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LABORATORY
TECHNICAL REPORT**

NO. 12942

Testing and Evaluation of JET
Electric Vehicle Models: 600,
1000, and 1000P.



Interagency Agreement No. DE-AI01-78CS55266

February 1984

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RESEARCH AND DEVELOPMENT CENTER
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The major purpose of this program is to test the performance and the economy of contemporary electric vehicle versus conventional internal combustion engine vehicle for delivery type industrial applications. The test data of these three different types of vehicles, compared to similar conventional internal combustions engine vehicles, operated at same locations and conditions, show that conventional vehicles have advantages over the electric vehicles and that as stated below:		

a. Total electric vehicle maintenance and energy cost is 58¢/mile.

b. Total internal combustion engine vehicle maintenance and energy cost is 24¢/mile.

Other advantages and disadvantages are stated in the Conclusions paragraph of this report.

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SECTION I. BACKGROUND

1.0. Program Background and Program Goals

a. On September 17, 1976, the United States Congress approved the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976 (P.L. 94-413). The Act required the demonstration of technological and economical practicality of the electric and hybrid vehicle and the involvement of Federal Agency Fleets in the demonstration and test of the electric vehicles as soon as possible. As a result, an interagency agreement was made between D.O.E. and D.A., in May, 1979. Per this agreement, funds were allocated by D.O.E. and TACOM for five (5) electric vehicles, two (2) mini-vans (model 600), one (1) van (model 1000), and two (2) pickup trucks (model 1000P). These vehicles were evaluated and tested (FY80-FY83) by TACOM and RRAD.

b. The purpose of this program is to determine, by actual field demonstration testing, the feasibility of the electric powered vehicle to replace the conventional internal combustion engine powered vehicle. RRAD has a fleet of 800 vehicles, and consume a large amount of gasoline each year. The five (5) electric vehicles were integrated into RRAD fleet for performance and feasibility in a delivery type of application.

2.0. General Design Features of the Electric Vehicle

a. The electric vehicle drive provides smooth acceleration, its speed and torque are controlled throughout the operating range by means of Voltage and Current Regulation System.

b. The electric vehicle generates little noise and no pollution to its surrounding environment.

c. The electric vehicle does, indirectly, contribute to the air pollution when its battery is charged with electricity generated in power plants fueled by coal or oil fuel sources. These power plants stack in the ambient air gas emissions like sulfur dioxide and oxide of nitrogen.

d. A contact-free type semiconductor device (Impulse Control System) is incorporated into the Electric Vehicle System to achieve variable speed control and energy regeneration during braking. This energy is recovered and fed back into the battery during braking operation. This design feature of the Regenerative Braking System is not incorporated into these RRAD test vehicles.

e. For low speed delivery type of application, the electric vehicle, versus the internal combustion engine vehicle, is economical in energy consumption.

f. In general, the electric vehicle has short range, poor hill climbing ability, less acceleration, and higher maintenance cost than the standard internal combustion engine vehicles.

2.1. Potential Advantages of the Electric Vehicle

The promised advantages of the mass applications of the electric vehicle are:

- a. Reduced fleet energy consumption.
- b. Contributing to the national goal of reducing petroleum consumption.
- c. Independence from petroleum fuel.
- d. Improved ambient air quality by reducing air pollution on the site of operations.

3.0. Test Vehicles Data

Figure 1 shows the test electric vehicle pictures and their model numbers. Table 1 lists their specifications and Table 2 lists the program schedule, with all milestones from the manufacturing of the vehicles to the program final report.

4.0. D.O.E. Performance Requirements for the Electric Vehicle

The following are the D.O.E. performance requirements of the electric vehicle:

- | | |
|---|-------------------|
| a. Acceleration from 0-50 KM/Hr (31 mph). | 15 sec. max. |
| b. Gradeability at speed 25 KM/Hr (15.5 mph). | 10% min. |
| c. Gradeability for 20 sec. (forward or reverse). | 20% min. |
| d. Max. speed (sustained for 5 min.). | 70 KM/Hr (44 mph) |
| e. SAE J227 A/B cycle cruising range. | 50 KM (31 miles) |

4.1. Acceptance Performance Data of the Five Electric Vehicles

Table 3 contains selected test vehicles acceptance performance data compared to the above D.O.E. minimum requirements.

4.2. Test Vehicles Acquisition Cost

- | | |
|--|----------|
| a. Two mini vans, model 600. | \$17,318 |
| b. One van, model 1000, and charger. | \$13,729 |
| c. Two pickup trucks, model 1000P, and chargers. | \$27,050 |
| Total cost: | \$58,097 |

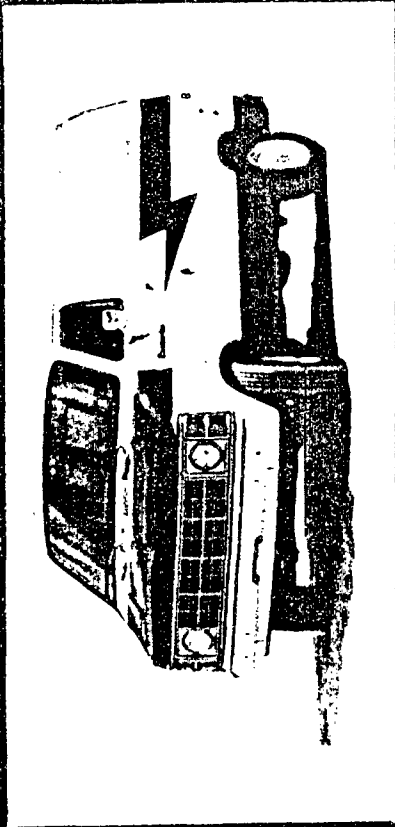
Section II. OPERATIONS

5.0. Test Site Description

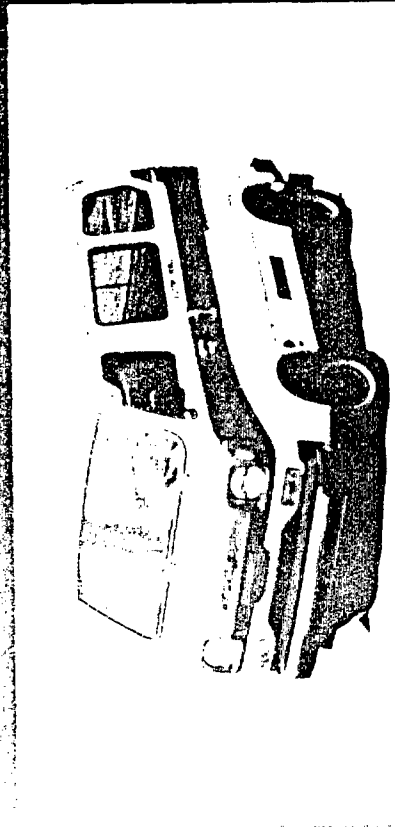
One of twelve depots in the US Army Depot Systems Command is Red River which is located eighteen miles west of the Arkansas-Texas stateline, in the city of Texarkana, with an employee strength of approximately 6,000 civilian employees and nearly 100 military personnel, Red River Army Depot is the largest single employer in the greater Texarkana area. Established in 1941, the depot reservation is over 36,000 acres and is one of the largest supply and maintenance installations in the US Army Materiel Development and Readiness Command.

5.1. Road and Climatic Conditions at the Test Site

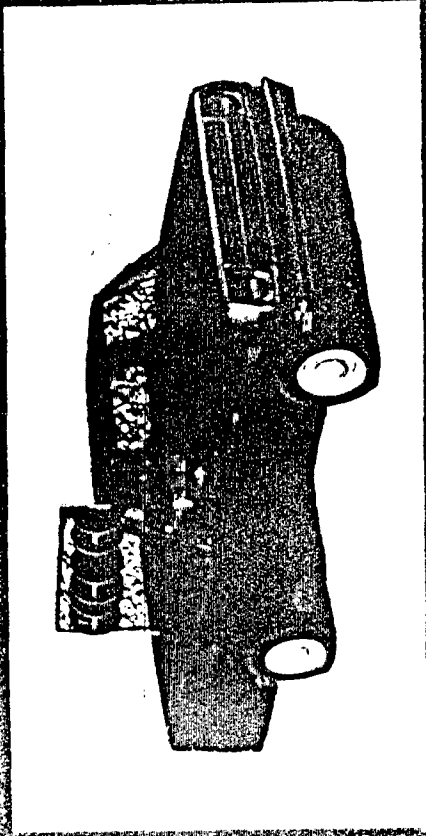
Red River Army Depot is relatively flat with all road systems used by electric



MODEL 1000



MODEL 600



MODEL 1000P

Figure 1

TABLE 1

ELECTRIC VEHICLE PROGRAM
Project No. 4331
ELECTRIC VEHICLES SPECIFICATIONS

Vehicle Model Number	600 Mini Van	1000P Pickup Truck	1000 Van		
Overall Height	64.6 inches	67.8 inches	77.23 inches		
Overall Length	135.0 inches	190.0 inches	176.0 inches		
Overall Width	54.9 inches	79.5 inches	79.82 inches		
Wheel Base	71.7 inches	115.0 inches	109.0 inches		
Cargo	76.56 FT3	N/A	208.0 FT3		
Inside Length	N/A	N/A	N/A		
Inside Width	48.0 inches	N/A	65.3 inches		
Inside Height	48.0 inches	N/A	47.18 inches		
Propulsion Motor					
Type	Series	Series	Series		
Insulation	H	H	H		
Size	7x16 inches	11x18½ inches	11x18½ inches		
Weight	105/160 lbs.	255.0 lbs.	255.0 lbs.		
HP Rating	20 HP AT 4707 RPM	37 HP AT 2039 RPM	37 HP AT 2039 RPM		
Propulsion Battery					

TABLE 1
ELECTRIC VEHICLE PROGRAM
Project No. 4331
ELECTRIC VEHICLE SPECIFICATIONS

Vehicle Model Number	600 Mini Van	1000P Pickup Truck	1000 Van		
TYPE	LEAD/ACID	LEAD/ACID	LEAD/ACID		
Voltage	102v	144v	144v		
Weight	1,122 lbs.	1,584 lbs.	1,584 lbs.		
Curb Weight	2,690 lbs.	4,790 lbs.	4,760 lbs.		
GVW	3,330 lbs.	5,790 lbs.	5,760 lbs.		
GAWR (front)	1,665 lbs.	3,000 lbs.*	2,860 lbs.		
GAWR (rear)	1,665 lbs.	3,100 lbs.*	2,900 lbs.		
Axle Ratio	4.375	3.5	3.5		
Transmission					
First Speed Ratio	4.363	3.09	3.09		
Second Speed Ratio	2.625	1.75	1.75		
Third Speed Ratio	1.809	1.0	1.0		
Fourth Speed Ratio	1.107	N/A	N/A		
Reverse Speed Ratio	4.272	3.0	3.0		
Steering					

TABLE 1
ELECTRIC VEHICLE PROGRAM
ELECTRIC VEHICLE SPECIFICATIONS

Vehicle Model Number	600 Mini Van	1000P Pickup Truck	1000 Van		
Turn Diameter	25 feet	47 feet	36.5 feet		
Turning Angle	37 degrees	33 degrees	37 degrees		
Wheels and Rims	500x10	15x5.50	15x5.50		
Controller	SCR	SCR	SCR		
Charger	On Board	Off Board	Off Board		
Input	115/220 V	220V	220V		
Max. Output	15/30 AMP	30 AMP	30 AMP		
*Note: 3000 and 3100 lbs are maximum design loads.					

TABLE 2

PROGRAM SCHEDULE
ELECTRIC VEHICLE PROGRAM

MS NO	MILESTONES TITLE	FY80				FY81				FY82				FY83				FY84			
1	Vehicles Manufacturing																				
2	Acceptance Testing																				
3	Vehicles Delivery																				
4	RRAD Testing																				
5	Program Final Report																				

TABLE 3

Selected Electric Vehicles Acceptance Test PerformanceCompared to D. O. E. Requirements

	<u>DOE REQ.</u>	<u>MODEL 600</u>	<u>MODEL 1000</u>	<u>MODEL 1000P</u>
<u>Acceleration: 0-31 Mph, Max., Sec.</u>	15	11	10	10
<u>Gradeability at 15.5 Mph, Min. %</u>	10%	15%	15%	15%
<u>Gradeability Limit for 20 Sec. Min. %</u>	20%	30%	30%	20%
<u>Max. Speed (Sustained for 5 min.), Mph.</u>	44	52	60	60
<u>Min. Range, on SAE J227 A/B Scale, Miles</u>	31	43.5	35	35

vehicle being hard surfaced. The posted speed limits range from a minimum of 15 miles per hour in congested areas to 45 miles per hour in outlying areas. The average speed limit in the administrative areas is 25 miles per hour. The climatic conditions for the Texarkana area are relatively mild winters and hot summers. Winter temperature ranges from a low in the mid teens to high in the mid thirties or low forties. Icing and snowfall occurs usually in January and February with little accumulation. Summer conditions are usually hot (mid to high 90's) with accompanying high humidity. Rainfall is prevalent in late spring and early summer with extensive dry periods during August and September.

In summary, the mission profiles, terrain, and climatic conditions prevalent at Red River Army Depot provide an almost ideal operational environment for the electric vehicles.

6.0. Vehicles Mission

The initial assignment of electric vehicles to using organizations was based on consideration of user interest, average miles per day user required to perform assigned mission, vehicle requirements (payload, hours of operation, maximum daily mileages, frequency, and minimum number of drivers required to operate the electric vehicles). Based on these requirements, electric vehicles were assigned to the Mail Room, Custodial Inspector, Missile Maintenance Operations, Computer Operations and General Supply.

6.1. Vehicle Model No. 600, Mini Van, ID No. EV0009 Assignment

The mail disbursing operations usually consist of three runs per day with a mileage requirement of 8 to 10 miles per run. The payload requirements per mail run was usually less than 50 pounds. Stop and start requirements for this operation ranged from 20 to 35 stops per day, five days per week. With the limited payload requirements, mileage requirements, and no passengers, the 600 mini van was assigned to this operation.

6.2. Vehicle Model No. 1000P Pickup Truck, ID No. CH6414 Assignment

The custodial inspector primary function is the inspection of work performed by the janitorial contractor, and the disbursing of janitorial supplies, such as, towels, cleaning compounds, floor wax, and various janitorial equipment, such as, brooms, mops, and floor buffers. The maximum payload requirement for this function is 200 lbs. The average daily mileage requirement is 15 miles with a maximum stop and start frequency of 15 per day, five days per week. In considering the aforementioned requirements, the 1000P pickup truck was assigned to this operation.

6.3. Vehicle Model No. 600, Mini Van, ID No. EV0010 Assignment

The Missile Maintenance Organization Vehicle Requirement was primarily one of messenger service, and taxi. The messenger service required the disbursing of various documents to associated organizations located at various sites around the depot. Passenger needs usually consisted of no more than one person. Data for daily mileage requirements indicated that the estimated

electric vehicle range limit of 40 miles would be exceeded. The reason for this high mileage is due to the remote location of this organization from the main depot administrative areas. These operational characteristics appeared to be an appropriate opportunity to test the electric vehicles daily mileage capabilities. Therefore, the 600 mini van was assigned to this organization.

6.4. Vehicle Model No. 1000, Van, ID No. CH6413 Assignment

The Computer Operations Function is very similar to the mail handling function. Their vehicle requirements entailed the daily disbursing of computer tapes, and delivery of computer paper to remote sites located at various points within the main complex of the depot. The maximum payload required for this mission is 100 pounds. The distinct difference between the computer operations and mail handling is that they operate seven days per week, 24 hours per day. Because of the requirement to protect the materials transported from inclement weather, the 1000 van was assigned to this function.

6.5. Vehicle Model No. 1000P, Pickup Truck, ID No. CH6412 Assignment

The General Supply Function of Red River Army Depot requirements entailed, a high frequency of stops and starts (60 to 70), delivery of various parts and supplies, and daily mileage requirements of 25 to 30 miles for five days per week. The maximum payload required for this mission is 50 to 100 pounds. The 1000P pickup truck was assigned to this function.

7.0. Existing Institutional Characteristics/Barriers

Because of the diverse operations performed at Red River Army Depot, the basic knowledge, skills, maintenance, and support requirements for the operation of electric vehicles was available to conduct the demonstration test. Personnel of the Depot Equipment Division are familiar with the mechanical and electrical systems similar to those found on the electric vehicles. This working knowledge results from their association with electric forklifts, and other electrically operated material handling equipment. Thus, equipment required to perform preventive and corrective maintenance for the electrical mechanical, and battery systems was available. The principal barrier that was contended with throughout the test was related to availability of manpower for maintenance and repair. The primary function of the material handling equipment personnel is the maintenance and repair of equipment that supports the depots three primary missions. Because of the extensive workload prevalent in these shops, repair of electrics was not always accomplished as expeditiously as possible. This, to a large extent, influenced the decision to contract maintenance and repair services in the last year of the demonstration test. The only other barrier was related to operator or user apathy, with respect to electric vehicles. This progressed from curiosity of the first six months to a marked distrust in vehicle reliability in the later stages of the test.

8.0. Vehicles Manufacturer Follow-up Support

Jet Industries, in Austin, TX, is the manufacturer of these five electric

vehicles. In the initial period of the demonstration test, the manufacturer responded adequately to operational and maintenance problems. However, as time progressed, support for repair parts, troubleshooting information, and other requirements steadily diminished. This condition was in part due to the financial problems that Jet Industries experienced during the test periods, and their plant fire.

9.0. Average Mile Per Day and Total Miles Driven for Each Vehicle

<u>Vehicle ID No.</u>	<u>Vehicle Model No.</u>	<u>Average No. of Miles Per Day</u>	<u>Total Miles Driven</u>
CH6412	1000P (Pickup Truck)	28.1	4,707
CH6413	1000 (Van)	19.9	1,983
CH6414	1000P (Pickup Truck)	12.2	2,601
EV0009	600 (Mini Van)	26.5	5,846
EV0010	600 (Mini Van)	22.0	5,202

The above information is compiled from the Daily Operator's Log Sheet.

9.1. Number of Stops Per Day for Each Vehicle

In determining these values, vehicles were not equipped with a device for recording the number of stops per day. The values presented are based on the user's entry on the Daily Operator's Log Sheet.

<u>Vehicle ID No.</u>	<u>Average No. of Stops Per Day</u>
CH6412	72
CH6413	5
CH6414	9
EV0009	21
EV0010	6

10.0. Frequency of Failures for Battery

<u>Batteries Replaced Because of Failure</u>	<u>Vehicle Mileage</u>
CH6412 - 2	3705
10	4090
3	4391
4	4440
CH6413 - 13	1391
10	1902
CH6414 - 3	1735
10	2080
4	2208
2	2264

<u>Batteries Replaced Because of Failure</u>	<u>Vehicle Mileage</u>
EV0009 - 2	3763
3	3921
5	3990
EV0010 10	3431
2	4752

10.1. Other Electric Vehicle Component Failures

Printed Circuit Board for Rate-of-Discharge Meter

Driver Block Assembly

Blower Motor

Charger

400 Amp Main Fuse

State-of-Charge Meter

Relay

10.2. Conventional Vehicle System Component Failures

1. Drive shaft sheared mounting strap at 1,168 miles.
2. Clutch assembly failed at 3,878 miles.

10.3. Time Required to Make Repairs and Reason for Excessive Downtime

Data pertaining to actual repair times is fragmented in most cases, the major factor contributing to excessive downtime for the electric vehicles was waiting time for repair parts. During the initial phases of the test, maintenance was performed by personnel of the Material Handling Equipment Branch of Depot Equipment Division. However, availability of personnel to perform maintenance on electric vehicles normally was of a lesser priority. This was due to mission workload requirements related to repair of production equipment. In the fall of 1982 the repair and maintenance of the electric vehicles were contracted out to an electric firm in Texarkana.

11.0. Operational Constraints

Constraints associated with the operation of electric vehicles at RRAD were minimal. Initial vehicle assignments were made based on the known capabilities. Charging stations were located adjacent to the using organization and with the on-board chargers. There were problems associated with the bi-weekly battery checks. Each using organization was assigned a particular day of the week to accomplish this Preventive Maintenance (PM) action. However, battery shop workload caused delays for the action not being accomplished. Weather conditions had a minimal affect on the EV's operation. In those cases, where problems did occur, were related primarily to rainy or wet weather. The problems encountered were blown fuses due to water causing a short circuit. Cold weather did not create any problems. This probably was due to the relatively mild winters of 1981 and 1982. On the other extreme, temperatures of 95-100F caused problems with battery water evaporation. However, substantiating data was not made available.

12.0. Vehicle Safety, Incidences and Accidents

Vehicle incidences involving electrics were not a major problem during the demonstration test. Only one major accident occurred with the electric vehicles. On 31 Jan 83 at 1625 hours, Vehicle ID No. CH6413, 1000 Van, was reported on fire. The installation fire department responded, and the all clear signal was given at 1650 hours. The vehicle sustained major damages to the interior of the van. The batteries, wiring, and controller were destroyed. The Aerospace Corporation investigated the fire at the test site at RRAD; the following are their findings:

- a. Fire occurred on 31 Jan 83 while the vehicle was being charged.
- b. Van Purchase Date: November, 1979.
- c. Mileage at date of fire was 1,983 miles.
- d. Vehicle Serial No: CH6413.
- e. Charger Type: 2/144 L028CBP
- f. Serial No.: N-3254.

Charging station used 230 volts AC. G.E. controller EV-1 was destroyed during the fire. Of the 24 batteries used in the vehicle, there were 12, XPV-23-3, two EEIV golf cart batteries and ten newer batteries with 120 amp-hour current. The traction motor and heater showed no fire damage. Two of the battery modules, the closest to the destroyed controller appeared to have exploded. The fire started either at the battery module (next to the controller), due to gassing during the charge, or that the wiring in the controller area shorted, and the heat caused the batteries to explode. The estimated damage to this vehicle was \$9,000.

13.0. Charging Routine of the Vehicles

The charging habits of all electrics during the demonstration test were essentially the same. Vehicles were operated five days per week during the hours of 0800-1600 hours each day. Vehicles were placed on charge at approximately 1600 hours each day, and removed from charging at 0800 hours the following day. The one exception to this was weekends. Vehicles were placed on charge at 1600 hours on Friday and remained on charge until 0800 hours the following Monday.

14.0. Energy Consumption, and Energy Cost for the Electric Vehicles Operation at RRAD

Table No. 4 summarizes total miles driven, total kilowatt hours consumed, kwh per mile, cost per mile, and average miles per kilowatt hours for each electric vehicle operated during the demonstration test.

Section III. MAINTENANCE

14.1. Maintenance and Batteries, Preventive Maintenance and Cost

Parts replacement during preventive maintenance actions primarily dealt with servicing batteries, controlling corrosion, replacement of battery connectors and cables, and lubricating vehicle mechanical systems. The parts replacement during PM actions was so limited that frequencies for accomplishing PM on individual parts could not be established. The information that was collected is provided as follows:

<u>Vehicle No.</u>	<u>Item</u>	<u>Quantity</u>	<u>Cost</u>	<u>Odometer Reading</u>
CH6413	Battery Cable	10 ft.	\$11.00	1902
CH6414	Cable Ends	18 ea.	41.04	2080
CH6414	Battery Cable	7 ft.	7.70	2080
CH6414	Battery Acid	4 gal.	5.80	2080
EV0009	Cable	96 in.	9.60	3990
EV0009	Cable Ends	16 ea.	39.04	3990
EV0009	Blower Hose	3 ft.	4.98	3990
EV0010	Battery Cable	108 in.	10.80	3431
EV0010	Cable Ends	20	48.80	3431
EV0010	Battery Compartment Pad	1	17.18	3431

Preventive maintenance actions were done at 6 months, for the lubrication maintenance and bi-weekly for the batteries and associated equipment. Time required for servicing the lube requirements was an average of 30 minutes, and the time required for servicing the battery system ranged from a minimum of 45 minutes to a maximum of four hours. Battery PM action times were dependent on whether batteries required removal for cleaning actions or for just adding battery water.

ENERGY CONSUMPTION AND ENERGY COST FOR EACH TEST VEHICLE

22

14.2. Corrective and Preventive Maintenance Cost

The corrective and preventive maintenance actions accomplished during the three year demonstration test are shown in Table No. 5.

TABLE No. 5

Corrective and Preventive Maintenance Cost

<u>Veh ID</u>	<u>Date Out of Service</u>	<u>Date In Service</u>	<u>Odometer Reading</u>	<u>Reason</u>	<u>Cost \$</u>	
					<u>Labor</u>	<u>Material</u>
CH6412	10/28/81	11/05/81	3705	Repl. 2 batteries	40	116
	12/17/81	02/01/82	3878	Rate-of-Discharge Card inoperative		
	02/24/81	05/13/82	4090	Driver block assy.		
	04/27/83	05/05/83	4187	Repl. 10 batteries	315	584
				Repl. blower motor	-	19.55
	05/25/83	06/08/83	4440	Repl. 7 batteries	140	412
CH6413	07/01/81	07/05/81	1201	Ck chg sys	26.72	
	08/05/81	04/13/82	1391	Repl. charger 13 batteries		
	12/15/82	12/24/82	1902	Repl. 10 batteries	120.0	558.60
				Repl. 10 battery cables		11.00
	01/31/83		1983	Vehicle destroyed by fire.		
CH6414	08/26/81	09/03/81	1168	Drive shaft sheared	115	
	03/06/82	05/10/82	1735	Repl. 3 batteries	60	174
	06/17/82	07/14/83	1772	State of chg meter	46	47
	12/01/83	02/01/83	2080	Repl. 10 batteries	280	558
				4 gal. battery acid		5.80
				7 ft. battery cable		7.70
				18 cable ends		41.04
				1 charger		985
	05/03/83	05/11/83	2208	Repl. 4 batteries	100	233.91
				Repl. 1-12 volt battery		57.81
				Repl. fan blower motor		44.13
	05/25/83	06/02/83	2264	Repl. 2 batteries	45	117
EV0009	03/04/82	03/08/82	3763	Repl. 2 batteries	40	111
	05/19/82	10/07/82	3878	Repl. clutch	82	118
	11/17/82	11/23/82	3921	Repl. 3 batteries	60	167
	12/21/82	02/21/83	3990	Repl. 3 blower hose	180	4.98
				Repl. 2 clamps		1.72
				Repl. 1 400A fuse		5.97
				Repl. 5 batteries		279
				1 blower motor		19.55
				96" cable		9.60
				16 cable ends		39.00

<u>Veh ID</u>	<u>Date Out of Service</u>	<u>Date In Service</u>	<u>Odometer Reading</u>	<u>Reason</u>	<u>Cost \$</u>	
					<u>Labor</u>	<u>Material</u>
EV0010	06/08/81	06/09/81	560	Adj transmission shift linkage	14	
	06/30/81	07/01/81	852	Charger fuse open	14	1.00
	11/02/81	02/02/82	2244	Repl. charger	26	685
	05/11/82	02/22/83	3431	Repl. 400A fuse	160	5.97
				Repl. relay		27.50
				Blower motor		19.35
				13 batteries		760
				108" battery cable		10.80
				20 cable ends		48.80
				1 Pad		17.18
	15/31/83	06/06/83	4752	Repl. 2 batteries		117

NOTE: Some of the itemized labor actions and service parts costs are not listed in Table No. 5 and are estimated for \$2,650.00 per five vehicles during the three years feasibility testing.

14.3. Site Facilities and Training Cost of the Electric Vehicles

a. Site Facilities Cost: There was a one time cost associated with the metering and power hook-up for the electric vehicles.

(1) Labor Cost: \$1,917.52

(2) Material Cost: \$2,635.32

b. Training Cost: Training cost associated with the electric vehicle test consisted of the following:

<u>Type</u>	<u>Cost</u>
Operation and maintenance training.	Cost included in the purchase of the electric vehicles.
Completion of data collection forms: one two hour session.	\$238.00
Additional training requirements - at least one 16 hour session on maintenance and trouble shooting.	\$536.00

All personnel involved in the demonstration test were on a part-time basis and are listed as follows:

	<u>% of Time Per Vehicle</u>	<u>Average Hourly Rate</u>
Project Leader	5%	\$16.75
Battery Mechanic	3%	\$13.36
Electronic/Electrical Mechanic	7%	\$13.36
Auto Mechanic	2%	\$13.36

Note: Above hourly rates include base, fringe and leave benefits.

Section IV. LIFE CYCLE COST

14.4. Life Cycle Cost (Energy, Preventive Maintenance and Corrective Maintenance) of the Electric Vehicles

a. Projected Life Cycle of the Electric Vehicle: The electric vehicle projected life cycle is 6 years or 72,000 miles, that is based on service life of a similar internal combustion engine powered vehicle at RRAD.

b. Electric Energy Cost Per Mile:

(1) Total energy (kwh) consumed by the electric vehicles is 20697 kwh.

(2) The cost of electricity per kwh is 4.33¢ (Dec, 83 rate at Texarkana).

(3) Total Energy Cost: $20697 \times 4.33 = \$896.18$.

(4) Cost Per Mile: $\$896.18 \div 20339 = 4.40\text{¢/mile}$.

c. Corrective and Preventive Maintenance Cost Per Mile:

(1) Material: \$6,421.00 for motors, fuses, meters, batteries, etc., per five vehicles as shown in Table No. 5.

(2) Labor: \$1,863.00 for corrective and preventive maintenance per five vehicles as shown in Table No. 5.

(3) Labor: \$2,650.00 for corrective and preventive maintenance per five vehicles, as shown in Table No. 5 and note.

(4) Cost Per Mile: $\frac{6421 + 1863 + 2650}{20339} = 53.73 \text{ ¢/mile}$

d. Total Cost (Energy + Preventive Maintenance + Corrective Maintenance) Per One Mile:

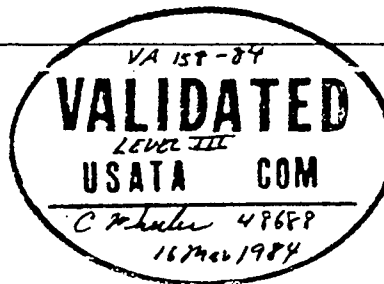
$53.73 + 4.40 = 58.13\text{¢/mile}$.

e. Life Cycle Cost (Energy + Maintenance):

$58.13 \times 72,000 = \$41,853.60$

f. Life Cycle Cost Using AR 11-28, Discount Factor: See the analysis on the following page for details.

Project Year	Operation Miles	Total Operating Cost \$	FY 83 Cost	Discount Factor	Total Operating Cost Using Discount Factors
1	12,000	6975.60	\$83	.954	6655
2	12,000	6975.60	\$83	.867	6048
3	12,000	6975.60	\$83	.788	5497
4	12,000	6975.60	\$83	.717	5002
5	12,000	6975.60	\$83	.652	4548
6	12,000	6975.60	\$83	.592	4130
TOTAL	72,000	41853.60			31880



NOTES:

- These costs are based on labor and energy cost rates in FY83 and durability cycle of the electric vehicle of 72,000 miles at RRAD.
- The vehicles service facility, the metering and power hook-up cost (material and labor), and the training cost which total to \$5,327.00 and which is considered as one time cost, is not included in the above cost calculation.
- The acquisition cost as shown in paragraph 4.2. is not included in this Life Cycle Cost Calculation.

14.5. Cost of Electric Energy Associated with Electric Vehicles

The electric power costs are based on several factors:

- a. The cost of raw material and labor of the energy sources used to produce electricity like fossil fuel, hydraulic energy, and nuclear energy.
- b. The demand, the quantity of kwh used by certain industrial organization.
- c. The location of the power plant and their industrial rate per kwh.

Red River Army Depot (RRAD) rate is 3.90¢/kwh in December, 1983, 4.77¢/kwh in September, 1983, and 3.98¢/kwh in August, 1982. The 1983 average rate per kwh for RRAD is 4.33¢/kwh.

The cost for kwh according to the United States Postal Service, Research and Development Laboratory, which operates JET Industries electric vehicles versus the jeep is 7¢/kwh in Austin, Texas and 3.70¢/kwh in Evansville, Indiana.

14.6. Maintenance and Energy Cost of Electric Vehicles Versus Conventional Vehicles

- a. Table No. 6 lists the energy and maintenance cost for the electric vehicles and internal combustion engine vehicles operated at Red River Army Depot and at the United States Postal Service, and the internal combustion engine vehicles operated at Tooele Army Depot and at the US Army Tank-Automotive Command.
- b. Table No. 7 lists the average energy cost for electric vehicles and internal combustion engine vehicles operated at Red River Army Depot.
- c. Table No. 8 lists the energy and maintenance costs of the internal combustion engine powered vehicles and operated at Red River Army Depot.
- d. Table No. 9 lists the energy and maintenance costs of the internal combustion engine powered vehicles and operated at Tooele Army Depot.

15.0. Vehicle Configuration Control

- a. During the demonstration test, the site operator made two minor modifications to the battery storage compartment of the model 1000P vehicle. The initiated changes consist of the installation of a rubber weather striping along the perimeter of the storage lid to prevent the seepage of water into this compartment. The second change consisted of the installation of a rubber mat in the above mentioned battery storage compartment to arrest the corrosion of the compartment lid.

TABLE 6
Electric Vehicle Versus Conventional Vehicle,
Energy and Maintenance Cost at Various Government Organizations

[illegible]

RRAD = Red River Army Depot
USPS = United States Postal Service
ICE = Internal Combustion Engine
TAD = Tooele Army Depot
TACOM = Tank-Automotive Command

TABLE NO. 7
Comparison of Energy Cost Between the Electric Vehicles
and ICE Vehicles at RRAD

Electric Vehicle	ID No. and Model No.	KWH/Mile	¢/Mile	Rate Per KWH	Equivalent ICE Vehicle Identification	Average Cal./Mile	¢/Mile	Cost/Gal. of Gasoline
	CH6412 CH6414							
	1000P Pickup Truck	Average 1.428	6.18	4.33¢ at RRAD December, 1983	Dodge Pickup Truck at RRAD	Average .0746	6.94	93¢ at RRAD December, 1983
	EV0009 EV0010							
	600 Mini Van	Average .8145	3.52	4.33¢ at RRAD December, 1983	Compact Sedan at RRAD	Average .04587	4.26	93¢ at RRAD December, 1983
	CH6413							
	1000 Van	.847	3.667	4.33¢ at RRAD December, 1983	Van Ford at RRAD	.0636	5.92	93¢ at RRAD December, 1983
E.V. = Electric Vehicle ICE = Internal Combustion Engine RRAD = Red River Army Depot ID = Identification								

Red River Army Depot Fuel Consumption and
Maintenance Cost Data for Their Vehicles Fleet

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TABLE 9

Tooele Army Depot Fuel Consumption and
Maintenance Cost Data for Their Vehicles Fleet

Vehicle Type	Fuel Consumption in Miles/Gallons	Fuel Cost c/Mile	Total Operating Cost Including Fuel c/Mile	Fuel Cost c/gal as of Dec 83 Reg/Unlead	Weight/Gross Vehicle Weight	Capacity of Fuel Tank	On-Duty Vehicle Load Range Average
Truck Cargo	13	9.80	31	\$1.26/1.29*	3800/4800	18	600 lb
Truck Carryall	7	18.21	31	\$1.26/1.29	5225/6725	18	900 lb
Truck Panel	13	9.80	31	\$1.26/1.29	5261/6761	18	1200 lb

* Tooele Army Depot pays commercial price for fuel.

Section V. USER'S ASSESSMENT (RRAD)

16.0. User's Assessment and Driver's Sentiments

a. The initial development of the demonstration program provided for no more than three drivers per vehicle. The reasons behind this requirement were data collection, operator training, and vehicle care and upkeep. As the program and vehicle maintenance progressed, the number of drivers increased. The following lists the number of drivers per vehicle:

<u>Vehicle ID</u>	<u>No. of Drivers</u>
CH6412	7
CH6413	12
CH6414	8
EV0009	2
EV0010	5
Total:	<u>34</u>

b. In the initial period of the demonstration test, personnel associated with the vehicles were enthusiastic and curious. Their comments on the operation of the vehicle consisted of how quiet the vehicle ran, smoothness, acceleration, speed, range, charging time, and energy cost. As the program progressed past the first year, drivers became dissatisfied with some of the vehicles (CH6412, CH6413, and CH6414) because of excessive downtime, and unreliability. Drivers of the two Jet 600 vans still remained satisfied with the performance and operation of these vehicles. This general feeling or opinion regarding the electric vehicles has remained even at the termination of the demonstration test. All personnel involved are somewhat relieved at the transfer of CH6412 and CH6414. However, the enthusiasm regarding the two smaller vans (EV0009 and EV0010) remains high.

16.1. Problems and Improvements to the Test Vehicles

The recommended improvements to the electric vehicles are primarily related to the Battery Storage and Battery Ventilation System. The battery storage compartment of the 1000P model created problems during battery checks. Batteries were difficult to remove, they were tightly arranged. Battery removal for maintenance and for the storage compartment cleaning caused excessive maintenance time. Also, this storage compartment leaked during rainy weather. The strap hinge in this compartment allowed water seepage into the storage container; as a result, batteries were removed to allow drainage. The Battery Ventilation System was disintegrating due to corrosion of the blower motor. Two other areas that created problems were the inadequacy of the operation and maintenance manuals, and the difficulty

in obtaining replacement parts. Trouble shooting guidance in the maintenance manuals, in most cases, was confusing and often had not been updated to reflect a change in the system being checked. Replacement parts delivery times were in many, if not all cases, very excessive. The battery changes for CH6413 took nearly 6 months for delivery. The clutch assembly for EV0009 was almost as long. Parts delivery was the major cause of excessive vehicle downtime throughout the vehicle demonstration test.

Section VI. MISCELLANEOUS

17.0. Design Improvement to the Battery

The successful development of the electric vehicle design is dependent on successful and innovative technology of the Battery System as an energy source. The present negative design characteristics of this Battery System are:

- a. Heavy weight.
- b. Short range.
- c. Low durability.
- d. High acquisition cost.
- e. High maintenance cost.

These negative factors discourage investment toward full development of the electric vehicle for mass application.

The following design features should be taken into consideration when the present Battery System of the electric vehicle is designed:

- a. Battery capacity should be designed on the basis of actual energy consumption of specific operation.
- b. The battery weight ratio to the design payload of the vehicle should be as low as possible.
- c. Battery cells should be installed in a supported compartment and be easily accessible for installation and removal and for maintenance work.
- d. An Automatic Water Refill System, controlled by the battery charging unit, could be incorporated into the design to assure constant level of electrolyte and reduce maintenance cost.
- e. Gel Cell Battery System is a relatively new design for electric vehicle application and is now undergoing a feasibility testing for life cycle, sensitivity to regenerative braking and sensitivity to high and low temperatures. This system has a potential to reduce the battery's service and maintenance cost.

17.1. Design Improvement to the Motor Drive to Increase Battery Range

The Regenerative Braking System of a shunt-wound motor drive is a good design choice to increase the battery range of the electric vehicle. The rate of increase in the battery range is function of vehicle speed, for 15 mph vehicle speed, and for delivery industrial type of application, the Regenerative Braking System increases the range of the battery by 5%. For higher vehicle speed, the battery range increases to as high as 12%. The regenerative effect is negligible below 12 mph vehicle speed. Figures 2, 3, and 4 show the block diagram of the electric vehicle drive and the circuit of an Impulse Control System in driving and in regenerative braking operations.

17.2. Operation of the Regenerative Braking System

Figure 4 shows how a circuit for regenerative braking is formed from the driving operation circuit shown in Figure 3. When the thyristor 2 of the Regenerative Braking System, shown in Figure 4, is switched on, while the motor 3 is running, a current flows in the direction opposite to that in driving operation. The motor acts as a generator 3, due to its reverse potential, and a braking force is produced. At the same time, energy is temporarily stored in the auxiliary inductance 4. When the thyristor is switched off, this inductive circuit is interrupted. The voltage at the auxiliary inductance 4 increases and the current can flow back to the battery, recharging it, via the diode 6.

VEHICLE DRIVE SYSTEM WITH REGENERATIVE BRAKING SYSTEM

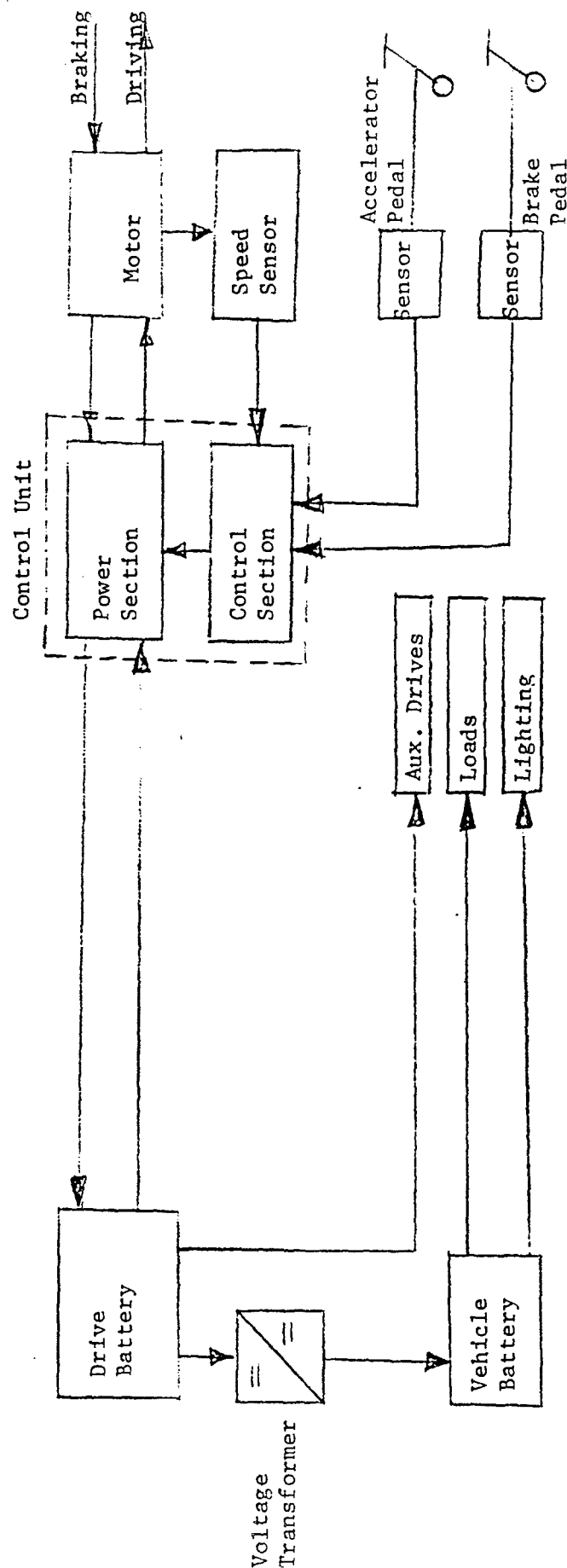


Fig. 2 Electric Vehicle Drive Block Diagram

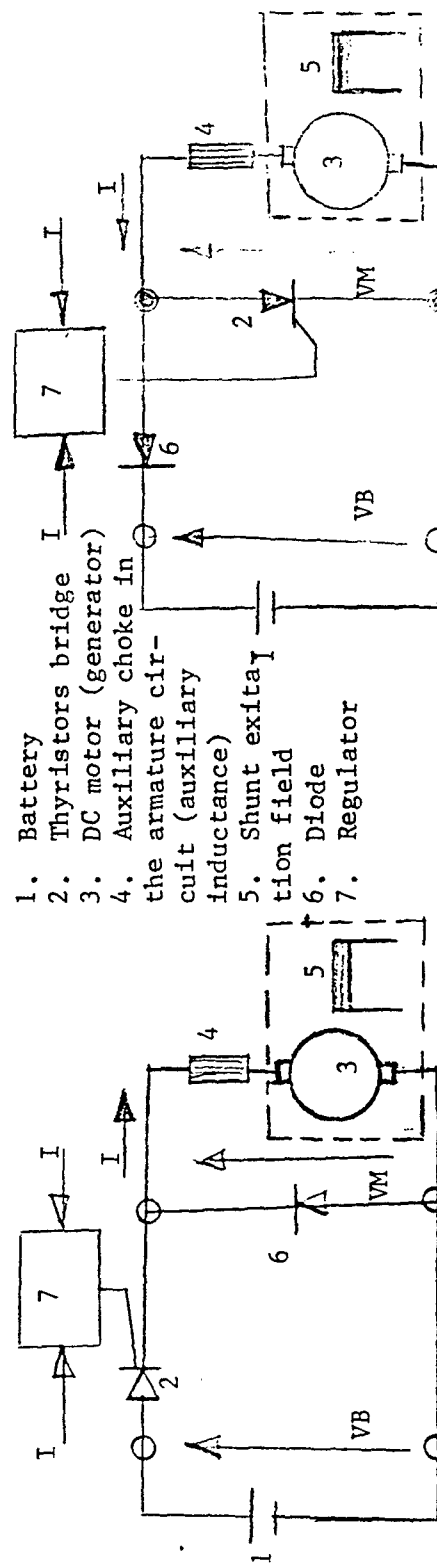


Fig. 3 Circuit of an Impulse Control System in driving operation.

Fig. 4 Circuit of an Impulse Control System in regenerative braking operation.

Section VII. PROGRAM CONCLUSIONS

18.0. Conclusion and Recommendation

The major objective of this program is to test the performance and the economy of contemporary electric vehicle versus conventional internal combustion engine vehicle for delivery type of applications. The test data of these three different types of vehicles compared to similar conventional internal combustion engine vehicles operated at same location and conditions show that the conventional vehicles have advantages over the electric vehicles as shown below:

- a. Average electric vehicle energy cost: 4.45¢/mile at 4.33¢/kwh.
- b. Average internal combustion engine energy cost: 5.70¢/mile at 93¢/Gal.
- c. Total electric vehicle maintenance and energy cost: 58¢/mile.
- d. Total internal combustion engine vehicle maintenance and energy cost: 24¢/mile.

Further, the acquisition cost and downtime for repair and various components failures of the electric vehicle are high. In addition, the battery heavy weight, short range, and frequent, and high maintenance cost, make the electric vehicle field applications at present time, not economical and not reliable compared to the reliability and economy of the conventional internal combustion engine vehicle. Some of the reasons for weak reliability and high cost of the electric vehicle are as follows:

- a. Funds to develop the electric vehicle are scarce.
- b. The performance and range of the electric vehicle are much lower than the performance and range of the internal combustion engine vehicle.
- c. The acquisition and the operating costs are much higher than the acquisition and operating cost of the internal combustion engine vehicle.

In summary, the electric vehicle has an inherent positive characteristic, that on site of its operation, is pollution free, quiet and has smooth acceleration. The cost of the energy consumption is relatively less than the energy cost of the internal combustion engine powered vehicle. The battery source of energy could be obtained from sources other than petroleum source of energy.

In order to benefit from the electric vehicle positive characteristics and make the negative characteristics acceptable for mass application, the electric vehicle must have extensive research and development program. The Government and industries cooperation to find solutions to the electric vehicle weak areas is essential.

18.1. Termination of the Test Program

The test results satisfied the requirements of this agreement and accumulated

more data and knowledge of the electric vehicle for delivery type of application. The Test Program accomplished its goal; and therefore, is terminated as of 30 October 1983.

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