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Final Report

FEASIBILITY STUDY FOR AIR-CONDITIONING A MEDIUM COMBAT TANK

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TABLE OF CONTENTS

FOREWORD

This report consists of a final summation and of recommendations concerning an investigation into the feasibility of ventilating, heating, and cooling a medium combat tank for the purpose of increasing crew comfort and efficiency. The work was done by engineering personnel and part-time students at the Aircraft Propulsion Laboratory, Ypsilanti, Michigan.

ABSTRACT

This project was initiated in order to determine the answers to the following questions:

(1) Do the effects of extreme temperatures on the operational efficiency of the crew create a serious problem?

(2) Can reasonable specifications be made for maintaining a proper crew-compartment atmosphere?

(3) Could such specifications be met by a system to be installed in the tank?

(4) Could the same system be used to regulate temperatures in the engine compartment?

(5) Could a system designed for these purposes be constructed as a "universal package" to fit into all tanks?

The answers to the above questions, as determined by the present project, are in the affirmative for the first three questions and in the negative for the last question. In answer to the fourth question, such a system can be used for easier starting of the tank engine, but it would be practically useless in helping the engine's operation.

This final report of the project is in the nature of a summary report, and presents conclusions and recommendations based on the findings of the more detailed phase reports.

OBJECTIVE

The objective of this project was to determine the feasibility of ventilating and heating, or ventilating and cooling, the crew compartment of a medium combat tank in environments characterized by extreme temperatures. The upper limit of environmental temperature anticipated by the project is 120°F and the lower limit is -30°F. The possibility of controlling temperatures in the main engine compartment was also to be studied, and an estimate was to be made of the practicability of attaining all the above objectives through the design of a universal package system which could be fitted to all tanks without the necessity for redesign.

I. INTRODUCTION

In many localities where terrain is suited to tank warfare, the climate is characterized by extremely high or low temperatures, large concentrations of dust or snow particles, and strong winds. The presence of any of these conditions is an inconvenience to the carrying out of normal activities, if only from the point of view of comfort of an individual. But when the activities of human beings are carried out under conditions of urgency, it is quite possible that, besides causing discomfort, the environment critically lowers human efficiency.

This, then, is a question worthy of consideration. Are these extreme conditions detrimental to the extent that they dangerously lessen the efficiency of the crew members of a combat tank, individually and as an operating unit? If this question is answered in the affirmative, then the logical solution is to condition the air entering the crew compartment in such a manner that these effects are minimized. This, in turn, leads to two more questions. First, what standards of air conditioning must be established so that the crew, while not being necessarily in an ideal state of comfort, will at least be able to operate with nearly normal efficiency? Second, with the use of components of ventilation, cooling, and heating that are in present-day manufacture, is it possible to attain the standards that may be established?

This project was begun in order to obtain reasonable answers to these questions. The plan for completing the project was to conduct a literature survey with the object of determining the physiological effects of extreme temperatures on human beings. The results of this survey have been reported, and a bibliography with abstracts of the included references was presented.[1] Following the literature survey, two other phases of the project were simultaneously carried on. One was concerned with an analytical study of the possibility of using various commercially available components in a suitable conditioning system for the combat tank. The other was an experimental and analytical study of the heat-transfer characteristics in the crew compartment of the tank. The experimental aspects were carried out on an M-47 medium tank. These phases have also been separately reported.[2][3] As work progressed on the project, it became increasingly desirable to obtain a "picture" of the basic air-flow patterns within the crew compartments as a result of turret ventilator operation and of combustion heater operation. This was done in a purely experimental manner, and the results were presented in a fourth report.[4]

The purpose of this final report of the project is to summarize the work done in the above-mentioned phases, and to present conclusions and recommendations for designing a feasible system. In keeping with the purposes of the project as enumerated above, the recommendations made are not definitive in nature. It is believed that the ultimate conclusion as to whether the possibilities merit an actual design study must be reached by the sponsoring agency.

II. DISCUSSION

It has been shown quite conclusively in the physiological literature survey[1] that the problem of extreme temperatures causing lowered crew efficiency is a serious one. Various investigators have shown that there is a large decrease in both mental and physical efficiency when ambient temperatures go above 90°F. In the low ranges the point below which efficiency declines rapidly was shown to be about 25°F. Air velocities were found to be comfortable up to 100 fpm when the air temperature did not exceed 95°F. Above this temperature air currents resulted in increased convective heat gain by the body, rather than any feeling of comforting coolness. Thus, at ambient temperatures above 95°F, ventilation with air that has not been cooled artificially would actually be a detriment rather than a help, except when the ventilator is used to dispel gun fumes. At the cooler atmospheric temperatures it is found that even low velocities of air flow (anything over 30 fpm) result in feelings of discomfort. Thus, at ambient temperatures below about 45°F, ventilation with unheated air would again be detrimental.

It should be pointed out that in the situation where the atmospheric air is, for example, 90°F or lower the uncooled ventilation air supply might be especially helpful in a combat tank. In such an environment, and especially with the sun shining from a clear sky, the tank wall temperature could go up to as high as 140°F or more. The temperature in the crew compartment of a "buttoned-up" unventilated tank is governed by the wall temperatures, and for this reason might go up to about 130°F or more. Obviously, a large supply of atmospheric air would, by reason of its temperature, alleviate the situation. In addition, there would be a cooling effect as a result of the velocity of the air. It is seen, then, that even for temperatures that are not normally considered extreme, a copious supply of atmospheric air distributed by a carefully designed duct system would be required to maintain peak crew efficiency. The ventilator in the M-47 medium tank as presently used does supply sufficient amounts of atmospheric air, but in the matter of good distribution the system falls far short of a desirable design. This can be seen by noting the ventilation flow patterns that have been drawn and presented.[4]

As already mentioned, unconditioned air ventilation at temperatures above 95°F would not be helpful. Yet it is clearly important that something must be done to remedy the situation created by a compartment atmosphere that is at a far higher temperature level than the outside atmosphere. Ventilation must be supplied and, in these cases of high ambient temperatures, the incoming air must be brought to a temperature low enough so that a reasonable cooling effect on the crew members is obtained.

In contemplating the design of a system suitable for cooling the crew compartment atmosphere, it can be supposed in the first instance that cooling will be attempted in the gross sense. That is, air in sufficient amounts is going to be cooled to a low enough level so that the mean temperature of the compartment as a whole will never rise above that specified for human requirements. This implies that the cooled air may be injected at random at any points in the compartment and that the refrigerator is designed to meet head-on, so to speak, with the heat exchange effects of the tank walls. In this way much of the cooling effect of the refrigerator is of no benefit whatsoever at the points where needed. As a result of the heat-transfer studies on the M-47 medium tank[3] it has been determined that, in order to maintain compartment temperature at 80°F when the ambient temperature is at about 120°F, approximately 6-1/2 tons of refrigeration would be required. If 1/4 inch of insulation having a thermal conductivity of 0.04 Btu/(ft^2-hr-°F/ft) is used to cover the compartment walls, the refrigeration requirement is reduced to 3-1/2 tons. These calculations were carried out under the assumption that cooling would be attempted in the gross sense as stated above. Reference, now, to Figure 1 will show that in order to cool 300 cfm of air at exit conditions (same volume as used in above calculations) from 120°F ambient temperature to 80°F at the refrigerator exit, the theoretical refrigeration effect on the air is about 1-1/2 tons. The conclusion follows that, since the comfort of each individual is of primary interest, efforts should be made to bring the cooled air as directly as possible to each man's position by means of a suitably insulated duct system. It is true, of course, that the air will pick up heat through the duct walls, and consequently, proper insulation of the ducts will be of great importance in determining the refrigeration requirement. Insulation of the tank walls would not be obviated as a desirable feature under these considerations, as this would affect the temperature on the hot side of the ducts and, thus, the heat picked up by the cooled air inside the ducts.

What has been said about the ventilation and cooling system of the tank is also true concerning the ventilation and heating system. Reasonable

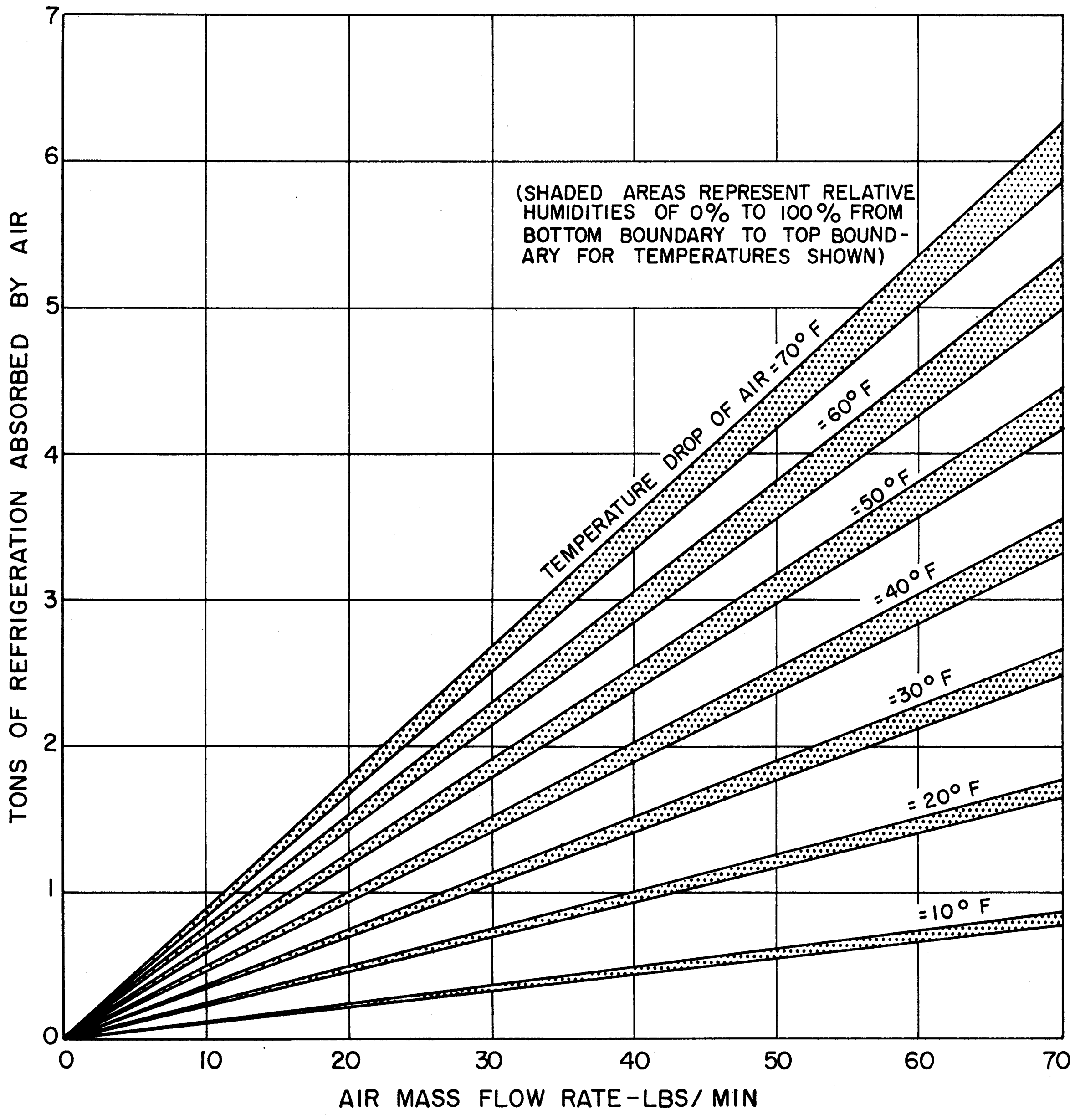

Fig. 1. Refrigeration absorption by air as a function of mass flowrate, temperature drop, and relative humidity.

goals can be set and achieved if the duct system is carefully designed and the walls of the duct and tank are properly insulated. As presently used, the combustion heater takes in recirculated air plus whatever new air leaks into the tank to replace old air that leaks out. The most immediate objection which arises in this system is that when the gun is fired the fumes from the expended shells will be distributed through the tank along with the recirculated air. It would seem, then, that a redesigned heating system should have some provision for taking air from the atmosphere at least when the gun is being fired.

Figure 1 can again be used to determine what amount of heat must be picked up by air passing through the heater to raise its temperature from -30°F at the heater entrance to +25°F at the heater exit. At the exit conditions, assuming a pressure of 1 atmosphere, the specific volume of the air would be about 12 cubic feet per pound. Remembering that a ton of refrigeration is equal to a cooling effect of 200 Btu/min, the concept can be reversed; the chart shows that heat is gained by the air in the amount of about 21,000 Btu/hr for a flowrate of 300 cfm at exit conditions. It should be kept in mind that these figures (tonnage for cooling and heat pickup for heating) are expressed solely from the point of view of effect on air temperature between the entrance and the immediate exit from the refrigerator or heater. Naturally, as the air moves to positions more remote from the immediate exit, heat exchange occurs in a detrimental sense. Thus, temperatures strived for must be smaller or larger than those desired at the distribution point as the case may demand. It follows, of course, that such heat exchange constitutes an inefficiency in the system, and that the power requirements and possibly the space requirements would need to be increased above the theoretical values.

The discussion up to the present point has been concerned with the magnitudes of heating and cooling that might be required to condition the compartment air to desired specifications. It would be fitting now to review the possibilities of obtaining the required heating and cooling effects, subject to space and power limitations imposed by inherent combat tank characteristics. The goal in combat tank construction is to attempt an overall design which will enable the crew to get to the enemy, to out-maneuver him, to outstrike him, and ultimately to defeat him. In the interests of achieving this goal the trend on one hand is to use thicker armor. This requires the construction of smaller tanks to help limit the weight, and more powerful engines to obtain utmost mobility. On the other hand, there are increasing numbers of accessories and greater fire power constantly being introduced in order to give the crew every possible advantage over his adversary. The inevitable result is that the engine, the guns, the auxiliary equipment, and the crew members are always in competition for the available space within the tank's dimensions. Available space can only be grudgingly increased, since it would in most cases require enlargement of the vehicle. It becomes necessary, then, to weigh the comparative advantages of one piece of equipment against another when certain combat conditions are anticipated over the long range of time. When the conditions anticipated include extremely hot or extremely cold environment, there should be a willingness to allot a considerable amount of the available space and power to the requirements of air-tempering. Such an allotment may dictate a re-evaluation of other auxiliaries with the idea of eliminating some as being of diminished value to tank operations at extreme temperatures. If it is decided that no changes in the tank's present equipment can be made, then perhaps the vehicles themselves should be designed large enough in future models to allow for installation of air-tempering equipment.

As an example of the possibilities of altering the present tank, the numerical requirements for crew members in the M-47 medium combat tank might be re-examined. At present, the crew for this vehicle consists of five men. The number of men in the crew of the M-48 medium tank is only four. The reduction was made possible by moving the driver's seat over to the center line of the tank and eliminating the bow gunner from the crew. It may be argued that this was done in the M-48 tank to allow for a more "battle-worthy" contour on the front of the tank, as well as to effect a 20 percent saving in tank manpower. In this instance it was thought that more advantage could be gained from the improved geometry and from the saving in manpower than from the duties that the extra man could accomplish. Could it not be possible that, under extreme environmental conditions, more advantages are gained from the use of an air-tempering system than from the presence of a crew member at the right side bow gun? If so, the bow gunner could be removed from the crew and the space vacated by him could be utilized for housing the desired equipment. By this alteration, 20 to 25 cubic feet of space are made available for the design engineers' use.

In view of these possibilities it will not be considered the province of this report to recommend a specific air conditioning system. Rather, the recommendations are made with regard to certain features that any such system should have. As a result of these recommendations and as a result of the conclusions expressed in the previous reports [1,2,3,4] it is hoped that the relative value and feasibility of incorporating such a system in present and future combat design can be reasonably predicted. It is also hoped that these conclusions and recommendations can suggest a trend that such a design might take.

III. CONCLUSIONS

The following conclusions have been arrived at after consideration of the project in the overall sense. Detailed conclusions pertaining to each phase of the study are given in the reports concerned with those phases.[1,2,3,4]

1. The problem of maintaining crew efficiencies in the face of extreme environmental temperatures is of primary importance. At atmospheric temperatures as high as 120°F or as low as -30°F the question may be one not merely of maintaining top efficiency but of being able to operate properly at a combat level.

2. The main variable upon which the interior compartment temperature depends is the armor plate temperature. This would have special significance in those environments typified by desert operations where solar radiation is quite strong. Even when atmospheric temperatures are reasonably low, the metal temperatures of the tank may rise far above 130°F.

3. The most critical features that will decide the amount of heating or cooling necessary in an air-tempering system are the duct system design and proper use of insulation on both the duct walls and the tank walls. It is important to place the discharge points for treated air in the immediate vicinity of each crew member's head. Also it would be advantageous to have small vents available for playing heated or cooled air over important adjustment levers. Such levers, incidentally, could more properly be either wood or cloth, covered in order to reduce the temperature effect on the human touch. Discharge points should be adjustable, at least as to direction and possibly as to volume of discharge.

4. The presently used systems for ventilation and heating in the M-47 medium tank are not capable of accomplishing their objectives, probably the only reason being lack of proper air distribution to pertinent points in the tank.

5. If air for the main engine were not taken in through the crew compartment, a smaller fan for the crew compartment could be used and greater distribution of air could be obtained. In addition, if artificial cooling is to be used, smaller amounts of air must be cooled in order to keep refrigeration tonnage requirements to a minimum. For the purpose of dispelling gun fumes, a large-capacity exhaust fan should be available for use when the gun is fired. The flow of air through this standby fan should be from crew compartment to exterior with a large area intake being provided as close to the gun breech as possible.

6. The most immediately feasible method for meeting the cooling requirements seems to be the use of a vapor compression system. Extensive design and development activities might demonstrate the feasibility of using an air compression cycle, and if such is shown to be possible this would be the most desirable system. However, the feasibility and desirability of using an air cycle become evident only if a centrifugal air compressor of small enough capacity can be developed. The vapor compression system would have to make use of a positive displacement compressor, since the required capacity is far too small to make use of dynamic compression.

7. The method of combustion heating seems to be the most practical means of heating both the crew and engine compartments when the tank's main engine is not running. For conditions where the main engine is in operation, the use of waste heat seems to be the most practical method of heating the crew compartment.

8. In the M-47 medium tank, if the bow gunner were eliminated from the tank crew organization and his space were made available for a refrigeration system, approximately 3 tons of refrigeration could be supplied. This would easily be adequate for crew needs, provided a well-designed duct system is used. For other tanks an evaluation of the comparative value of having an air conditioning system as opposed to other equipment in the tank would have to be made with reference to anticipated extreme environmental temperatures. On this basis the possible available tonnage of refrigeration could be estimated for the particular tank involved. If it is found that at least 1-1/2 to 2 tons cannot be provided, then any attempt at artificial refrigeration would probably not be worth while.

9. A system suitable for ventilation, heating, and cooling probably could not be designed as a "universal package" for convenient fitting in all tanks. The reasons for this are (1) the relatively large size that such a package would have and (2) availability of space would be based on competition between the air conditioner and other items as desirable auxiliaries in a particular tank. In addition, duct components could not be considered as part of such a package because of the need for tailoring the duct to conform to the geometry of each tank.

IV. RECOMMENDATIONS

The following recommendations are made on the basis of a consideration of the project in the overall sense. Recommendations for specifications for the crew compartment atmosphere have been presented in the physiological survey report.[1]

1. A duct system should be designed for use with the present turret ventilator and combustion heater. These two components would be of far greater value than they now are if means were provided to carry air to distribution points that are located preferably near the heads of the individual crew members and, in the case of heating, also to the vicinity of the body extremities.

2. Attempts should be made to provide engine air intake in such a way that this air will not have to pass through the crew compartment.

3. Investigation should be made of the possibility of applying insulation to the tank walls. Particular attention should be given to the new type of sprayable insulation that has been introduced on the market.[(2)] This insulation seems to overcome many of the objections previously raised against the use of insulation in the tank.

4. The M-47 medium tank as presently designed and equipped does not permit enough space for the installation of a practical refrigeration unit in the interior. Compressor portions of such a unit should not be placed on the exterior of the tank since they would be too susceptible to damage and also because they could detrimentally alter the outside geometry of the tank. Therefore, no attempt at artificial refrigeration should be made in present tanks unless some other auxiliary equipment can be eliminated on the basis of comparative evaluation with reference to extreme temperatures.

5. The possibility of reasonably eliminating the bow gunner from the M-47 tank crew organization should be considered. The vacated space in his compartment could then be utilized for housing a refrigeration and heating system capable of satisfying the requirements of the tank.

6. In consideration of components of contemporary design, the only method of refrigeration which seems adaptable for use in the combat tank is the positive-displacement vapor-compression cycle. Further, the use of refrigerants for this cycle should be limited to the class of the halogenated hydrocarbon compounds.

7. For heating purposes and in consideration of contemporary design, continued use should be made of the combustion heater for service when the main engine is shut down. Provision should be made for switchover to the utilization of engine waste heat when the engine is running.

8. No attempt should be made to use the air cycle unless a suitable centrifugal compressor can be designed for the low capacities required. Advantages of the open air cycle with centrifugal compression are so great, however, that a strong attempt should be made to design and develop a suitable centrifugal compressor.

9. An overall system suitable for ventilation, refrigeration, and heating should incorporate at least the following features:

(a) Refrigeration and heating components should be situated as close to each other as possible.

(b) A separate exhaust fan should be provided for expelling gun fumes, as stated in Conclusion 5, above.

(c) The refrigerator and heater should normally use recirculated air, but provision should be made for drawing fresh air from the exterior atmosphere as desired.

(d) A common, suitably insulated duct system should be used to carry air under all circumstances directly to each crew member through adjustable exits. Small side vents should be provided for direct heating or cooling of metal control levers when desired.

(e) A complete duct system should carry the air to both the turret and driver's compartment, and should not depend on discharging warm air at some point, for example, under the turret basket. The problem of crossover of the ducts between the hull and the turret can possibly be solved by bringing the ducts up through the turret verticle axis.

(f) Provision should be made for operation of the ventilator fans through the same duct system without supplying any refrigeration or heating effect.

(g) Provision should be made for cutting off air flow from all personnel distribution points and concentrating the heated or cooled air flow through ducts that will enclose the main engine and oil lines, so that starting of the engine may be facilitated.

(h) All controls for the system should be manual, with the possible exception of the ventilator fan for removal of gun fumes.

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