-air missiles, antiaircraft artillery, or MiGs, pilots got lost, were forced to jettison their bombs and/or fuel tanks, or bombed the real target with much less accuracy than they had the target on the practice range." (Nordeen, 1985, p. 209)

During the Vietnam War, the fighter's reliance on "SAM killers" (mentioned in the "Attrition Management" section) to attrit or suppress ADA sites was heavy: "With the strike forces and escorting fighters flying at 500 knots and higher, seconds became critical. If a Weasel's timing were off, it could well mean that a member of the strike force would be shot down or that the enemy's defenses would force unacceptable bombing errors". (Momyer, 1979, p. 131)

"The most frequently used and frightening antiaircraft weapons the Hueys encountered were the 12.7 mm or 50 caliber machine-guns. These weapons had a distinctive sound and fired tracers every few rounds, which looked liked basketballs or pumpkins coming at the aircraft." (Fulbrook, 1986a, pp. 43-44)

"Generally, there are two types of aviators when bullets start flying. All of us experience a lot of anxiety, but some have a facilitating anxiety and actually fly more precisely. Others have a debilitating anxiety and overtorque or overcontrol their aircraft in an instant." (Fulbrook, 1986b, p. 12)

pilots, this stress may not necessarily affect certain kinds of performance, as perceived by the pilots. A questionnaire was administered to 563 members of the Red River Valley Fighter Pilot's Association (Kantor & Ideen, 1980). Membership in the Association is contingent upon having flown combat missions around the Hanoi region. Data regarding the pilots' combat experience was obtained through questions pertaining to the frequency with which they performed or encountered each of 43 events common to combat missions. They also rated the stress of each. These data were analyzed as a function of their perceived "number of sorties that could be flown effectively by a single pilot in a two-week period under the stress levels encountered in missions flown into North Vietnam." Events such as personal encounters with and perceived stressfulness of ADA were not judged by these pilots to be significant limiters of sortie run estimates.

British pilots in the Falkland Islands War reported that they did not see tracers or flak bursts fired at them because they were too busy concentrating on the task of making their run and keeping the cross-hairs centered on the target (i.e., the "tunnel vision" effect).

An hypothesis put forth by Haering (1986) states that ADA does not function as a stressor which reduces pilot accuracy, but acts as a precipitator of tactical changes which reduce risk (i.e., the application of attrition management). The statement is based on Vietnam War United States Air Force (USAF) F-105 data which indicate that dive bombing accuracy was similar whether air defense intensity was light or heavy. It is to be noted that release altitude was 8,000 feet, visual bombing was employed, and the dive bombing tactic placed the aircraft over the drop area for no more than 10 seconds. To summarize Haering's position, ADA could cause reduced weapons delivery accuracy by virtue of the necessity to use nonoptimal target identification and attack profiles (e.g., the prudent practice of increased standoff or one target run), but if the experienced pilot commits to a tactic during the attack phase of his mission, accuracy is not affected.

It is noteworthy that Air Force command and control foresaw possible performance degradation during a pilot's last few missions in Vietnam (recall that WWII pilots were concerned with the "law of averages" catching up): In recognition of the potential harm of end-of-tour distractions in fighter pilots (i.e., paying undue attention to external danger and internal fear stimuli), their last ten missions were flown in relatively benign combat environments. This policy was an attrition management practice in recognition of the human tendency of the pilot to become more conservative (i.e., suppressed) in his willingness to take risks and to be more oriented toward self-preservation behavior near the end of the tour. As stated by a former USAF fighter pilot: "After X number of missions, human nature being what it is, the pilot suddenly realizes he has made it this far alive and it seems that there is indeed a chance that life may be possible. It becomes utterly priceless again, and the warrior becomes a Candy-Ass. He starts planning to survive the terminal disease of war, and his courage leaves him. He is now vulnerable and a hazard to himself and his compatriots" (Basel, 1982, p. 103).

Summary of Factors Influencing Suppression

Attrition management was previously defined as command and control practices which function to weigh the risk of assets against mission needs.

To some degree suppression could be construed as a pilot's self-initiated prudent practice and the reasons for the behavior could be manyfold: for example, (1) unforeseen events near the target area (such as threat intensity much greater than anticipated); (2) cockpit task workload in a threat-rich environment on a particular mission becomes too high to the point of overload (cognitive suppression), as manifested perhaps in inaccurate or incomplete weapons delivery; (3) preoccupation with nearness to end of tour could cause lapses in attention or a conservative attitude, resulting perhaps in early bomb release or over jinking.

Thus, many variables are interactively at work influencing pilot performance on a ground attack mission under pressure. These variables are listed in Table 4. The relative weight or importance of any given factor would be time-and-pilot specific, but one which showed to be important in WWII was that of mission experience. Pilots in their initial combat missions were more concerned with peer pressure to behave properly under fire (performing as trained) and not look bad to the rest of the squadron. As the number of required missions or number of combat hours was reaching completion, combat motivation decreased and more concern was shown for self-preservation, making it safely to the end of the tour (Rachman, 1978, pp. 53, 59-60; Stouffer et al., 1949, p. 385). The Air Force practice of having combat pilots fly relatively safer missions for the last ten missions of their Vietnam tour was to guard against concern over the "law of averages".

Many of the other factors listed in Table 4 are equally important in terms of their influencing the pilots' performance on any given mission. For example, a pilot may be more willing to accept risk and be oriented toward completing his mission if he is in the middle of his tour (i.e., combat experienced), if the mission has been briefed to him as being critical, if he perceives his aircraft, weaponry, and own personal skills as superior to those of the enemy, if he is well rested, and if visibility and other weather factors favor the successful accomplishment of the mission. If these factors are weighted negatively, he may become more risk-adverse and inclined to adapt a more conservative attack profile in "heavy" operational conditions.

SUMMARY

As with many weapons, air defense artillery can be an effective deterrent. In fact, ADA can affect air-to-ground weapons delivery accuracy without actually shooting down aircraft: (1) Its existence could force the invoking of attrition management, command and control practices which allow a protected target to be attacked but with a reduced risk to pilot and aircraft (safer attack profiles, single passes, use of standoff weapons, use of countermeasures, support aircraft in strike package, instructions for action upon contact). A nonlethal effect, then, of ADA is that the attacking force's strategy is altered to preserve resources, and as a result accuracy may be sacrificed. Attrition management is widely practiced as evidenced by the examples provided in Table 2. (2) Suppression of pilot performance can be achieved by task overload. In the face of ADA, the numerous duties in addition to simply keeping the aircraft airborne may be so demanding that proper attention may not be paid to weapons delivery. (3) Pilot factors (self-induced prudent practices) as presented in Table 4 can have a suppressive effect on the efficacious use of a high-tech fighter's firepower.

Table 4

a

Factors Influencing Pilot Performance on a Given Combat Mission

Pilot Characteristics

- Combat experience
 - Beginning, middle, or end of tour and how pilot felt he performed on previous missions
 - Aircraft ever been shot at
 - Aircraft ever been hit
 - Squadron aircraft ever been hit
 - Number of hazardous missions flown recently
 - Type and intensity of ADA is as predicted, or is different from, the intelligence forecast
 - Visual sighting of tracers by self or others in formation; cockpit warning signifying enemy missile lockon; observation of signature signifying a SAM launch
 - Performance expectations: Perceived ability and confidence in flying and weapons delivery skills; perception of supremacy of aircraft (speed, firepower, maneuverability, ability to take hits) and capability of ordnance on board; perception of control over situation
 - Perception of usefulness of countermeasures such as ECM, chaff, and flares
 - Perceived probability of ADA missiles or guns scoring a hit; perceived skill of the enemy; reputation of enemy's ADA
 - Degree of hatred of enemy; degree of desire for revenge
 - Fatigue level (is the pilot's confidence undermined, does he become afraid of his own abilities while in a less-than-optimal level of alertness)
 - Crew configuration (1 or 2 seater) and workload; if 2-seater, is the pilot in charge of weapons delivery
 - Amount of time between mission briefing and take off (precombat apprehension)
-

a

Performance is defined as completeness and accuracy of weapons delivery accuracy.

Table 4, cont.

a

Factors Influencing Pilot Performance on a Given Combat Mission

Mission Characteristics

- Type of target
 - Type of mission: E.g., close air support over friendly lines or a strike deep within enemy territory
 - Type and intensity of ADA threat (intelligence forecast)
 - Visibility around target area
 - Type of terrain
 - Night or daytime mission
 - Attack instructions
 - Exposure time over target
 - Attack profile
 - Attack order in squadron
 - Number of passes over target
 - Use of stand-off weapons
 - Aircraft fired upon during ingress phase
 - Predefined command and control instructions for action upon enemy contact; criteria for mission abort
 - Type and number of support aircraft (strike/support ratio)
 - Suppression of ADA and radar by ground forces or standoff airborne jamming; ECM and flare equipment onboard
 - Importance of targets (both to command and control and to pilot) and necessity of achieving target damage on this particular mission
-

a

Performance is defined as completeness and accuracy of weapons delivery accuracy.

The stress of operating in a dangerous environment may be expected under certain conditions to result in some degradation, but severe stress reactions (aborting, exhibiting severe startle responses, or overflying the aircraft) would in general not be expected given these considerations:

- It is a reasonable hypothesis that pilots who become combat pilots have by virtue of previous exposure to stressful experiences during their stringent training period been somewhat "immunized" to the stress of performing in dangerous environments.
- Pilots are the most highly trained of all the combat arm skills and are trained to act in emergencies under realistic conditions.
- Their high task orientation, motivation, confidence in their skills (i.e., high self esteem) and the abilities of their high performance aircraft would give a sense of controllability (mastery; influence on outcome) over the situation.
- Pilots are indoctrinated during their expensive training that they are worth several million dollars and are an important investment. They know that they are flying a very expensive aircraft, and believe that command and control decision makers will carefully weigh the risks when sending airpower on a mission. The prudent practices represented in attrition management preclude pilots from being placed in conditions of unacceptable risk. Their actions upon contact are covered in the mission briefing.
- Pilots believe that their air defense countermeasures (ECM, chaff, evasive maneuvers) reduce the effectiveness of current ADA weapons. The belief that their aircraft's capabilities represent a technological lead over ADA produces pilot confidence. "Fully aware of the dangers which beset him, the good pilot is provoked to put out his best and meet them by appropriate and effective activity." (Davis, 1948)
- The gradual indoctrination of pilots into "heavy" missions lets one adapt to operating in stressful environments, to know what combat stress feels like and that one can perform in spite of it.

Any resulting incomplete or inaccurate weapons delivery on a given mission could be a combination of attrition management, workload, and pilot factors. The relative influences of each would be mission-and-pilot specific, but the biggest contributor would seem to be attrition management practices, followed by workload stress in and around the target area, and pilot factors.

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APPENDIX A

SUMMARY OF THE-STRESS-AND-PERFORMANCE LITERATURE

Types of Studies

A large body of laboratory literature exists on the psychology of stress, generally defined. Such studies have been categorized (Harris, Mackie, & Wilson, 1956; see also McGrath, 1982) as those involving (1) failure stress (e.g., test anxiety; contrived experimental situations such as difficult tasks, unreasonable time limitations), (2) distraction stress (acoustic and visual noise stimuli), (3) fear stress (electric shock; observation of gory movie scenes), (4) physical discomfort stress (high-intensity noise; induced muscular tension; extreme temperatures, as e.g., hand or foot in cold water), and (5) pacing or speed stress (high rates of responding per unit of time).

Of interest for the present application is performance in real-life stressful environments, that is, situations in which external stressors present a perceived threat of physical or psychological harm. For obvious ethical reasons, this topic has not been widely studied. Information is available from such naturalistic settings as (1) public speaking (Idzikowski & Baddeley, 1985), (2) examination taking (Wine, 1982), (3) sport deep sea diving (Baddeley & Idzikowski, 1985), (4) sport parachuting (Fenz, 1975), and (5) hazardous duty occupations: (a) Explosive ordnance disposal operators (Rachman, 1982; Cox, Hallam, O'Connor, & Rachman, 1983); (b) military deep sea diving and submarine duty; (c) military parachuting (Hammerton & Tickner, 1969); (d) true combat studies and contrived combat scenarios.

Widely cited examples of contrived military situations are studies conducted by Berkun and colleagues (Berkun, 1964). Deceptions included: (1) A "ditching" experiment in which basic trainees were led to believe their aircraft would have to make an emergency landing. Performance measures were collected on the accuracy of completing an Emergency Data Form which had difficult-to-follow instructions, and on retention of a recently read SOP for ditching; (2) an "artillery" situation in which basic trainees, tested individually, underwent a supposed military exercise in a remote area; the subject was led to believe both by radio transmission and by preplanted nearby charges that he was in danger from inaccurately fired artillery rounds. The performance measure was the speed with which the subject could follow instructions and convert his radio to an emergency-transmission mode so that his position could be identified for a rescue effort; and (3) a "demolitions" experiment in which the subject was led to believe he has inadvertently injured a fellow worker because of his improper wiring of a demolition switchbox. The performance test was the speed and accuracy with which he could follow instructions to fix a malfunctioning field telephone to call for medical help. All experiments used control groups, and the three scenarios showed significant performance decrements between the stressed and unstressed subjects.

An example of a study dealing with ground combat is the FIGHTER project which attempted to characterize effective versus noneffective combat infantrymen in the Korean War (Egbert, et al., 1958). A psychological battery was given to 310 soldiers. It consisted of questionnaires and inventories, and 60 objective tests which measured personality, intelligence,

aptitude, motivational, interest, and background variables. Classification by the experimenters of a soldier into either a "fighter" or a "nonfighter" group was based on ratings by fellow unit soldiers. A fighter tended to be more intelligent, masculine, socially mature, and a doer, was preferred socially and in combat by his peers, had more leadership potential and a greater amount of military knowledge, better emotional stability, health and vitality, a more stable home life, and showed greater speed and accuracy in manual and physical performance.

It should be mentioned that a straightforward interpretation and application of most of the stress data to efficiency of behavior in real-life dangerous settings is difficult for the reasons listed below (these points are adapted from Harris et al., 1956, Labuc, 1981, & McGrath, 1982):

- Variation in individual response to stress: In part a function of motivation, intellect, and trait anxiety (as related to efficiency of coping behaviors)
- Situational and stress validity: Realism of the ethically acceptable stress situation -- does each subject perceive the setting and intensity of stimuli as stressful; has the true meaning of the experimental question been kept from him; do the experimental stress conditions adequately mimic real-life serious threat situations, or are they too artificial for applicability
- Task validity: For example, does a laboratory psychomotor test "map" well to the applied situation of operating specific equipment under stress
- Temporal relationship of stress and performance tasks: In many settings it is necessary for the tasks to be measured before (i.e., during the anticipation interval) the subjects enter or after they exit from the dangerous environment; stress level may well be lower than that during the operational period and measures might not relate to behaviors which directly interact with the stressful environment
- Wide variation in duration of stressors from study to study
- Variety of methodological conditions and stressor parameters
- Confounding of combat data with fatigue, therefore making it difficult to attribute performance decrements to fear alone

- Use of subjective ratings on combat situations: Caution is required, because subjects may not want to state that they were afraid, and that indeed their performance was affected. How accurate will their statements be when gathered after the fact?

Psychiatric Battle Casualties

Another source of data on stress and performance, although non-experimental in nature, is from the psychiatric casualty literature. A severe form of degradation of performance under stress is manifested in the signs and symptoms of combat psychiatric casualties. The phenomenon has been given many descriptors (for reviews, see Bourne, 1970; Chermol, 1983; Glass, 1969; Ingraham & Manning, 1980; Kubala & Warnick, 1979; Labuc, 1981; Michel & Solick, 1983; and Tischler, 1969):

- "Nostalgia" in the Civil War
- "Shell shock" in WWI (termed "war neurosis" at end of War)
- "Psychoneurotic anxiety", "exhaustion", "operational fatigue" during WWII
- "Combat exhaustion", "combat fatigue" in the Korean War
- "Combat reaction", "stress reaction" in the 1973 Middle East War
- "Neuropsychiatric casualties", "psychiatric battle casualties" today

Of the many behavioral forms that the severe stress reaction could take on the battlefield, some of the ones most important from a performance point of view during an engagement are freezing, severe shaking, frequent lapses in attention, problems with concentration and judgment, excessive verbal preoccupation with the danger of the battlefield, or otherwise inappropriate responses (e.g., constantly lagging behind the unit). Reference was made to WWII infantrymen who may have been so overwhelmed by the sights and sounds of combat that they did not fire their weapons (Marshall, 1947). It is noteworthy that individual participation increased during the Korean War, supposedly a function of troop perception that firing was essential to survival, to better training, and to a more active mingling amongst the troops by leaders during engagements (Marshall, 1952).

Not all abnormal behavior during combat need necessarily warrant the "label" of psychiatric battle casualty. Occasional episodes of nonproductive combat behavior are generally considered a natural response within the context of battle. However, when symptoms persist even after withdrawal from the stressors, or when clearly inappropriate, non goal-directed behavior is frequently exhibited during combat, the label of psychiatric battle casualty is more apt to be appropriate.

Incidence of combat psychiatric casualties is generally considered to be

an interaction of the following variables: The intensity, duration, and type of conflict, number of battle casualties, time in a combat setting, type of weather, type of unit one is in and its amount of idleness, battle anticipation, uncertainty concerning the nature of the battle, ability to retaliate, cohesion and leadership, and personality factors of the individual soldiers (Bourne, 1970; Gal, 1988; Kubala & Warnick, 1979; and Michel & Solick, 1983). The lower incidence rates during the Vietnam War as compared to other wars has been attributed to the 12 month tour of combat duty, a good support system (phone calls, mail), rest and recuperation opportunities, air support of ground troops, and engagements which were reduced in duration, intensity, and lethality (Bourne, 1970; Chermol, 1983).

APPENDIX B

ROLES OF COMBAT AIRCRAFT, CREW SIZE, AND WORKLOAD IMPLICATIONS

Missions

In the current decade, the term "multi-mission aircraft" is becoming increasingly common. The foremost reason for such aircraft is the prohibitive cost of developing dedicated interceptor, air superiority, and ground attack aircraft. Another reason is that the distinction between "fighter" and "attack" aircraft has become blurred in today's threat-intensive combat scenario. A pilot may fly combat air patrol one day and close air support the next. This lesson was learned in Viet Nam where the F-4 Phantom distinguished itself as a true multi-role aircraft, delivering a variety of weapons loads and holding its own against the MiG-21 (a dedicated point-defense interceptor) in air-to-air combat. An example of a multi-mission combat aircraft of the current generation is the McDonnell-Douglas F-15E Strike Eagle, which is capable of extremely fast (above 900 mph), low level (below 500 feet), low-profile penetration missions, and can carry a variety of weapons. It is also highly capable in the role of air-to-air combat.

One Versus Two Crewmen

The trade off for an aircraft's multi-mission capability is that it may require a two-man crew (the aircraft mentioned above are two-seaters). There are a few notable exceptions, for example the single-seat F-16C and the FA-18, but these are not true all-weather aircraft in that they cannot bomb a target "blind." There are also some salient questions about the ability of a single pilot to deliver weapons accurately in a threat-rich environment. The Air Force has taken a firm stand requiring the two-man cockpit for all-weather, multi-mission capability; the Navy has been somewhat equivocal on the issue, citing the FA-18 as an example of low observability (the aircraft is hard to see) being traded off for the added capability afforded by a two-place aircraft. Even so, the Navy still maintains and operates the two-place, subsonic A-6 series which can operate under poor weather conditions and at night, and it has considered adding another crewmember to the next generation of FA-18s.

Although experts tend to agree on the advantages of a two seat configuration, there are only a few definitive simulator studies which cite empirical support for this position. A study conducted by Hughes Aircraft (1977) is a notable example. In this study, single and two-seat-configured cockpits were compared as pilots flew simulated air-to-ground strike missions. The central finding of this study was that as threat density increased, the performance difference between the one and two-man crews became greater, with the latter consistently demonstrating superior performance. The rationale explaining this difference is predicated upon the effects of multiple threats (such as SAMs, AAA, and aircraft) on single pilot workload. The Hughes (1977) report added that the presence of the additional crewman freed the pilot from defensive tasks, such as monitoring Rear Warning Radar (RWR) and other displays, to allow him to scan visually outside of the cockpit for ground and air threats. In aerial combat especially, the unseen threats are the most dangerous (Flanagan, 1981). For example, in Vietnam, unseen MiGs accounted for 80 percent of US air-to-air losses (O'Mara, 1979). Marine Corps records

show that most threats were spotted by the back-seater in the F-4 (O'Mara, 1979). Flanagan's (1981) position that the Navy F-4's low loss rate per sortie was due to the ability of the back-seat pilot to handle defensive functions against MiGs and SAMs and the pilot to concentrate on offensive functions gives further support to the contention that the two-place configuration is optimal for the multi-mission aircraft.

Workload Implications

Consider the duties of a fighter-bomber pilot on a ground attack mission: He will have to employ countermeasures against aircraft and SAMs, scan his radar for detected threats and AAA radar lock-ons, search the world outside the cockpit for undetected aircraft and flakbursts, and at the same time go through the tasks necessary to navigate, designate, and bomb the target, which is likely to be heavily defended. In addition, he may be transmitting and receiving messages regarding incoming threats. He is required to make many important, split-second decisions. The workload of the pilot can quickly become task saturated (see e.g., Kitfield, 1989; and Thompson, 1987).

There is anecdotal evidence of pilots resolving the competition between concurrent tasks by actually turning some systems off so as to minimize the "distraction" from other tasks which they considered more critical to the mission. But it is also common for a pilot to overlook some routine but critical tasks because of the severe strain imposed on his information processing and task time-sharing abilities. Thus, even if ADA is not able to kill an aircraft, its use might be able to overtax the pilot's workload to the point where he simply cannot be vigilant to all threats and press home his attack at the same time.

Many F-15E crews will be drawn from the F-111 and F-4 communities. Since the F-15E is several generations removed from its predecessors, one would expect that the crew workload has been reduced through the use of automation and multi-function displays. Such is not the case. Some maintain (e.g., Bell, 1987) that the transition from earlier systems to the Strike Eagle will result in a much heavier workload, primarily because there is so much more to do in the F-15E. The principal reason for the workload increase is the enhanced multi-mission capability of the F-15E and the host of sensors that are integral to the system (Bell, 1987). Because of the complexity and capability of the system, the US Air Force's Human Resource Laboratory (Williams Air Force Base, Arizona) is currently investigating the allocation of responsibility between the pilot and Weapons Officer (WO). The WO's typical duties now involve navigation and timing of the mission as well as weapons release and electronic countermeasures. Some of these duties can be traded off between crewmen if this becomes necessary. A F-15E simulator study (Bell, 1987) found that if one crewman is injured or incapacitated on a simulated mission, the degradation in performance can be large. This result seems consistent with the Hughes simulator study, and presents a cogent argument for the advantages of a two-place cockpit in the multi-mission aircraft.

A large number of studies has investigated the relationship between task loading (number of discrete tasks; difficulty of individual tasks) and performance (see Damos & Lintern, 1981; Wickens, Sandry, & Vidulich, 1983).

A generalization from these studies is that when a pilot in a simulator is confronted with multiple tasks the effects of task loading on degree of performance degradation tend to be multiplicative. This degradation is partially due to the demands which are imposed upon the pilot's information processing resources.

The demands of multiple tasks are especially severe when the input and output channels are mediated by opposite hemispheres of the brain. Such is true in the case of visual input, motor output tasks, which comprise a large number of those performed by pilots. Wickens (1980) has found that the ability to time-share concurrent tasks declines as the degree of overlap between input and output channels mediating these tasks increases. Thus two tasks that share the same information processing resources will be in competition with one another, and hence the amount of degradation may be significant. For example, a pilot must center the target in his head up display, designate it by pressing a button on the throttle or joystick, at the same time monitor his altitude and airspeed, and track incoming SAMs and AAA radar lock-on showing up on his RWR display. In the foregoing example, all inputs were visual and all outputs called for were motor. The intervening cognitive processes related to controlling the aircraft are predominantly spatial. When information processing channels become saturated, performance likely will decrease. Thus, even if ADA does not achieve a kill, an increased workload due to its presence could be enough to degrade weapons delivery accuracy.