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A Study of the Gas Turbine Powered MB-5 Aircraft Firefighting and Rescue Vehicle

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ABSTRACT

One of the MB-5 series of crash trucks was equipped with a gas turbine engine as a source of power. During the testing of this vehicle the operating characteristics of the engine were monitored under different load conditions, variable road speed, and variable foam pump speed. The turbine powered vehicle was compared to other, conventional engine model, trucks now in operation, both for rapidity of acceleration and for ease of operation.

A standardized simulated firefighting operation called a "scramble" operation was devised for the integration of human engineering with the relative efficiency of each of the three vehicles. Time intervals required to reach a given series of check points during a fixed firefighting procedure were recorded by multichanneled instrumentation or by observation.

The turbine-powered vehicle proved to be superior in acceleration performance and equal in firefighting capability to conventional engines. These factors alone may not justify the higher initial cost of the turbine power plant. Future field studies involving maintenance costs over extended periods of field operation and vehicle performance under severe environmental conditions might alter present considerations.

PROBLEM STATUS

This is a final report on the turbine engine for the MB-5 series of crash trucks. Work on other phases of aircraft-crash firefighting is continuing.

AUTHORIZATION

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A STUDY OF THE GAS TURBINE POWERED MB-5 AIRCRAFT FIREFIGHTING AND RESCUE VEHICLE

INTRODUCTION

General

As a part of the Navy's continual-improvement program for aircraft firefighting and rescue vehicle development, it was desired to determine the characteristics of a gas turbine prime mover.

A conventional gasoline engine was removed from an available MB-5 vehicle and replaced with a gas turbine. The MB-5 is classed by the Navy as a medium size aircraft firefighting vehicle. This vehicle has a 4 × 4 wheel arrangement, it carries 400 gal of water, and it has a 3000 gpm foam pump supplying a single turret. It was the intended purpose of these tests to determine such operating characteristics as vehicle acceleration, foam generating system output, human factors, and driver reaction. The foam generating system was investigated because it is driven by a power take-off drive from the vehicle engine.

Power Train Revision

The MB-5 as originally conceived was to be of relatively light weight design and construction in order to provide good road performance. For this reason, the firefighting systems were arranged to be driven from the vehicle engine. This eliminated the weight of an additional prime mover or other heavy power-divider installation and also eliminated drive train complexity, however, it also had a somewhat limiting effect on the firefighting capabilities because it was not possible to move the vehicle without disengaging the foam makers. At the time of revising the power train to accommodate the turbine installation it was also part of the program to design and install a system which would permit vehicle movement independent of and without interruption of full foam production.

The original MB-5 engine mounting and drive arrangement is shown in Fig. 1. In order to permit independent drive of the firefighting system, the new arrangement utilized a flywheel-driven power takeoff and a drive line, drawn in Fig. 2. Drive gear ratios were selected to permit the vehicle to move forward to a maximum speed of 10 mph and backward to 5 mph, when the pumps were being operated at their full rated speeds. Independent clutches which could be engaged and disengaged at the correct engine pumping speed permitted control over the foam systems. The unique power characteristics of the gas turbine allowed it to serve as its own transmission by building up high torque at low output speed, but in order to provide for reverse operation a gear box was required. A commercial torque converter transmission was judged to be the most expedient answer. It also provided a point for "slipping-off" power when the vehicle was to be operated below its maximum speed, while pumping was in process.

The original axles were replaced with a heavier duty type to handle the higher torque from the turbine engine.

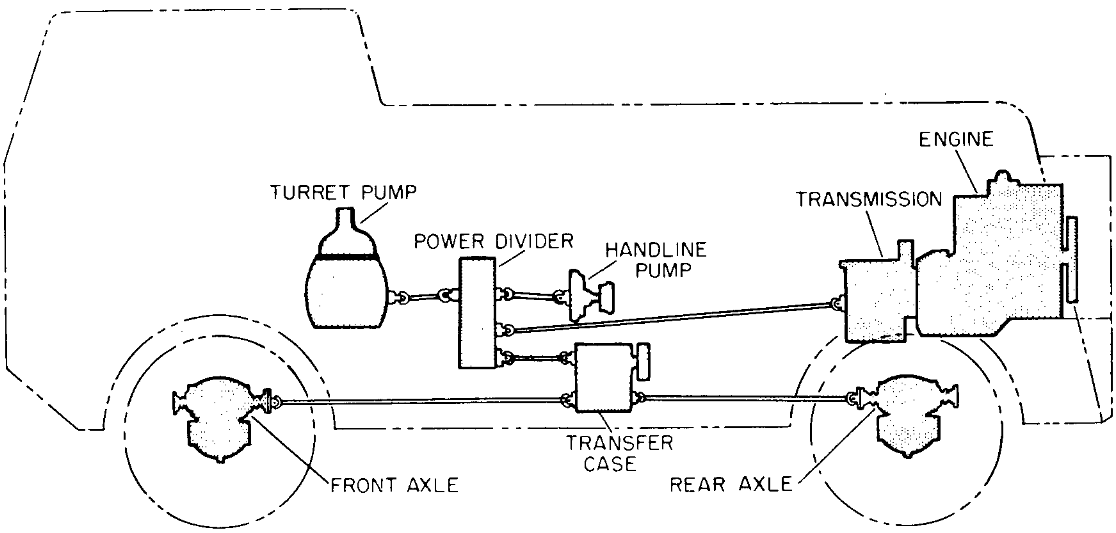

Fig. 1 - Drive train arrangement of the original gasoline-engine powered MB-5

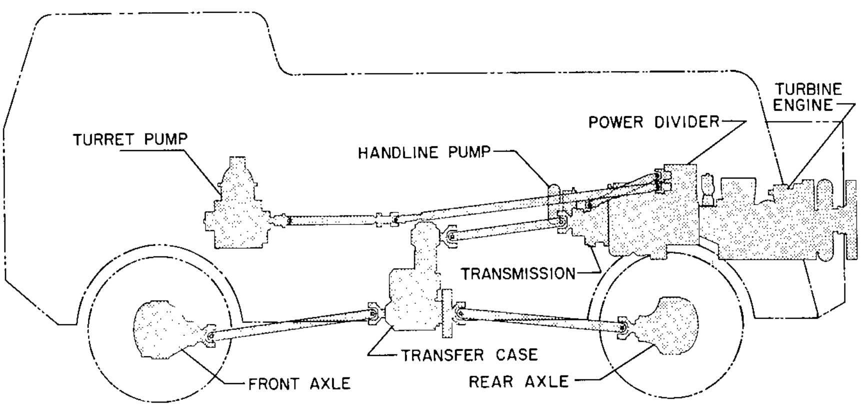

Fig. 2 - Drive train arrangement as revised and installed in the turbine powered version of the MB-5

Turbine

The gas turbine selected for installation was the Boeing Model, 502-10MA, rated at 300 horsepower. It had been previously employed in fire service vehicles built by the American-LaFrance Corp. of Elmira, New York, the contractor awarded the Navy work.

An overall photograph of an actual turbine, cut away to show the interior construction, is shown in Fig. 3. Figure 4 is a schematic cross-section drawing of the same unit, illustrating the operating principle and working parts. Note that there are two power turbines extracting work from the hot gases, but that they are not connected mechanically. This gives rise to a desirable characteristic for vehicle drive which is just the opposite to the corresponding characteristic of the conventional engine. In the turbine maximum output torque is developed when the vehicle is completely stalled. The more the vehicle is slowed down by heavy going through mud, or sand, or going up a steep grade, the more torque is developed to push it on. A conventional diesel or gasoline engine develops its highest torque rating at high speed. Consequently, when progress is difficult, dragging

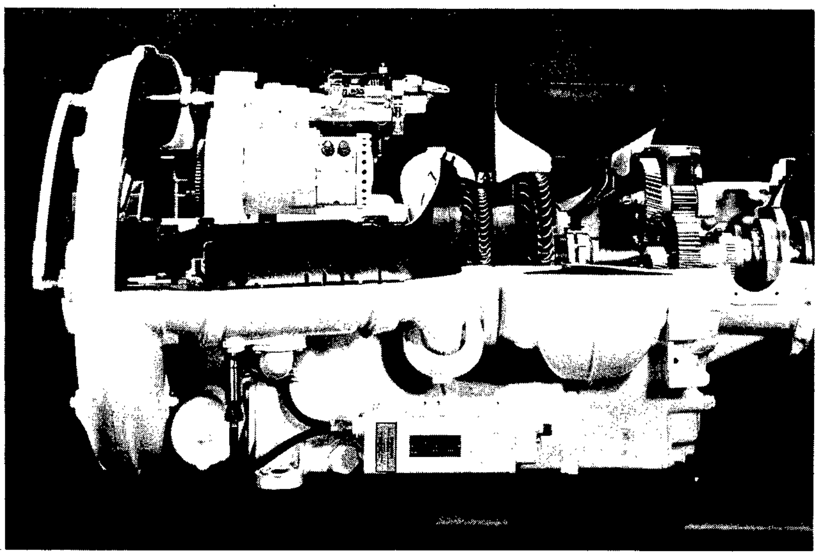

Fig. 3 - View showing the external appearance and internal construction of the turbine power plant

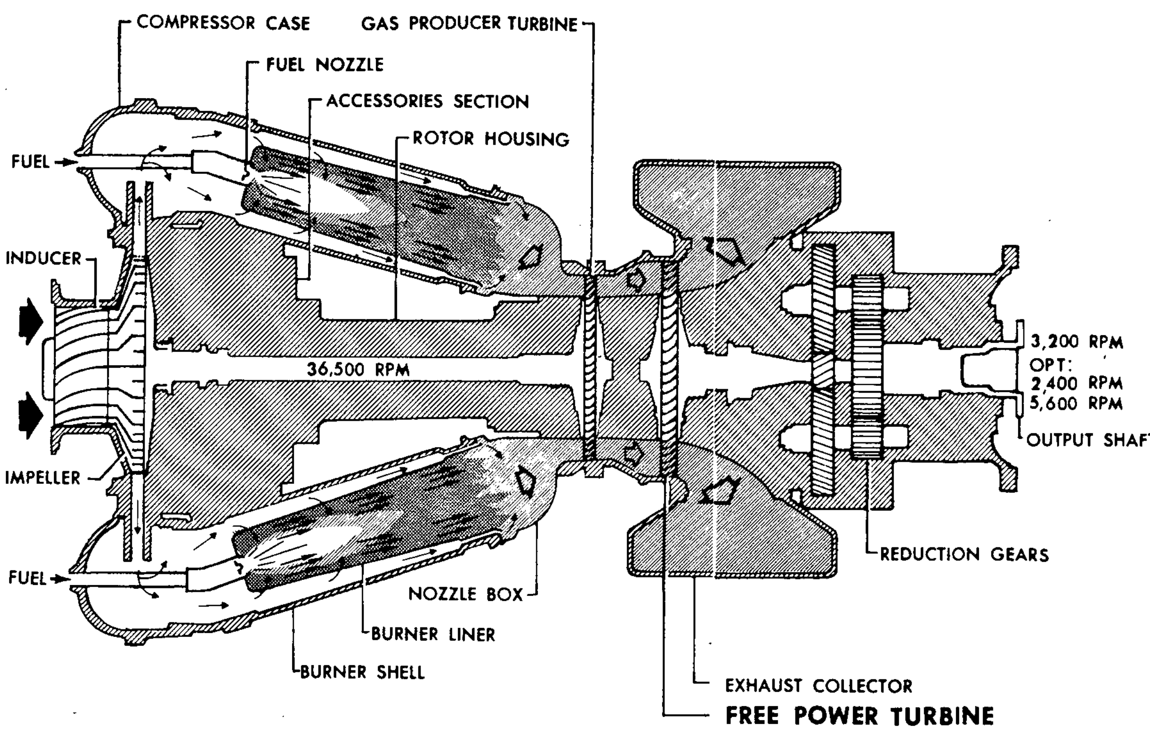

Fig. 4 - Schematic cross section which shows the working parts of the prime mover

the vehicle and engine speeds down, the torque which is then urgently needed is dropping out. In effect, then, the turbine serves as its own gear box and a transmission can be eliminated from the power train.

The compressor section of the turbine furnishes the necessary volume of hot gases to the output turbine to meet the load demand. It is essentially a two-speed action, idling at 18,000 rpm and running at 38,000 rpm when power is called for. An isochronous governor controls the fuel flow to the burners. The output power shaft is driven through a reduction gear set of about 11:1 making its top speed 3200 rpm, which is approximately the speed of conventional engines.

Control System

As a part of the new installation, it became necessary to devise a control system for the varied operating components. This was done by the use of hydraulics with the pressure being supplied by a pump driven off the flywheel power takeoff. The hydraulic system, operating at a maximum of 250 psi pressure, serves to actuate the front axle drive clutch, the pumping speed governor, the handline pump clutch and valves, and the foam pump clutch, and finally the return oil serves to lubricate the transfer case and power take-off gears. The foam pump valves are operated through a mechanical linkage from the foot treadle at the turret operator's station, in the manner of the original MB-5.

Because the pumps are driven directly from the vehicle prime mover, a means must be provided for preventing overspeed of the pumps and for regulating the pumps at their correct speeds during firefighting operations. A section of the isochronous governor accomplishes this by holding the turbine output shaft at the correct pumping speed when the high speed (road speed) section of this governor is locked out. Vehicle-drive gearing permits forward movement up to 10 mph and rearward movement up to 5 mph when the turbine is operating at the maximum proper pumping speed. The governor responds to the added load of moving the vehicle by causing an increased fuel flow, resulting in turn in higher gas flow and power but no output speed change.

The safe operation of the vehicle is insured not only by governing the pumping speed to the proper value, but also by an additional safety device. This device is a solenoid control valve, normally closed, in the hydraulic system, which blocks operation of the hydraulic pump controls unless the turbine output shaft speed and vehicle speed are below the normal pumping speed. Thus, foam generation cannot be started, during an approach to a fire, until the vehicle has been slowed down to 10 mph. This is desirable because it is the usual tendency of crews to want to start foam application too soon and when they are moving too fast. Considerable foam is then wasted by not reaching the fire and the driver's windshield becomes foam splattered and the turret operators become blinded by driving into their own foam discharge.

The solenoid also prevents engagement of the pump unless the transmission is in the neutral position. If the transmission is in either the forward or reverse position the solenoid will prevent engagement unless the brake pedal is being depressed by the driver. In this way the possibility of inadvertent motion of the vehicle, which might endanger personnel, is minimized. Any time the pump controls are already engaged the turbine is automatically running at correct pumping rpm and the vehicle is capable of moving, if the transmission is placed into gear. Maneuvering and operating the vehicle requires attentiveness and alertness on the part of the driver at all times.

The hydraulic slippage caused by continued braking of the vehicle while maneuvering and pumping will result in heat generation in the converter oil. The oil cooler will normally prevent overheating. However, if it does not prove adequate, an indicating light on the instrument panel signals the driver to start the manually operated cooler fan for additional cooling capacity.

TEST PLAN

Automotive

A certain number of the automotive tests and characteristics normally measured in a vehicle test program were not conducted in this case because the aspects involved were not different from those of the original MB-5 vehicle. The original vehicle was thoroughly evaluated from the automotive standpoint and reported on by the Aberdeen Proving Ground in 1956.

The biggest area of change expected by the installation of the turbine was in vehicle road performance as reflected by the 50% increase in horsepower. Lack of facilities at this Laboratory made it impossible to conduct any vehicle performance tests other than acceleration.

Driver's reactions to the vehicle's different handling characteristics were carefully noted throughout the testing program.

Firefighting Operations

The outputs of the two foam producing systems, the handline and the turret, were unchanged by the engine modifications and so no foam tests or fire tests were deemed necessary.

An important change in the design and operation of this vehicle was the use of the power divider to permit moving and pumping simultaneously. This feature is a difficult one to evaluate in comparison to the premodification arrangement. For firefighting with the old design, it was necessary to bring the vehicle to a complete stop before shifting the transmission into neutral, engaging the power takeoff, and shifting the transmission back into gear. In order to relocate, it was necessary to reverse these operations before moving and then go through them again after relocating. It was a complicated and time consuming series of operations on the part of the driver, as compared to the new procedure.

As a means of assessing the differences in effective times, a "scramble" type operation was devised covering a number of sequential events as they normally occur in fighting a typical aircraft fire. Starting at zero time, with the driver standing 15 ft away from the vehicle, situated 1,320 ft from the "fire" center, times for the following events were taken:

Zero time – Driver standing 15 ft from vehicle

Event 1 – Hit starter switch

2 – Vehicle underway

3 – Attain 40 mph speed

4 – Start deceleration

5 – Stop 50 ft back from "fire" center

6 – Foam system "up"; continue pumping 30 seconds then advance while still pumping

7 – Stop 20 ft from "fire" center; continue pumping 30 sec longer

8 – Shut down foam system and reverse vehicle

9 – Vehicle reaches point 100 ft from "fire" center; start approach to new position, 90° from the original position

10 – Stop 20 ft from "fire" center.

Figure 5 illustrates the course of the vehicle while engaged in the "scramble" and indicates the timing check points significant during aircraft fire fighting and rescue work.

Instrumentation

The logging of data during the test program was done through the use of a high-speed multichannel recording oscillograph. This simultaneous recording of all events offered the best means of analyzing the efficiency of the turbine governor in preventing overspeed and underspeed of the foam pump during the varied operations.

Two recording channels were used to follow the turbine performance, one for the compressor speed and one for the power output shaft. These were convieniently tapped into the instrument panel tachometer electrical connections and required no modifications. A magnetic pickup coil was installed adjacent to the hand-brake drum attached to the rear-axle drive shaft with the inductive signal being received from the eight mounting bolts on the brake drum. The installed pickup coil is shown in Fig. 6.

The rotational speed of the shaft was converted from frequency to road speed and recorded on the chart in the third channel. The fourth recording channel was for the foam pump speed; it was activated by a magnetic pickup affixed to the stub end of the pump shaft.

Figure 7 illustrates the recording instrumentation equipment as mounted in the cab of the vehicle.

TEST RESULTS

Installation

The outward appearance of the vehicle was little changed from the original. The turbine was completely enclosed within the original engine compartment as seen in Fig. 8. The air intake had taken the place of the radiator as shown in Fig. 9, and the exhaust stack projected upward through the top of the compartment as shown in Fig. 10. Sufficient additional air is inducted into the exhaust gas stream so that no hazard existed there.

Figure 11 is a view of the instrument panel. The turbine instruments and controls, with the exception of the tachometers, are mounted within the light colored subpanel. The four large handles to the right are the hydraulic controls for the firefighting systems.

Weight

The fully loaded original MB-5 vehicle without crew weighed 15,715 lb, as stated in the Aberdeen report. The gasoline engine removed weighed approximately 725 lb and the turbine which replaced it weighed approximately 335 lb. However, the change in power train arrangement required heavier axles and the addition of the flywheel power takeoff. Also added was a 150-lb dry chemical system with a total weight of about 475 lb. The modified vehicle weighed a total of 17,410 lb. For the reasons cited above it is not clear

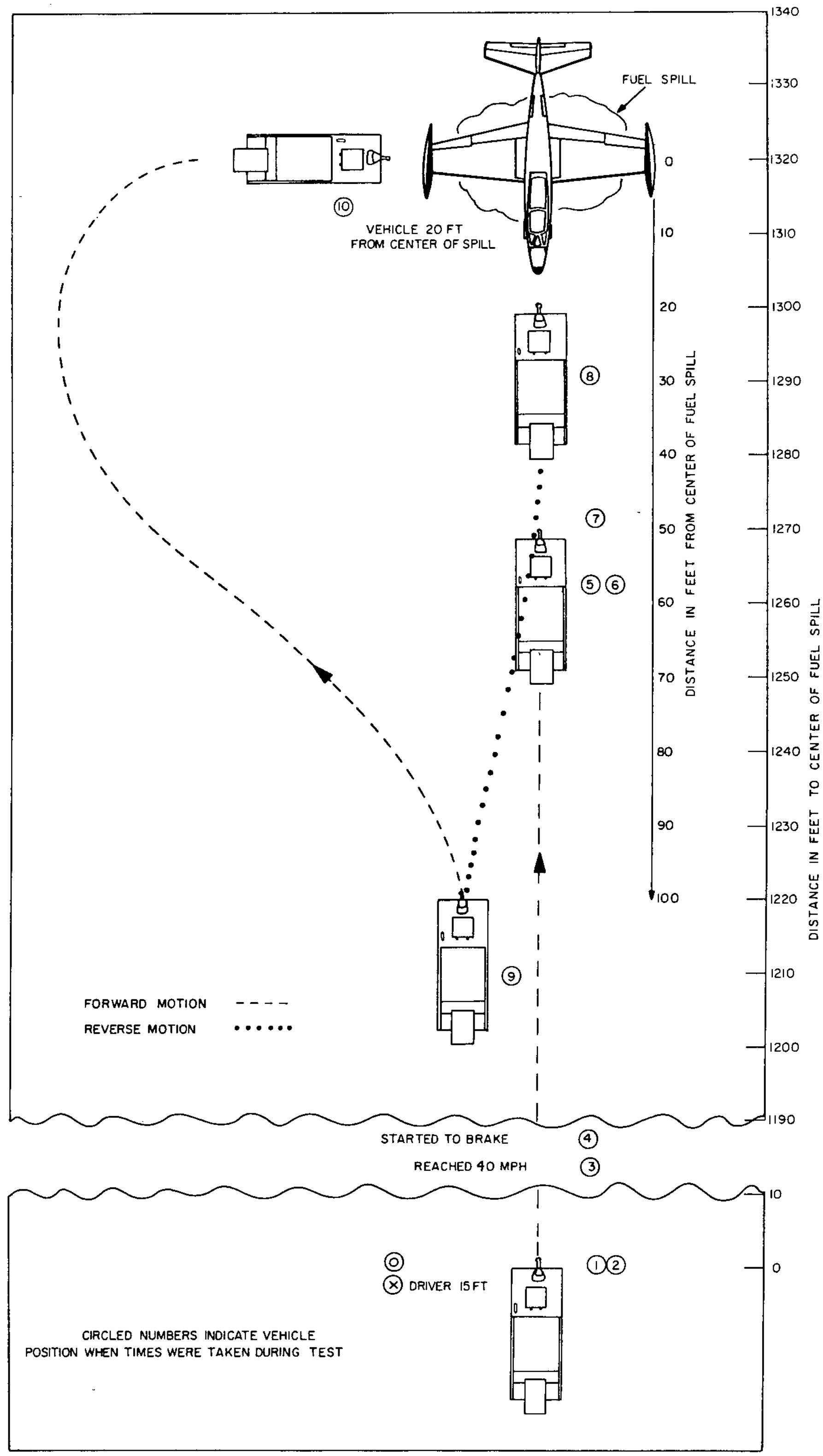

Fig. 5 - "Scramble" course layout for checking times needed to perform critical operations necessary during aircraft fire-fighting and rescue work

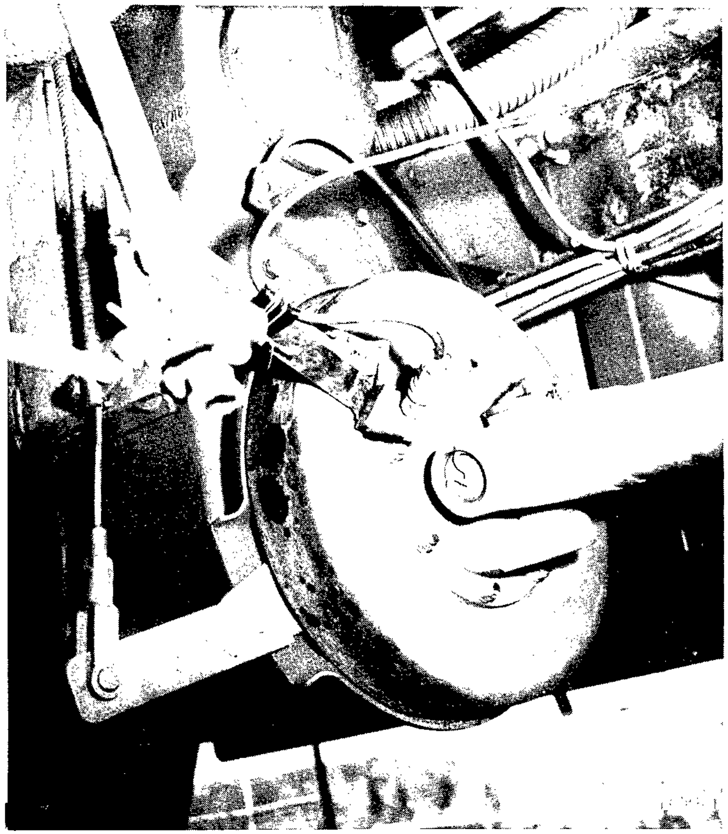

Fig. 6 - Installation of magnetic pickup device for recording vehicle road speed. The signal is received from the eight bolts used to mount the hand brake drum on the drive shaft.

Fig. 7 - Instrumentation as mou
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simultaneous recording of th
output, and vehicle speeds.

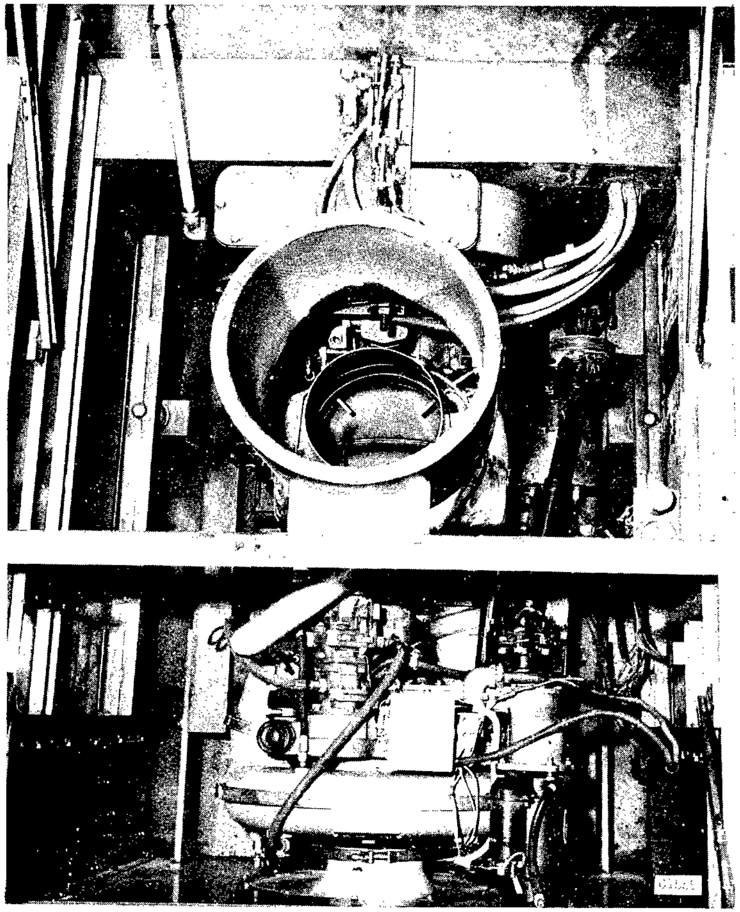

Fig. 8 - Downward view into exhaust stack and engine compartment to show turbine as mounted in vehicle

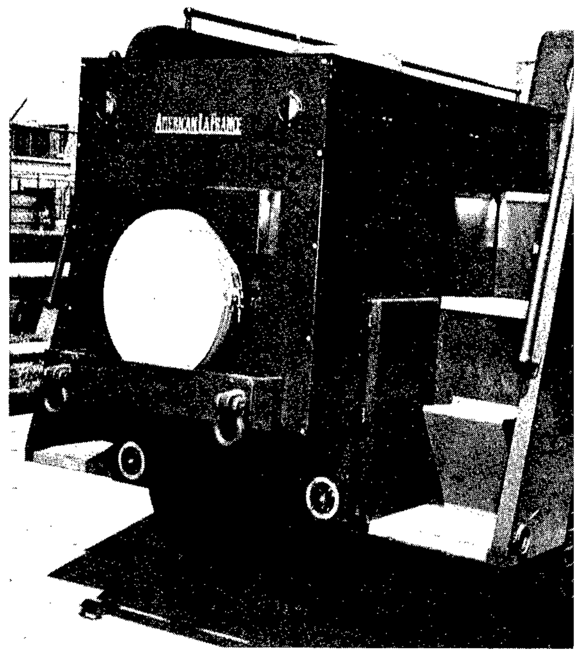

Fig. 9 - Rear view of vehicle showing t
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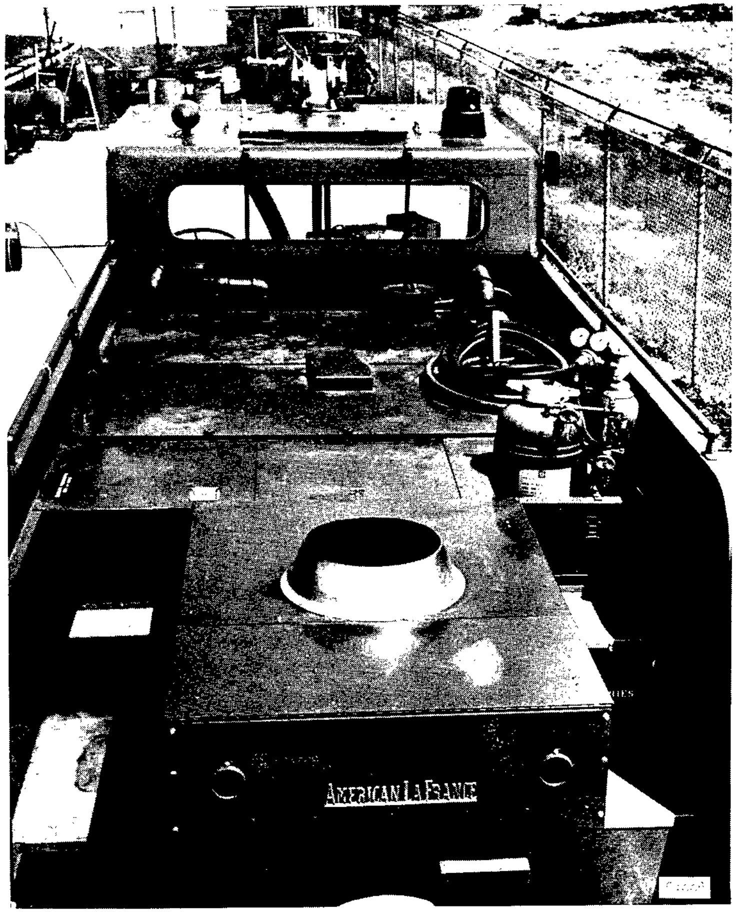


Fig. 10 - Rear deck of vehicle with exhaust stack flange rising from engine compartment

Fig. 11 - The turbine controls, located
and the foam system controls located (
of the vehicle cab instrument panel

cut as to how much, if any, gross weight can be removed through the employment of a turbine prime mover in a new vehicle. The turbine engine would not appear to offer much possibility of overall weight reduction.

Acceleration

One undesirable characteristic of the gas turbine was the time required for the gas producer section to get up to full speed. Until this speed built up the power output was materially reduced. Approximately 7 seconds was required for the gas producer to build up, from the idling speed of 18,000 rpm to the full speed of 38,500 rpm, after the accelerator was completely depressed. This was true whether the vehicle was moving or being held stationary with the brakes. Maximum acceleration runs were tried two ways; by simply fully depressing the accelerator and by fully braking the vehicle until the gas producer reached full speed and then releasing the brake. The comparative results are shown in Fig. 12. Although the "retarded" start does give greater acceleration after brake release, the net time needed to reach any given speed is longer because of the initial delay waiting for the gas producer to build. The disturbances in the speed and turbine output curves were caused when the transmission automatically shifted from the converter into a direct lockup at 2400 rpm and transferred an increased load onto the turbine output shaft.

This lag or delay in initial vehicle acceleration is disconcerting to drivers unaccustomed to turbine driven vehicles and is especially so when pulling out onto arterial streets. After some experience it is possible to develop a technique wherein the gas producer speed is kept up by maintaining the accelerator partially depressed with the right foot while controlling the vehicle speed with the left foot on the brake. Waiting at stop lights or at intersections gives the driver an opportunity to anticipate his starting time and to bring his compressor up to speed. Then he is truly in a "go" condition when the time comes to move.

Acceleration curves are given in Fig. 13 for three versions of MB-5's using three different power trains; gasoline-engine manual transmission, gasoline engine automatic transmission, and the turbine. It is seen from these comparative curves that the turbine vehicle was slower in acceleration until about 20 mph had been reached. From that point on the turbine was markedly faster and reached 60 mph in about one-half the time of the other two. All of this was not brought about through the turbine's basic characteristics. The turbine's horsepower rating was about 50% greater than that of the gasoline engine in the other two trucks. This engine inequality helps to explain part of the difference in performance.

In comparing the curves of the other two models using the same engine, there was essentially no difference in acceleration between the automatic transmission and the manual transmission versions.

It is of interest to compare the designer's projected acceleration curve made in the early design stage to the actual final data. This has been done in Fig. 14. At the lower end of the scale the curves are concentric and in good agreement, except for the offset which amounts to about 5 seconds. This offset is about the time required for the gas producer to achieve optimum speed. It is likely this was not taken into account in the original calculations. Above 50 mph the actual performance drops off a little more than 5 seconds from the predicted curve. The formulas, as used by the automotive industry, appear to have reached a high state of development. The calculated gradeability performance curves were not checked for lack of a suitable course. There appeared to be no trouble in achieving sufficient traction and good tire contact in level acceleration, in contrast to the expressed fears of the designers.

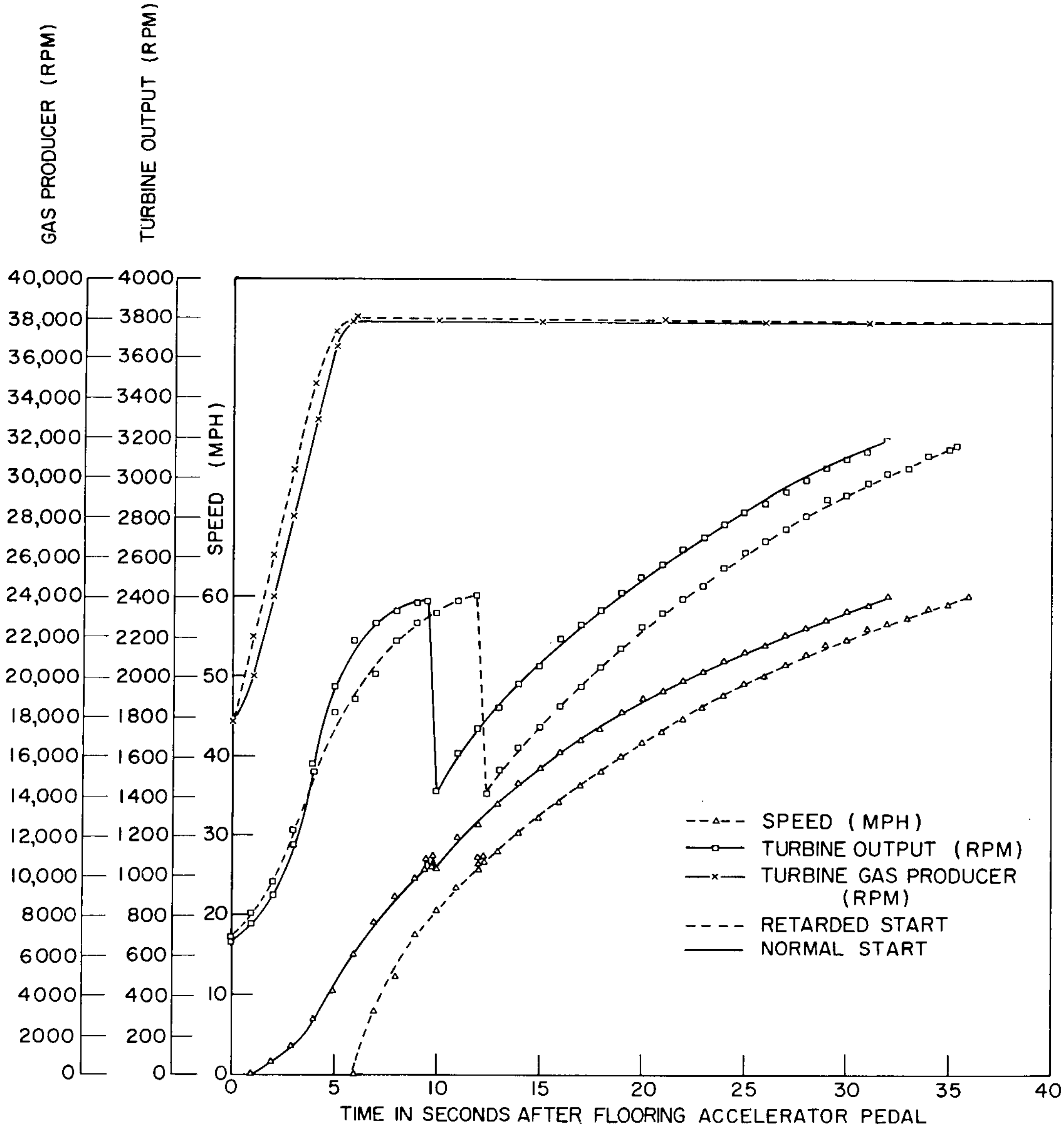
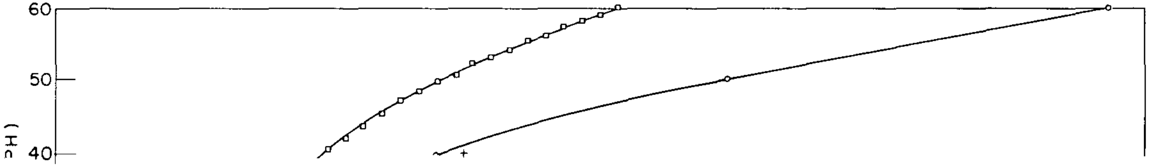


Fig. 12 - Comparative accelerations of turbine powered vehicle from a conventional start and a brake "retarded" start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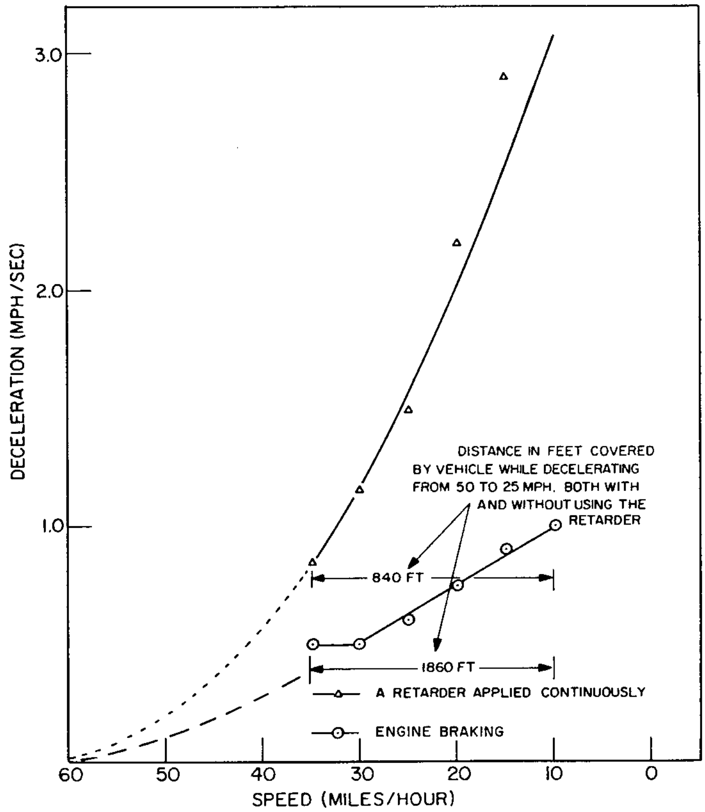

Fig. 15 - Decelerating ability of the retarder is shown as a function of vehicle speed and compared to an engine braking

Foam Pump Operation

The degree of accuracy provided by the instrumentation made it possible to follow closely the speed relationships between the gas producer, the turbine output shaft, and the foam pump, as this foam pump load was imposed and removed. The traces, recorded simultaneously, are shown in Fig. 16. These traces were taken without the vehicle being in motion. Zero time was taken as the control was switched to the "on" position and at 15 seconds the stream position was changed from the straight stream pattern to the spray pattern. In doing this the pump discharge pressure dropped from 17 psi to 13 psi because of the lower backpressure at the nozzle. Foam pumping continued to a total time of 30 seconds, when the control was switched to the "off" position.

The initial pump response was rapid. It began to turn over within 1 second, and it built up to 70% of its operating speed in less than 2 seconds. This quick pickup, however, was solely because of the inertia of the power turbine section, and the speed rapidly dropped off as the foam pump load dragged it down. The gas producer response to the sudden load of the foam pump was very good and its rpm began to increase rapidly within about 2 seconds, but it required about 7 seconds before it generated sufficient gas and power to fully assume the load. The gas producer overshot the desired speed by about 10%. This was followed by an undershot of about 4% and a second overshot of 2%. Then the rpm settled down nicely until it dropped off when the foam pattern change was made. The power output shaft and foam pump speeds roughly followed the same course as the gas producer; thus it required about 8 to 9 seconds for the foam pump to achieve its equilibrium speed. Although this was an appreciable time lag, the turret foam discharge

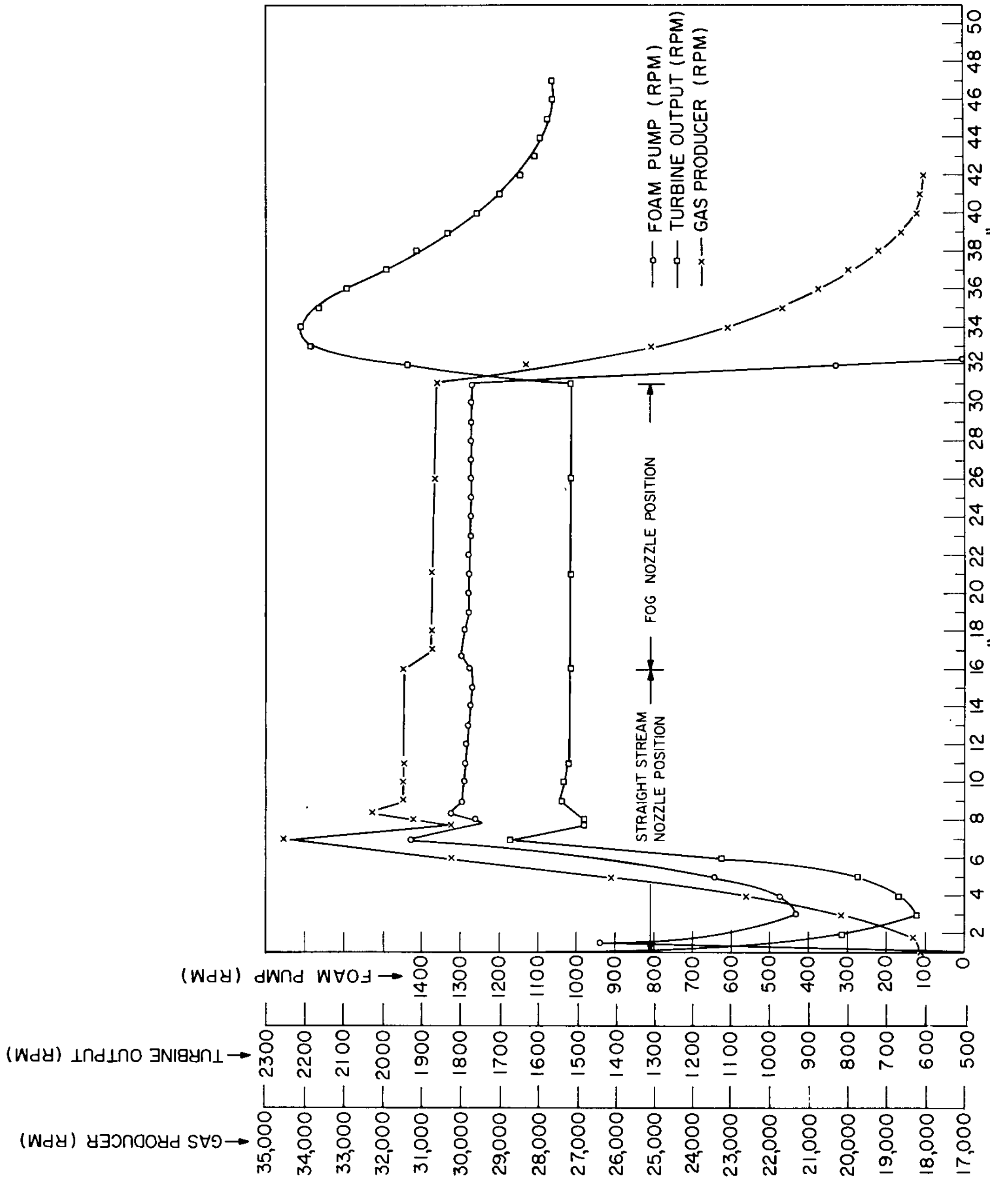

Fig. 16 - Speed relationships of gas producer, turbine output shaft, and foam pump during foam making operation with vehicle stationary

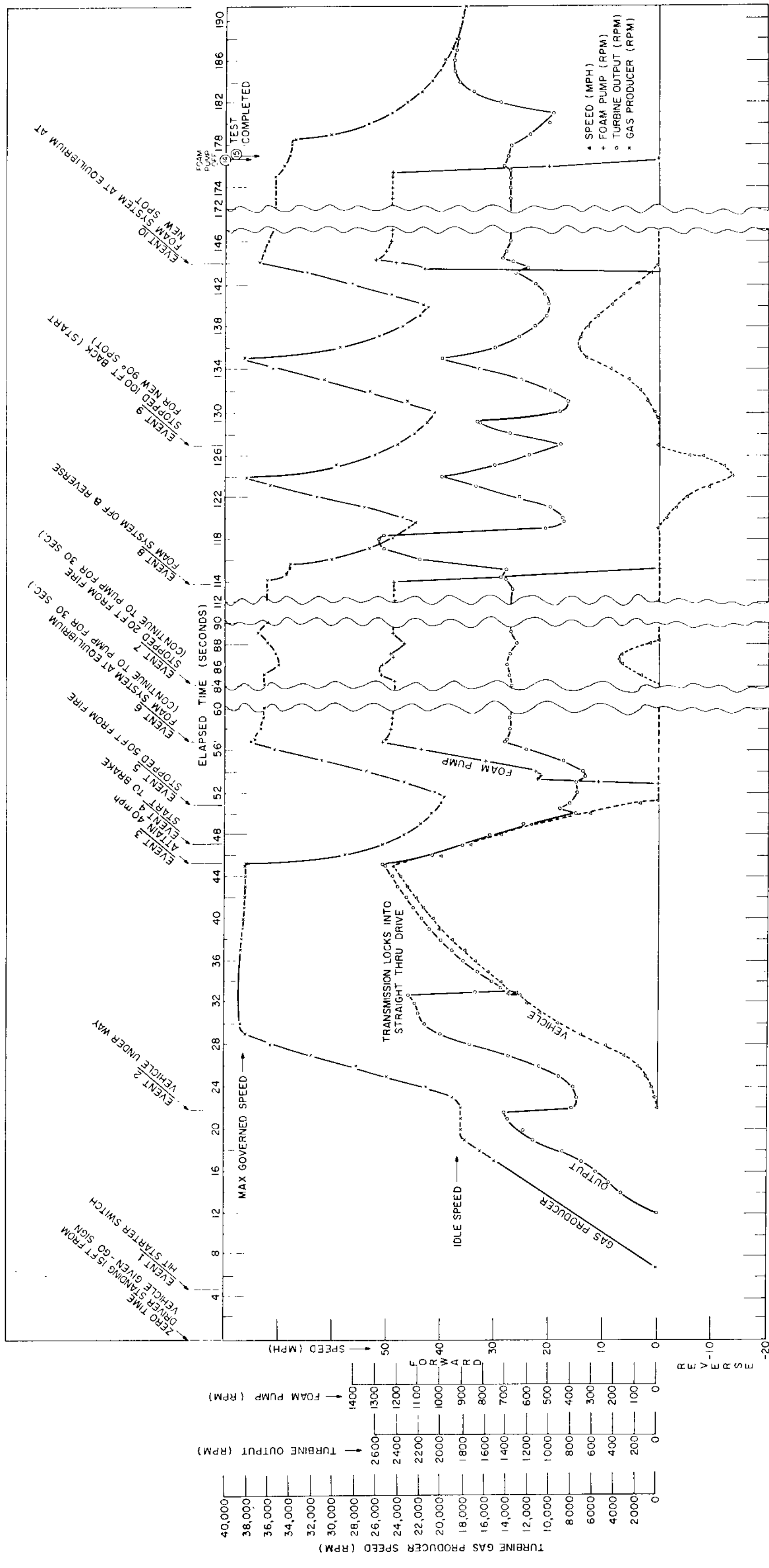

Fig. 17 - Recorded traces of vital functions occurring during a typical "scramble"

would have been acceptable for firefighting purposes from about 6 seconds on. Transition at the stream position point was very smooth.

Simulated Firefighting Procedures

Several complete firefighting "scramble" runs were conducted in the manner discussed previously and illustrated in Fig. 5. Timings were made both by observers with stopwatches and by the recording instruments. The instruments provided a much more detailed record on turbine speeds and other factors, but timing of the events could be more readily accomplished by observers. Typical recording traces of a single run are shown in Fig. 17, showing the gas producer speed, turbine output speed, and vehicle and foam pump speeds when operating. Three brakes are shown in the traces when all systems were at equilibrium for extended lengths of time. This was done solely to shorten the length of the horizontal time axis. Indicated on the top time scale are the points when each of the times for the designated events took place.

The driver was given the "go" signal when he was standing 15 feet from the vehicle and the timing was started. He was required to get in the cab and then press the start button. In this case it required 7 seconds. The period required for the turbine to start and come to idle speed before the vehicle could get underway was 16 seconds (event 2). The time at which the vehicle attained 40 mph speed, event 3, was 45 seconds or 23 seconds from the time of initial movement. The driver was instructed to start his deceleration at the latest time that would enable him to stop at the first designated stopping point, 50 ft in front of the center of the spill fire area. As shown in Fig. 17, he started braking at 45 seconds, which was at the time he reached 50 mph and was stopped at 51 seconds. Within 1 second after stopping the foam pump was building up speed and reached equilibrium speed within 6 seconds after stopping. After 30 seconds of pumping at this location, the transmission was engaged and the vehicle moved up 30 feet toward the fire without disengaging the pump. The foam pump trace reveals a 6% temporary increase in speed as the vehicle started forward and then a 3% drop as the vehicle stopped. Neither of these momentary speed changes could be considered as being detrimental to firefighting capabilities. A maximum speed of 7.5 mph was reached during the move. Thirty additional seconds of pumping were allowed at the 20-foot spot before shutting down the foam pump.

With the reduction in load occurring after pump shut down the turbine output shaft coasted up to higher speed, while the gas producer was slowing down. When the transmission was engaged and the new power demand was imposed by backing the vehicle, the turbine speed trends were reversed. Event 9 was the time at which the vehicle had backed to the 100-foot-distant point, and event 10 when the vehicle had pulled up to a point 20-feet distant from the spill center, at 90° to the first 20-foot point, and with foam in full production.

Using the same event checkpoints as above, similar procedures were carried out using two MB-5's: one with a manual transmission and one with an automatic transmission. Table 1 summarizes the results for ease of comparison. The same data have been plotted in Fig. 18 on a time basis curve to better illustrate the comparative operation of the vehicles.

The turbine powered vehicle was found to lag behind the gasoline driven vehicles until between events 7 and 8, after which time it is faster. The initial slowness is, of course, caused by the slow starting characteristics of the turbine power plant. This occurs despite its 50% greater horsepower capacity. Acceleration to a speed higher than 40 mph would have brought out the edge of the turbine earlier because of its marked superiority in high-speed acceleration (Fig. 13). It was not possible for the gasoline driven vehicles to attain speed greater than 40 mph within the distance of one-quarter mile allocated, so 40 mph had to be selected in order to provide a common basis of comparison.

Table 1
Time Data of Firefighting Operations for MB-5
Type Vehicles According to Power Train

Checkpoints	Elapsed Time/(sec)		
	Turbine	Automatic	Stick
Zero time - Driver 15 ft from vehicle	0	0	0
Event 1 - Hit starter switch	5	4	5
2 - Vehicle underway	22	7	10
3 - Attain 40 mph	39	29	35
4 - Start deceleration	46	35	-
5 - Stop 50 ft from fire	51	40	44
6 - Foam system up	57	44	50
7 - Stop 20 ft from fire	84*	75	83
8 - Start in reverse	114	120	129
9 - Reach 100 ft back	127	134	139
10 - Reach new spot & foam system up	144	153	167

*Pumping time was 27 sec instead of the recommended 30 sec.

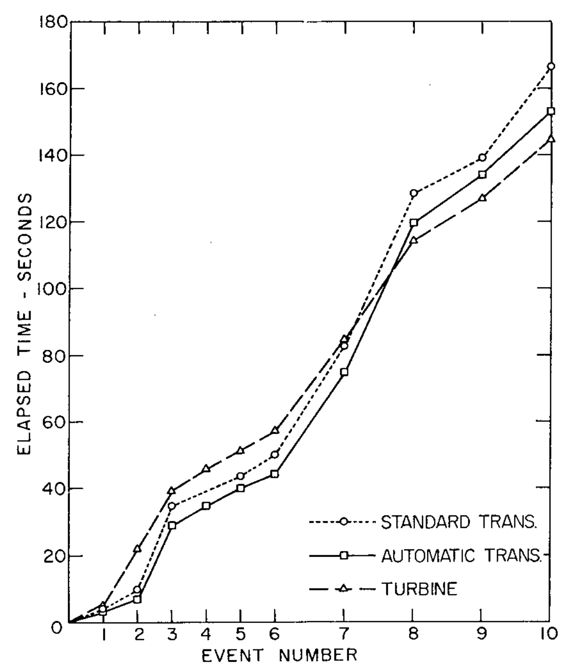

Fig. 18 - Comparison of the three MB-5 times operating on the "scramble" test

Once pumping and/or maneuvering of the vehicle had started, the turbine vehicle proved to be a better performer than the other two. The fact that the gas producer was maintaining some speed by virtue of carrying some load meant that it was very responsive to additional power demands. The superiority of the turbine vehicle late in the scramble procedure should not be taken completely as being a product of the turbine, but instead, as partial products of both the turbine and the improved power train arrangement, which does not require the frequent shifting back and forth between transmission and power takeoff drives.

Noise Level

Noise level readings were made in the vicinity of the vehicle using a General Radio Type 1555-A Sound Survey Meter. No attempt was made to analyze the sound regarding specific frequencies. Readings were taken on the C or C + 30 weighting position, which gives substantially equal response to all frequencies between 40 cps and 8000 cps.

The highest sound level found was that present around the rear of the truck near the air intake, where the readings were 110 db, with the gas producer at full speed. As the meter was taken away, the level dropped off to 98 db at 5 ft, to 87 db at 20 ft, and to 80 db at 100 ft. Under these operating conditions the level within the cab with the doors closed was 90 db.

Under pumping conditions, with the vehicle stationary, the noise level around the vehicle was 103 db, except in the area immediately to the rear, where it was 106 db. Within the cab with the foam pump engaged and with the doors and hatch open, the noise level at the driver's seat was 112 db. The foam pump was located inside the cab alongside and just to the rear of the driver.

Noise levels as those observed would not be considered dangerous, especially under the exposure times anticipated. To personnel working around or in the vehicle, the noise was not uncomfortable and did not interfere unduly with the conduct of normal duties.

Human Factors

The system concept of design has come into a prominent position in the military in recent years (1). This concept recognizes that man plays an important role in any system. A system must display information in the best manner for an operator to receive it, to analyze it, and then to take appropriate actions through manipulation of controls. Methodology for accomplishing these objectives is defined as human engineering. Through it an attempt is made to make the machine fit in with human factors such as man's sensory systems, his learning capability, his physical size, strength and reach, his anxieties, and his reaction to pressure.

Naturally the more complex an operation is, the more complex the human engineering task. A supersonic all-weather fighter aircraft or a man-carrying space ship are commonly recognized as extremely complex systems, but not so commonly recognized is the fact that emergency ground vehicles, like aircraft firefighting and rescue vehicles, have some of the same problems and should receive similar attention. One step in this direction has already been taken by the Office of Civil Defense, which has had prepared for use, a survey of the human engineering problem in firefighting equipment (2).

Laboratories operated by the military have issued manuals of standard practice for vehicle design (3). In these manuals environmental limits, such as atmospheric contaminants, noise, and vibration, are established and requirements for visual displays, gross-movement controls, visibility, safety, automotive subsystems, and safety and physiological factors are specified. These standards will be increasingly used in Navy vehicle specifications and should take a big step forward in correcting the "intangibles" about vehicle design which have been found difficult to cover in past procurements.

It would not be appropriate to go deeply into a study of the human factors involved in the existing turbine vehicle because it was a conversion of an existing unit and most of the design was inherited. The only aspects discussed will be those concerned with the specific items added in the conversion.

The gas turbine drive system, because of the lack of mechanical connection between the gas producer, which is the noisiest section, and the power output, gives rise to an uncertain driver reaction. Not until handling this vehicle does a driver realize how much he depends on his ears to supply him with information as to what is happening. The gas producer's high-speed operating range, 18,500 to 36,000 rpm, gives rise to a high-pitched sound, which is unusual and somewhat alarming. In gasoline or diesel engines things begin to disintegrate at speeds far below this. Also, the gas producer's speed has no fixed relationship to what the vehicle is doing, and the vehicle is always lagging behind by a disturbing degree.

These problems are easily and normally overcome by a driver as he accumulates experience, and in time will develop driving techniques to utilize the turbine's characteristics to best advantage. The civilian driver-operators for aircraft firefighting and rescue vehicles are being replaced in increasing numbers with young military personnel. The military personnel are usually not as well trained as the regular driver-operators and usually do not remain at this job long enough to become experienced driver-operators, although they do make good fire fighters. Any complications or unusual features effecting driver training must, therefore, be given more consideration in the selection of vehicles for naval applications. The general feeling received by the driver is more that of taxiing a Viscount aircraft than driving a truck.

Although the previously cited difficulties do not specifically concern a hazard, but, rather, a matter of proficiency, one potential hazard is felt to exist in the drive arrangement which requires the driver to control the movement of the vehicle by continued and positive braking while the firefighting system is operating. If the driver is not alert at all times, he may permit the vehicle to drive into the fire or into personnel working immediately in front of it. The single handline storage compartment is installed in the nose of the vehicle and the handline man must be in this area to remove or to replace the line; this area is not readily viewable from the driver's position. A safety device is provided here which requires the brake to be depressed before the transmission can be initially engaged, but once engagement has taken place, safety devices are no longer in effect. This operation will have to be closely watched after the vehicle is placed in the field to see if modifications are in order or whether the present design is acceptable.

The information display as presented on the vehicle instrument panel is good. All mechanical indicators are grouped immediately in front of the driver, the electrical switches are grouped to the right of the indicators, and the firefighting system controls are grouped further to the right. The gas turbine display is contained on a separate submounted panel, but still within the groupings as above. Figure 11 is a photograph of the panel with the groupings indicated. Labeling of the display is inadequate according to requirements established (1,3). Also, zone markings to indicate various operating conditions on the instruments have not been provided. These are desired to make it obvious at a glance whether operation is within acceptable limits and to make it equally obvious when immediate corrective action is required. Such markings are especially desirable on the handline pressure gage and the hydraulic system pressure gage.

The green indicator light which is used to signal acceptance of the firefighting system controls is much too small and faint; it should be 1/2 inch in diameter (1) for easier reading.

Maintenance and Reliability

During the test period, the vehicle was operated intermittently from its receipt in December 1963 until April 1965 and accumulated 296 engine starts, 51 engine hours, and 162 miles. These brought the totals up to 607 starts, 95.3 hours, and 443 miles as of April 1965. The gas turbine operated satisfactorily at all times and received no maintenance except for the checking of the oil levels. Thus, the turbine has lived up to its reputation for reliability and low maintenance.

The only problem encountered in the test period was the failure of the pump in the hydraulic control system. This pump, mounted on the power takeoff case, is approximately 5 feet above the transfer case sump, where it takes suction, and a faulty shaft seal allowed the pump to take in air, which in turn produced only intermittent hydraulic pressure. After replacement of the pump shaft seal no further difficulties were encountered with the hydraulic system or the vehicle.

CONCLUSIONS

A thoroughly satisfactory vehicle has resulted from the conversion of a gasoline powered MB-5 to a turbine powered MB-5. However, the current testing program, which emphasized fire fighting operation and only touched on automotive testing, did not indicate the turbine vehicle to have any overall superiority to the original form. Some areas showed improvement and some areas showed impairment. The picture was clouded by other nonturbine required modifications made in the drive train and by the greater horsepower rating of the turbine.

In the only automotive testing accomplished, the turbine vehicle acceleration was found to be considerably higher than the gasoline powered version at speeds above 20 mph. The turbines higher acceleration rate offset any lag in getting underway, if a run of any distance was made.

The sounds and feel associated with driving this vehicle are quite foreign to a new driver, but it is believed that the training required to obtain good driving performance could be accomplished within a short time.

Simulated firefighting procedures showed the turbine to be faster in maneuvering and more capable than the gasoline vehicle, but these advantages were attributed to the improvements in the drive system rather than to the turbine power.

The very high initial cost of a gas turbine makes the overall vehicle cost high when compared to conventional power. The comparative performance data obtained thus far cannot justify the added expense.

A "scramble" firefighting operation with timing checkpoints provides a meaningful set of data for comparing performance of aircraft firefighting and rescue vehicles.

RECOMMENDATIONS

It is recommended that the turbine vehicle be sent to the Aberdeen Proving Ground for limited additional automotive testing. Such tests should be concerned with gradeability and off-highway performance.

At the conclusion of Aberdeen tests, if any, it is recommended that a conventional type engine be reinstalled and the vehicle put back into field service. If this should be economically unsound, the vehicle should be scrapped. In any event, Boeing Aircraft Co. should be contacted relative to buying back the turbine engine, which is already an obsolete item.

It is also recommended that the newest version of the MB-5 currently in production, using a gasoline engine and a power train similar to the turbine vehicle, be evaluated in order to separate the contributions of each to fire fighting efficiency.

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13. ABSTRACT

One of the MB-5 series of crash trucks was equipped with a gas turbine engine as a source of power. During the testing of this vehicle the operating characteristics of the engine were monitored under different load conditions, variable road speed, and variable foam pump speed. The turbine powered vehicle was compared to other, conventional engine model, trucks now in operation, both for rapidity of acceleration and for ease of operation.

A standardized simulated firefighting operation called a "scramble" operation was devised for the integration of human engineering with the relative efficiency of each of the three vehicles. Time intervals required to reach a given series of check points during a fixed firefighting procedure were recorded by multichanneled instrumentation or by observation.

The turbine-powered vehicle proved to be superior in acceleration performance and equal in firefighting capability to conventional engines. These factors alone may not justify the higher initial cost of the turbine power plant. Future field studies involving maintenance costs over extended periods of field operation and vehicle performance under severe environmental conditions might alter present considerations.

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