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USAARU REPORT NO. 67-5

APPROACH TO THE EVALUATION OF TOXIC HAZARDS
FROM WEAPONS EXHAUST IN ARMED HELICOPTERS

By

G. L. Hody, CPT, MC

NOVEMBER 1966

U. S. ARMY AEROMEDICAL RESEARCH UNIT
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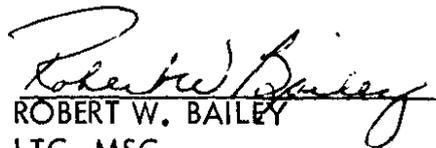
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ABSTRACT

The complexity of flying and the environmental stresses encountered by pilots of armed helicopters are continuing challenges. Under such difficult conditions any interference with mental or sensory capabilities of the pilots can be reflected in an increased casualty rate. Helicopter mounted weapons release a toxic exhaust which could disturb vision and hearing and might adversely affect reaction time and the reasoning process. A brief exploratory study confirmed the impression that the weapons exhaust can reach the crew in measurable concentrations. An objective assessment of the hazard is obviously needed before costly or inconvenient corrective measures need be considered. A careful search failed to reveal existing methods for the required evaluation which involves continuous measurement of rapidly changing contaminant concentrations in a confined and vibrating environment. An experimental program designed to explore a technique for meeting the operational requirement is being implemented in cooperation with the Air Force Rocket Propulsion Laboratory. While the potential for a hazardous situation is very real in all armed aircraft, the concern is with the new, experimental helicopters, equipped with multiple rapid fire weapons systems, in addition to those armed helicopters now deployed in the field.

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ROBERT W. BAILEY
LTC, MSC
Commanding

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INTRODUCTION

The armed helicopter has proven itself to be an indispensable weapon for the close support of ground troops. Because of the high weight lifting capability of modern turbine powered helicopters the installation of a high concentration of weapons systems of many types is possible. All of these systems are activated by the burning of propellants and for this reason emit exhaust products. If the aircrew are exposed to the products it is possible that their ability to perform well in combat and flying may be impaired. The most vulnerable human faculties are the senses of hearing, vision and the intellect.

The problem is not academic. Preliminary measurements of carbon monoxide (a principal exhaust component) in armed helicopters have shown that a significant exposure to gun gas is possible despite brisk ventilation^{1,2}. Aircrew-members have also reported informally that they noted eye and throat irritation as well as an increased incidence of motion sickness when exposed to gun gas. Eye and throat irritation and any impairment of sensory or intellectual function can be contributory causes of aircraft accidents, particularly under the strenuous conditions of low altitude combat flying. The more subtle effects of early carbon monoxide poisoning are similar to those of hypoxia in that they cannot be detected subjectively by the victims and must be demonstrated by special techniques.

It is true that personal protective devices, cabin ventilating systems, pressurization, or oxygen breathing could solve the problem. On the other hand these approaches involve considerable expense and, more important, would load down the aircraft with excess weight. It must be remembered that the armed helicopter is used in a combat environment, in which minor risks associated with armament are accepted if the weapons are effective in reducing a much greater hazard from enemy action. Thus, what is needed at present is not a corrective scheme but rather an accurate method of evaluating the toxic hazard so that it can be considered in the proper context.

In a previous report¹ it was proposed that in flight measurement of carbon monoxide might serve as the basis for a more complex toxicological analysis of the environment. In this paper the concept will be developed in detail and an ongoing study will be described.

DESCRIPTION OF APPROACH

The problem at hand is a special illustration of the general case in which it is desired to predict the performance decrement resulting as a response to the stress placed on subjects by an unfavorable environment. There are at least two ideal solutions, which though they are beyond the present technology, are useful to consider in the derivation of a workable analysis. The first of these is the complete physical and chemical characterization of the environment from which precise prediction of performance would be made. The prediction would be based on previously performed physiological and psychological experiments correlating performance decrement with environmental parameters. A quantity of appropriate data is available in the literature. The second ideal solution is the total assessment of pertinent pilot and crew performance measure in actual flight under all possible operational conditions of interest.

Psychophysical Measurements of Performance. Considering the latter approach first, it must be remembered that the recent development of miniature solid state components makes it possible to bring many of the instruments used for psychophysical experiments into aircraft environments. In fact most parameters of performance, including visual and auditory acuity, reaction time, and higher orders of intellectual function such as pattern and speech discrimination and learning, can now be tested accurately in "the field". Nevertheless, it is not practical to consider psychophysical techniques for the proposed study program. The most important reason why this is the case is the extreme difficulty in accurately duplicating the environment of an armed helicopter in a "fire fight" sufficiently long for the required measurements to be taken. A second difficulty is the large variety of flight profiles and weapons systems that need to be tested. This requirement for a large number of tests is further aggravated by the quantity of data points and the difficult data reduction normally associated with psychophysical experiments. It becomes obvious that the magnitude of effort required is prohibitive for a first study. Finally, certain toxic gases including nitrogen dioxide can cause serious damage, but because their effects are delayed for several hours, or days, their presence would not be revealed by psychological tests.

Physical and Chemical Measurements. The alternate approach which begins with atmosphere analysis permits the ready use of a large amount of toxicological and psychological data available in the literature. However, complete characterization of the toxic exposure is complicated.

Prediction of toxic effect requires a precise knowledge of the type of toxic materials present and the way in which the amounts (concentrations) vary as a function of time. This "concentration - time" history must be precisely defined

because, unfortunately, many toxic materials do not act in direct proportion to their "concentration time product". Another way of saying this is that, the toxic effects of many compounds are different for an exposure at a high concentration and a short time than for a low concentration and a long time even if the product of concentration and time are the same in both cases.³⁻⁴ This is particularly true for irritant gases, some of which may be found in the airplane environment. The problem of obtaining suitable concentration-time measurements is difficult because easily obtained instruments in most cases have long time constants. While these are acceptable in industrial situations where concentration of contaminants in the air are relatively stable, the same instruments will not do a proper job in an aircraft in which brisk circulation and intermittent use of the weapons contribute to rapid changes in concentration of contaminants.

Two additional problems also complicate analysis. First, quantities of highly toxic materials in the aircraft are expected to be as low as 10^{-4} to 10^{-6} moles per hundred moles (moles %) or less. In the presence of less toxic gases such as CO_2 at 10^{-2} or 10^{-3} mole % concentrations, important trace materials could be missed. Second, optimum propellant systems for weapons are underoxidized. Thus the end products of combustion, which are emitted under high pressure and temperature from the gun barrel or in the rocket exhaust, could be reactive upon making contact with oxygen and water vapor in ambient air. In the armed helicopter, aircrews are exposed to the exhaust from the weapons systems very promptly after its emission (in most cases within two to ten seconds), and it is the composition of the gas during this brief time interval which is of interest rather than the equilibrium products obtained after complete chemical reaction is permitted to occur. For these reasons the possible reactivity of the effluent gases also complicates the required analysis.

Selection of Method. Consideration of the available industrial techniques in the light of the above information is discouraging. First, collecting the helicopter atmosphere of interest in evacuated cylinders, a popular technique, permits continuing interaction of the components. Cryogenic sampling might decrease the rate of the chemical reactions sufficiently but in any case no trapping technique could provide an accurate description of the way in which contaminant concentrations change with time because it would require an unreasonable number of samples to resolve rapid changes in concentration.

Obviously, continuous measurement of all toxic gas concentrations, by instruments installed directly in the aircraft, would be a suitable solution. For such a project, the instruments used would have to combine the best available properties with respect to speed, sensitivity and resolution. It is not yet possible to obtain instruments sufficiently rugged and compact to be flown in the limited

space and high vibration environment of the helicopter which also meet the analytical requirements.

Fortunately there is another approach, based on the finding that carbon monoxide is a major component of the exhaust products. Carbon monoxide can be measured with compact instruments*. If the carbon monoxide concentration in the aircraft can be determined accurately as a function of time during typical firing runs the concentration of all air contaminants in the aircraft can be calculated. For any exhaust material of interest the calculation is made from the ratio of the concentration of that material to the concentration of carbon monoxide in weapons exhaust. For example, if it has been shown that hydrogen cyanide is emitted in the rocket exhaust in such a way that its concentration is 1/100th that of carbon monoxide and that the carbon monoxide concentration in the aircraft is at a given time 1000 parts per million (PPM), it follows that the concentration of hydrogen cyanide at that time is 1/100th of the carbon monoxide concentration or 10 parts per million.

Obtaining reliable information about the concentration ratios of components of the weapons exhaust can now be approached by search of the literature, computer predictions and measurement made under laboratory conditions rather than flight conditions. In the laboratory it is possible to study the exhaust components shortly after emission from their source and in much higher concentrations than can be safely obtained in the aircraft, increasing the possibility of detecting significant trace materials.

For the chosen scheme to be effective there are two basic requirements:

1. There must be no extraneous source of carbon monoxide on the aircraft which could interfere with the measurement. (For example, if carbon dioxide had been selected as a basis for measurements the breath from the crew would interfere). On turbine powered helicopters, carbon monoxide is not present in significant quantities in the engine exhaust and no other extraneous sources have been demonstrated.

2. The concentration ratios measured in the laboratory must be preserved during the air mixing and diffusion which occur after the gases leave the weapons in the helicopter environment. Possible causes for changes in concentration ratios include interaction of exhaust constituents and uneven diffusion caused

*"Off the shelf devices" can be modified so that their speed of response and resistance to vibration will permit their use in the helicopter. Such a modification is the subject of a concurrent project.

by differences in densities of individual components. The latter mechanism can be ruled out because of the rapid air flows. The effects of continuing chemical reactions must be checked experimentally.

WEAPONS EXHAUST COMPOSITION

Work by Others. A search for existing exhaust composition information was initiated with the help of consultants and a formal library search. The computerized facilities of the Defense Documentation Center and the National Library of Medicine (MEDLARS system) were utilized. A summary of the library systems and institutions represented in the search appears in Appendix I. The search was aimed at uncovering both exhaust composition and measurement techniques already in the literature. While much interesting work was discovered its bulk was directed to the solution of ballistic or gun erosion problems.^{5, 6} The explosive hazard of gun exhaust had also been investigated.^{7, 8} No readily toxicologically interpretable information was found except for specific gas measurements in tanks:

In 1943 and again in 1955 tests of tanks revealed very high levels of carbon monoxide associated with firing of weapons.⁹⁻¹³ Ammonia concentrations were also undesirably high but nitrogen dioxide was found to be within acceptable limits. Complete characterization of the exhaust composition was not attempted and CO, NO₂, and NH₃ were assumed on theoretical grounds to be the only toxic materials of interest. The weapons used were not the same as the ones currently mounted on helicopters.

Site Selections. Review of the literature confirmed that the proposed study was timely and necessary and that the mode of attack was reasonable. However, to make the needed measurements an extensively equipped laboratory and a staff experienced in trace gas measurement are needed. The first planned research effort is exploratory in nature and it does not seem that the establishment of a new task force of sufficient magnitude at the US Army Aeromedical Research Unit laboratories at Fort Rucker, Alabama, can be justified for now. Fortunately it has been possible to enlist the assistance of the Air Force Rocket Propulsion Laboratory at Edwards AFB, California. The use of an existing facility is expected to result in striking financial advantage and, perhaps more important, will provide valuable data in a much shorter period of time. On the other hand, the AFRPL is engaged in a large variety of ongoing research programs of high priority and must limit the duration of their support to three months of actual work. For this reason the initial investigations will be restricted to the examination of just three of the weapons in common use in armed helicopters. The 50 caliber and 7.62 mm machine guns were chosen as typical of conventional rapid fire small arms and the

2.75 inch FFAR Naval rocket was picked as representative of the double base propellant rocket systems.

Plan of Test. A joint project proposal has been written and approved by the Air Force Rocket Propulsion Laboratory and the US Army Aeromedical Research Unit^{1,2}. Both the time table and the exact nature of the experiments are expected to be flexible and can be changed at the discretion of the responsible investigators. It is intended to initiate the work with a laboratory simulation study consisting of controlled burning of propellant from each of the three weapons represented, followed by chemical analysis of the effluents. This work is designed to provide stability data which will assist in the design of sampling methods for subsequent phases of the project. The second and third portions of the experiments will consist of exhaust analysis during field firings of the three weapons.

Simulation Experiments. During the simulation phase of the study typical propellants used in machine gun ammunition and in rockets will be ignited in specially constructed chambers. Moderately elevated pressures will be permitted and a means for expansion and mixing with known amounts of air will be provided, probably in the form of a burst disc. Following combustion, mass spectrometer and infrared analysis will be undertaken to characterize the effluent gases and vapors. Consecutive analyses of the air-gas mixture will be done to reveal changes in concentrations of principal species with time. Although concentration ratios will be estimated only a low order of accuracy is needed. More precise information from simulation of this type would be academic because of the differences between conditions in the model system and those in the real weapons.

Field Firing of Weapons. Test facilities at Edwards AFB (AFRPL) will permit live firing of machine guns and rockets in close proximity to a limited selection of portable instruments. A rapid-scan infrared spectrophotometer* with a long path (1 meter) gas cell will be used "on line" on the firing range. Other instruments, specific for certain gases of particular interest, will be obtainable. Unfortunately, both available mass spectrometers and the high sensitivity infrared instruments are too delicate and bulky to be moved to the firing range. Thus, to bring these instruments into the act short term storage of the exhaust products will be required. Every effort to minimize and evaluate changes in the gases after collection will be made. When needed, two principal gas collecting devices will be used. The first of these will be a group of stainless steel cylinders which have been evacuated and are closed by rapid acting solenoid valves. The solenoids will be cycled by a solid state timer in such a way as to sample the exhausts at

* Beckman Instruments Mod #102 (Beckman Instr., Fullerton, Calif.)

various times during the firing.¹⁵ It may also be desirable to select the location of samplings to differentiate the exhaust from the breech of the weapons from that which emerges from the muzzles. In all cases it will be possible to cycle the solenoid valves through their open and closed positions sufficiently fast to provide samples at less than ambient pressure because sampling at low pressures can limit interaction of the components of the gas mixture among themselves and with the walls of the steel cylinders.^{16,17} The second device will be a simple three stage low temperature condensation trap using ice and salt water; dry ice and trichloroethylene; and finally liquid nitrogen. It will provide concentration and partial separation as well as quenching of reactions, particularly manifested in the liquid nitrogen stage.

In addition, a limited number of samples will be absorbed on charcoal and silica gel canisters for subsequent vacuum desorption and gas chromatographic analysis using a method developed at the Naval Research Laboratories.*

Computer Prediction. A number of programs are available which enable the computation of the exhaust composition of propellant actuated devices from an input consisting of propellant composition, temperatures and pressures of interest, and constants. Unfortunately a limited number of species can be economically considered. Typical results (Table 1) reveal that a large quantity of carbon monoxide is expected, the only finding of toxicological interest. Certain newer programs will be used to estimate exhaust composition for the three weapons being fired at Edwards AFB during this study.** The estimates will be compared with the actual analytical results. If the two are similar, the newer program could then be used profitably in broad and preliminary comparisons of weapons systems and to orient the analytical procedures. At present, slowly formed species such as ammonia are not accurately estimated because the assumption is made that equilibria are achieved. Further difficulties are experienced in the accurate prediction of particulate emission because this involves variable interactions with the metallic parts of the weapons.

Particulate Analysis. Significant particulate contamination is a realistic expectation because visible haze accompanies weapons firing. Either immediate irritation from raw metallic matter or adsorbed gases, or a delayed health hazard are possible. Characterization of the hazard requires both organic and inorganic

* Analyses performed through the courtesy of Mr. Ray Saunders, Physical Chemist, NRL. Sampler manufactured by GRI Associates, Washington, D. C.

** Courtesy of Mr. L. Stiefel, Frankford Arsenal, Philadelphia, Pa.

chemical analyses in addition to particle size-distribution determination. It will be difficult to relate particulate contaminant data to gas measurements in the study because of practical problems involved in making simultaneous measurements of these parameters at the same location in the apparatus. Nevertheless the particles will be collected (on 3 μ pore membranes with "hurricane" samplers*) in an effort to orient future work already planned which will consist of collection of the particles in the aircraft environment. At present it appears most likely that the examination of the collected dusts will be performed at the Naval Aerospace Medical Institute, Pensacola, and by a private company.

CONCLUSION

The need for evaluation of the hazard from weapons exhaust in armed helicopters has been shown by preliminary experiments. The necessary information on weapons exhaust composition was not found despite an extensive effort by consultation and investigation of the literature. A purely operationally oriented research program of minimum length and expense has been designed to meet the need for toxicologically significant data. If the results of the exploratory effort are satisfactory, prediction of toxic hazard due to effluents from the 7.62mm and 50 caliber machine gun and the 2.75" FFAR rocket will be calculable from in flight measurement of carbon monoxide and particulate concentrations only.

* Gelman Instrument Co., Ann Harbor, Michigan

Component	IMR Propellant (%)	"Ball" Powder (%)	N-5 Propellant
CO	47	48.5	45.8
CO ₂	7.8	5.2	8.3
H ₂	17	17.8	17.7
H ₂ O	21	17.3	17.3
N ₂	10	10	10.6
Pb	-	-	1.0

Table 1. Typical Computed Exhaust Composition Predictions*

* Courtesy of CDR C. J. Jordan (USN) BuMeds

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APPENDIX I

List of Institutions Consulted for Acquisition of Background Information or Specific Weapon Exhaust Composition Data

1. Library Systems
 - Defense Documentation Center
 - National Library of Medicine (MEDLARS)

2. Military Organizations, Army
 - Aberdeen Proving Grounds (Dev & Proof Services;
Ballistics Research Lab.)
 - Chemical Research and Development Lab (Toxicology
Branch)
 - Detroit Auto Tank Center (Human Factors Advisor)
 - Environmental Health Agency
 - Frankford Arsenal (Chemistry Research Laboratory)
 - Picatinny Arsenal (Propellants Laboratory)
 - Redstone Arsenal (Small Rockets Division; Director of
Research and Development)

3. Military Organizations, Air Force
 - 6570th Aeromedical Research Laboratory (Toxicology
Branch)
 - Rocket Propulsion Laboratory (Bioenvironmental Engi-
neering)
 - School of Aerospace Medicine (Bioastronautics Dept)
 - Project Office, Hercules Powder Co., Magna, Utah

4. Military Organizations, Navy
 - Aerospace Medical Center (NAMI)
 - Bureau of Medicine and Surgery (Ind. Hygiene &
Safety Br.)
 - Ordnance Test Station (NOTS) (Weapons Branch)
 - Ordnance Laboratory (Advance Chemistry Division)
 - Medical Research Institute (NMRI) (Toxicology Unit)
 - Research Laboratory (NRL) (Physical Chemistry)
 - Weapons Laboratory (Weapons Development and
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Appendix I (Cont'd)

5. Other Military

Armed Forces Institute of Pathology (Toxicology
Branch)
Canadian Armament Research and Development
Establishment

6. Government, non-military

Bureau of Standards (Fire Research Section)
N. A. S. A. (Biotechnology Division)
National Institutes of Health (Toxicology Branch)
National Research Council (Adv. Com. on
Toxicology)
Public Health Service (Div. of Air Pollution, Field
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7. Other Sources

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