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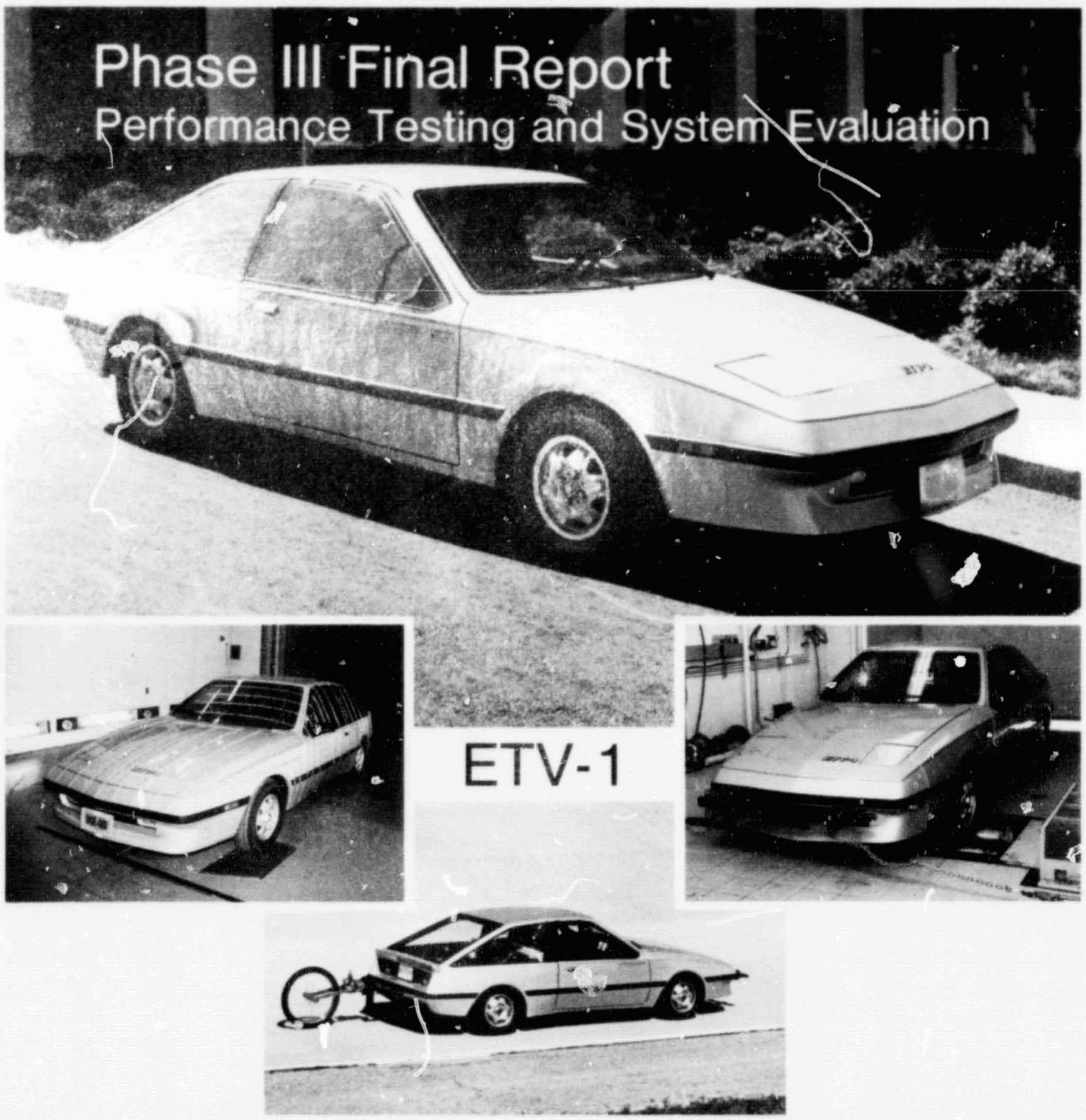
Electric & Hybrid Vehicle System
Research & Development Project

DOE/CS54209-3
Distribution Category UC-96

The DOE ETV-1 Electric Test Vehicle



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The DOE ETV-1 Electric Test Vehicle

Phase III Final Report

Performance Testing and System Evaluation

Donald W. Kurtz

December 1981

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with the National Aeronautics and Space Administration
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ABSTRACT

The DOE ETV-1 represents the most advanced electric vehicle in operation today. Engineering tests have been conducted by the Jet Propulsion Laboratory in order to characterize its overall system performance and component efficiencies within the system environment. A dynamometer was used in order to minimize the ambient effects and large uncertainties present in track testing. Extensive test requirements have been defined and procedures were carefully controlled in order to maintain a high degree of credibility. Limited track testing was performed in order to corroborate the dynamometer results. Test results include an energy flow analysis through the major subsystems and incorporate the aerodynamic and rolling losses under cyclic and various steady speed conditions. A complete summary of the major output from all relevent dynamometer and track tests is also included as an appendix.

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EXECUTIVE SUMMARY

A. PROGRAM OBJECTIVES AND PERSPECTIVE

The Electric and Hybrid Vehicle (EHV) Research, Development and Demonstration Act of 1976, Public Law 94-413, later amended by Public Law 95-238, established a governmental role in EHV technology development. Administered originally by the Energy Research and Development Administration, (ERDA), the Program objective was to decrease this nation's dependence on foreign petroleum by developing the technologies required to guarantee the successful introduction of EHV's into the marketplace.

A major element of that Program was a phased activity designed to develop the performance potential and economic viability of advanced electric vehicles that could be put into production in the 1980's. Phase I, involving three contractors, was aimed at the preliminary design of a state-of-the-art, energy-efficient Electric Powered Passenger Vehicle (EPPV).

General Electric, Corporate R&D was one of two contractors which initiated Phase II. Phase II proceeded from the Phase I preliminary design to the final design, development and delivery of a proof-of-concept electric test vehicle. The Jet Propulsion Laboratory (JPL) provided the technical contract management for the Department of Energy (DOE).

The final phase of this activity involving the General Electric DOE Electric Test Vehicle (ETV-1), was the Phase III Test and Evaluation performed by JPL. The purpose of this report is to describe the system-level operation of the DOE ETV-1 during the engineering tests designed to characterize and evaluate its performance.

B. TESTING PHILOSOPHY AND APPROACH

The concept of "system-level" testing is a prime example of a technology and discipline developed and refined during the space program. JPL and other aerospace contractors discovered that even with carefully designed subsystems, final assembly and check-out always resulted in the discovery of unanticipated and often very challenging new problems due to "system interactions." The development of sophisticated electric and hybrid vehicles poses many of the same generic problems and can, therefore, benefit substantially from an integrated approach to system design, development and testing.

Although a vehicle's natural environment is outdoors and on the road, it is impossible to conduct engineering tests under those conditions. The vagaries of weather, road conditions, and the requirement for on-board instrumentation combine to thwart any serious attempt to quantify subsystem operations making up the total system performance. Precision dynomometer testing provides the only reasonable alternative and a few carefully controlled track tests are useful to validate the extensive dyno results.

The key to accurate dynamometer testing lies in the set-up procedure or road-load determination. Coast-down testing is the most direct method to obtain the necessary information. Although it is a simple principle, properly conducted tests are very difficult to perform. The wide range of weather and seasonal effects require that sufficient precision be adopted in order to provide aerodynamic and rolling resistance coefficients so that standard condition principles can be applied. This procedure has been under development at JPL since 1975.

Testing of battery-powered vehicles added new and difficult dimensions to the automotive test procedures already adopted by the auto industry, the EPA and others. New instrumentation had to be designed in order to measure the high-frequency chopped current signals. However, battery charging procedures and test termination criteria had to be developed through iterative processes. Standardized test procedures were adopted including regulation of the initial battery electrolyte temperature since this has a first order effect on battery capacity. The actual electrolyte temperature which might result under consumer use is a function of many parameters including ambient temperature (regional as well as seasonal considerations), previous discharge history and battery condition. Nevertheless, by appreciating and addressing all of these problems, the system-level test activity at JPL has developed a credible test capability for making subsystem and total vehicle evaluations. This capability was applied to the DOE ETV-1 for the Phase III Test and Evaluation activity.

C. RESULTS AND CONCLUSIONS

Although the ETV-1 embodies many of the features necessary for commercial application, it is by name and purpose a test vehicle. For that reason, it was appropriate that it be evaluated not only as a total end to end system but that the major subsystems be evaluated within the system environment as well.

The measured energy required to drive the ETV-1 at constant speeds and over the SAE J227a D and EPA Urban (FTP) driving cycles on the dynamometer and in the supporting track tests is presented in Figure 1. Energy required is normalized by distance traveled in order to compare the energy consumption of the total vehicle under various driving conditions. The non-monotonic relationship between energy consumption and speed results because of the interrelationships of the various subsystems and their individual efficiency characteristics. In order to determine how the energy was distributed and consumed among the various subsystems, an energy flow analysis was performed. During constant speed operation, a power balance equation was used to help isolate the contributions of various components. Data from recently conducted tests of an ETV-1 breadboard power-train at the NASA/Lewis Research Center were required to separate the losses inherent in the motor-transaxle combination under various loading conditions. An example of the energy flow diagrams which result from such an analysis is shown in Figure 2. Motor, controller and transaxle losses can also be expressed in terms of their through-put efficiencies. Auxiliary power is used to continuously charge the accessory battery which, in turn, powers the cooling fans, control relays, status lamps and lighting.

The controller loss is negligible above the motor base speed (approximately 45 km/h or 28 mph) where the armature chopper is bypassed and full battery voltage is applied to the motor armature. Likewise, the motor efficiency, above base speed, is quite respectable ranging from 86% to 90% at

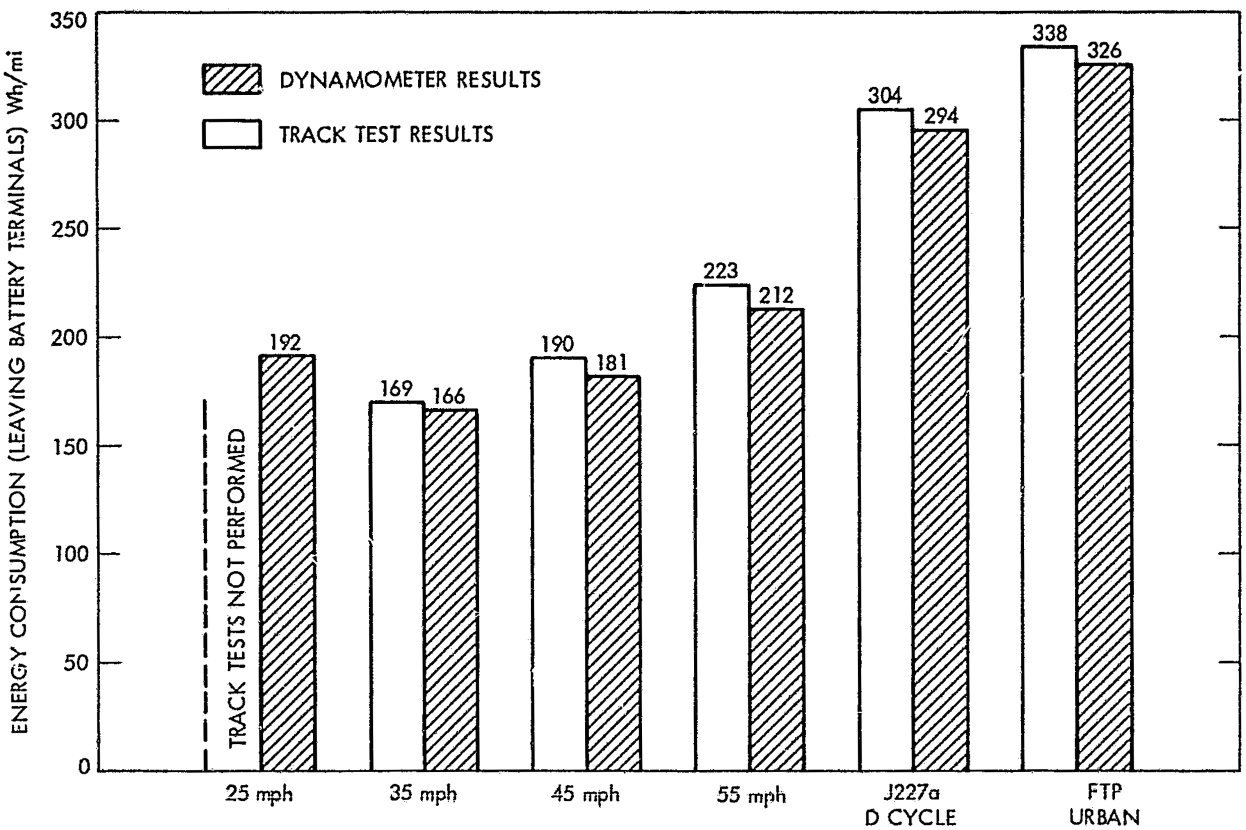

Figure 1. ETV-1 Energy Consumption; Correlation of Dynamometer Test Results with Track Test Results

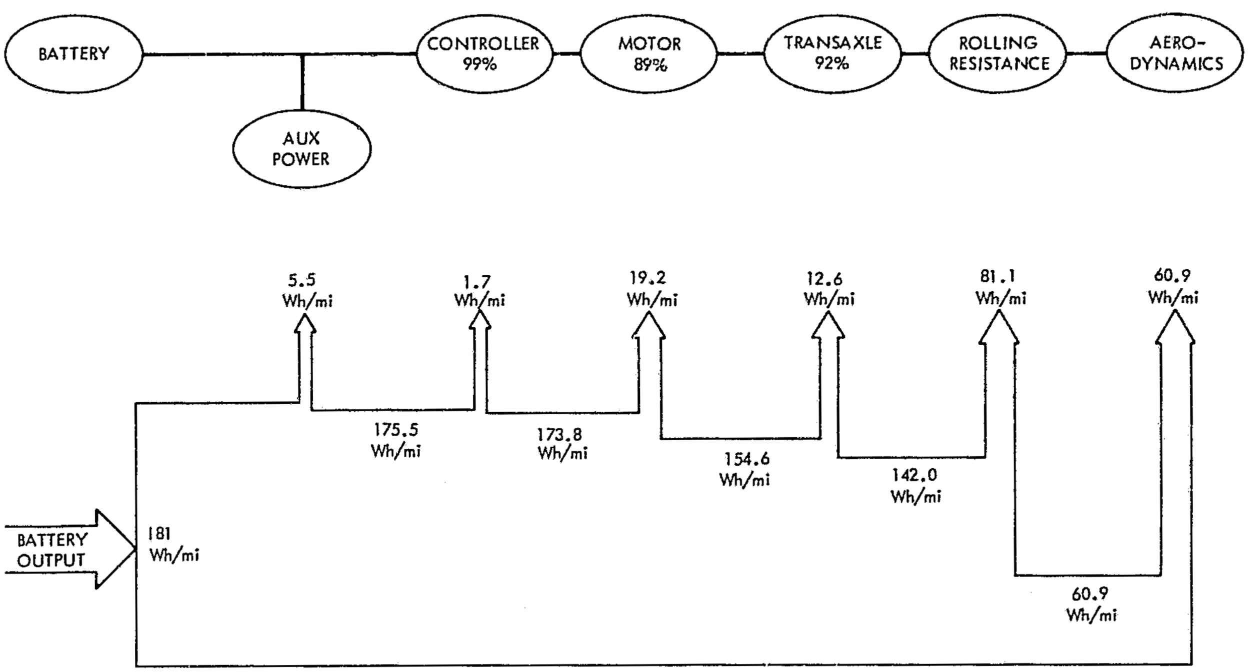

Figure 2. ETV-1 Energy Flow Distribution at a Steady 45 mph Speed

vehicle speeds of 56 km/h (35 mph) to 88 km/h (55 mph) respectively. The transaxle efficiency appears to be rather insensitive to speed variations at these low torque requirements characteristic of steady speed running. This result is typical for a chain reduction drive as used in the ETV-1 transaxle.

The rolling resistance and aerodynamic losses are totally dissipative and cannot be expressed in terms of efficencies. The ETV-1 exhibits an exceptionally low coefficient of drag (C_D = 0.32) and aerodynamics becomes the largest loss component only at speeds in excess of 80 km/h (50 mph). All of the major component losses, as a percent of the total energy required to operate the vehicle at steady speeds, are presented in Figure 3.

An energy flow analysis performed over repetitive driving cycles (such as the SAE J227a D) is more involved and requires additional information. Because of the transient nature of a driving cycle, an energy balance, rather than a power balance equation was used. Figure 4 shows the energy flow distribution over an SAE J227a D driving cycle. The energy consumed has been normalized by distance traveled in order to have compatible units with the previously developed constant speed energy distribution. Both the controller and motor-transaxle combination (data were not available for reverse-torque operation) are significantly less efficient during regeneration, however, over 42% of the kinetic energy stored in the vehicle during cruise makes its way back to the battery terminals.

To this point, any discussion of the range performance, or energy economy at the wall plug, of the ETV-1 has been purposely avoided. The

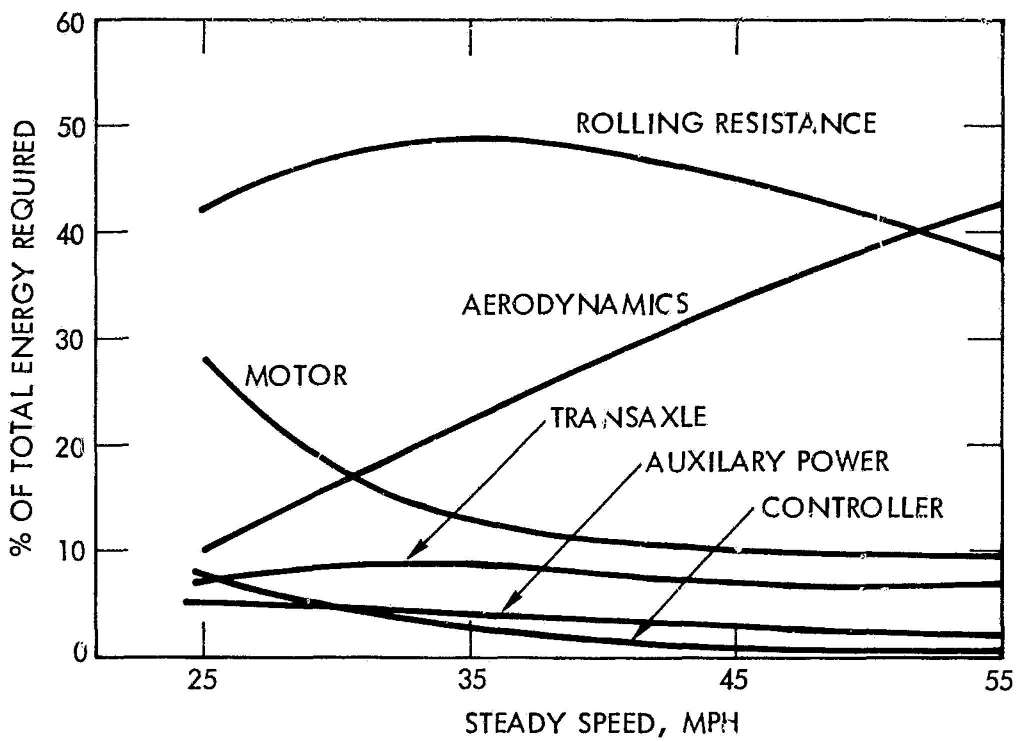

Figure 3. Measured Component and Subsystem Energy Requirements as a Percent of the Overall

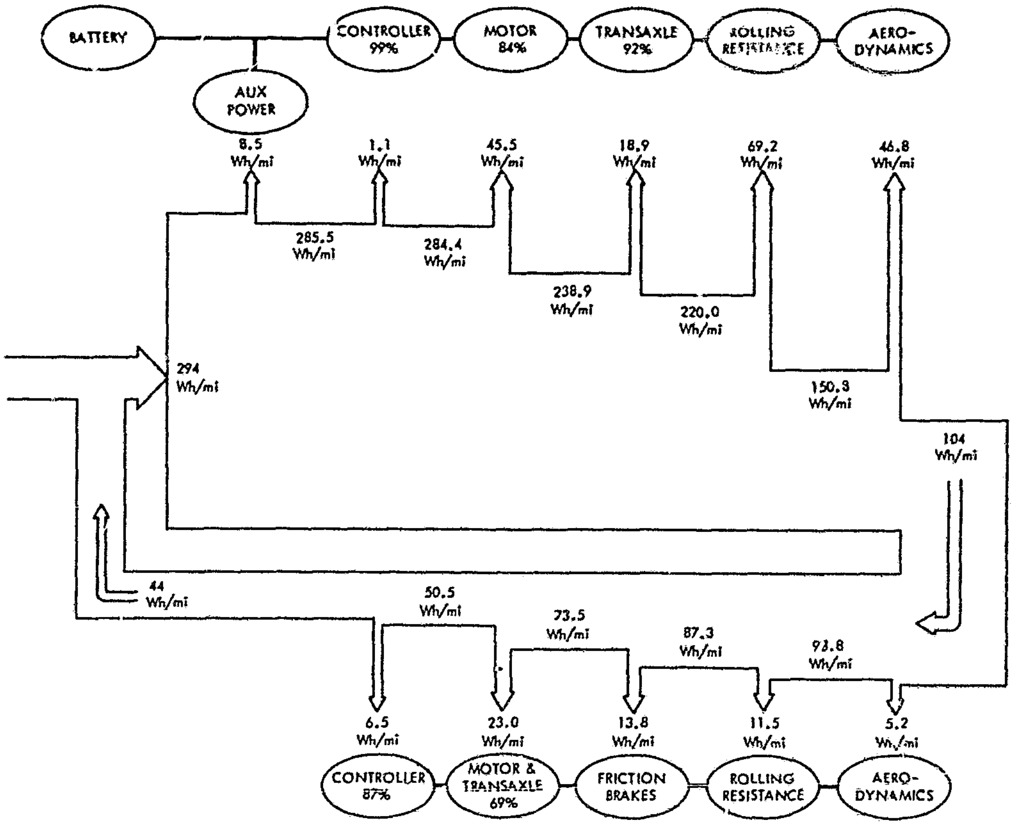

Figure 4. ETV-1 Energy Flow Distribution Over the SAE J227a D Driving Cycle

characteristics of the battery systems which power the vehicle are much more inconsistent than any other subsystem or component. A battery's potential for producing power and especially energy are sensitive, and unquantified, functions of such variables as:

(1) Charging procedures.

(2) Age.

(3) Temperature.

(4) Previous discharge history.

(5) Discharge rates.

Some of these variables can be controlled in a testing environment by strictly regulating the procedures. A private or fleet user, however, could not be expected to consistently maintain such controls. Therefore, statements regarding range performance, under some particular set of circumstances, are of questionable value. This situation is similar to EPA fuel economy ratings for internal combustion (IC) engine automobiles. Unlike the fuel energy content of an IC vehicle however, the energy available from an electric vehicle's battery pack introduces major additional uncertainties.

The DOE urban range goal for this Program was 120 km (75 mi) and General Electric demonstrated, at the conclusion of Phase II, that under some conditions this could be achieved (Reference 1). The JPL standard test procedures, however, are not designed to either maximize the range or be representative of the way a vehicle may be used in a consumer environment. For instance, battery capacity and range can be significantly increased by initiating testing immediately following a charge while the electrolyte is much warmer. Nevertheless, JPL did duplicate the GE procedures (as faithfully as possible) in a special test and achieved a similar range result.

The ETV-1 Electric Test Vehicle represents a significant step forward in the development of an acceptable electric passenger vehicle. Developed using a total system design approach, the various electrical and mechanical subsystems have been properly integrated to produce an aesthetically pleasing vehicle having outstanding energy economy. The battery subsystem, however, still remains the weak link to continued development and public acceptance.

Although the ETV-1 (as with any prototype vehicle) is not without flaw, exposure to the automotive community has generally resulted in the favorable assessment that the EV may have progressed from a curiosity to a future market potential.

SECTION I

INTRODUCTION

The Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976 established a governmental role in successfully bringing EHVs into the commercial marketplace. The Energy Research and Development Administration (ERDA), as the original administrator, defined a phased activity which would become a major thrust of the DOE objective to reduce the nation's dependence on foreign petroleum by developing the performance potential and economic viability of advanced electric vehicles that could be put into production in the 1980's.

Phase I, involving three contractors during 1976, provided the preliminary design of state of the art, energy efficient Electric Powered Passenger Vehicles. General Electric, Corporate R&D was one of the two contractors which continued on into Phase II in 1977. The purpose of this phase (Reference 1) was to develop, fabricate and deliver the Electric Test Vehicle (ETV-1). A total systems design approach was adopted incorporating subsystem technology improvements in order to achieve a level of performance substantially better than demonstrated by previous electric vehicles (Appendix A). The DOE goals for the Phase II activity are shown in Table 1-1.

Contract technical management was provided by the Jet Propulsion Laboratory, California Institute of Technology. Two vehicles were delivered in October 1979. The first was made available to the automotive community on several occasions for their evaluation and appraisal of such things as driveability, producibility and general overall appeal. This exposure favorably impressed the industry that EV's had the potential to progress from curiosities to a marketable reality. It has since become a benchmark of the state of the art of electric vehicle technology.

Because the automobile is such a complex system, the automotive industry has traditionally regarded only complete-vehicle tests as the ultimate proof of concept. Although significant effort is applied to component and subsystem development, the nature of system interactions requires that they be fully integrated and proven within the system environment. Electric vehicles are equally complex systems. They have many of the same attributes as a conventional vehicle but eliminate several undesirable features while adding new ones unique to EV's. Through its EHV system R&D Project, DOE has chartered JPL to develop such a system-level test and evaluation capability.

The objective of this report is to describe the results of the system-level testing and evaluation performed by JPL on the ETV-1. Special emphasis has been placed on determining the distribution of energy losses through the major subsystems and components.

Table 1-1. Phase II DOE Goals

Parameter	DOE Goals
Minimum passenger capacity	4 adults
Maximum curb weight, lb	Open
Minimum urban range (J227D), miles	75[a]
Maximum initial cost, projected in 1975 dollars	5,000
Minimum life, miles	100,000
Minimum life, years	10
Maximum life-cycle cost, projected in 1975 $/mi	0.15
Cost of energy in $/mi urban driving	0.05
Maximum recharge time, hr (115 V, 30 A service)	6
Minimum top passing speed, mph	60[a]
Minimum top cruising speed, mph	55[a]
Minimum accessories	Heater/defroster, on-board charger
Safety features	FMVSS requirements at time of contract
Minimum unserviced park duration, day	7
Maximum years until production is ready	5
Maximum critical materials required	Few
Minimum acceleration (0-30 mph), sec	9[a]
Minimum merging time (25-55 mph), sec	18[a]
Sustained speed on 5% one-mile grade, mh	50
Maximum scheduled maintenance, $/mi	0.02
Minimum ambient temperature range, °F	-20 to +125
Interior noise	Minimum
Turning and braking	No power assist required

[a]Goals specifically addressed and evaluated during the Phase III test activity.

SECTION II

APPROACH

The EV system-level test activities at JPL, described as engineering development tests, address the niche between detailed component evaluation and fleet demonstration. The continually evolving test methodology has four major objectives:

(1) To establish the absolute level of EV performance.

(2) To determine the relative level of performance under various test conditions.

(3) To define component/subsystem performance within the system environment.

(4) To develop and refine test techniques and procedures.

Clearly, the second objective is easier to attain than the first since some accuracy can be subordinated in order to obtain precision[1]. Relative measurements may be entirely adequate, e.g., if the task is to evaluate the effects of battery type on a specific EV's performance.

For the testing reported herein, however, goals one and three are of primary interest. Therefore, additional emphasis has been placed on the accuracy issues while maintaining a high level of precision.

Because of the vagaries of atmospheric conditions, accomplishing meaningful performance testing in a road or track environment is very difficult and time consuming. The uncontrollable swings in ambient temperature and winds can greatly affect not only the battery subsystem performance but the road-load losses (aerodynamics, tire resistance, etc.) as well. For these and other reasons, most of the ETV-1 system evaluation and performance testing was done on a chassis dynamometer. This not only provided a controllable environment but allowed the use of a large, high-speed fixed data recording system. However, precisely because this dynamometer testing was carefully controlled, it does not reflect the real on-road conditions a consumer would likely experience. Reasonably controlled track testing (standard driving cycles, low winds, small grades, etc.) represents some intermediate ground which is useful to correlate the dynamometer results with actual outdoor moving vehicle tests and, if successful, may be used to validate that the dynamometer rolls acted as a reasonable facsimile of the road. Therefore, brief but representative track testing was employed in order to provide this dyno-to-road correlation and to characterize some of the dynamic handling properties of the ETV-1.

The general approach to this testing is based on the SAE J227a Electric Vehicle Test Procedure (Reference 2). However, in order to attain the accuracy and precision levels desired, it was necessary to adopt more stringent requirements in several instances.

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[1]Precision is a measure of test repeatability; accuracy is a measure of deviation from the "true value".

SECTION III

TEST PROCEDURES

A. DYNAMOMETER ROAD LOAD DETERMINATION

Before a vehicle can be properly tested on a chassis dynamometer, it is necessary to characterize the dissipative losses associated with on-road travel such as the aerodynamic drag and rolling resistance losses. There are several ways in which these can be determined but coast-down testing is probably the most common and direct method. Because of its apparent simplicity, the procedure is widely used. However, results are often inaccurate. Properly conducted coast-down tests are, in reality, very difficult to perform.

The key to successful coast-down testing is to carefully measure and monitor as many variables as possible and to minimize all that cannot be measured or controlled. For instance, wind speed and direction were continually recorded and no testing was performed unless the speeds were less than 3 km/h during the test period. This is the maximum allowable wind speed where yaw angle effects on drag can be ignored (previously determined by JPL, Reference 3). The tire temperatures were recorded after every second run. In order to minimize other uncertainties, the half axles and disc-brakes were removed so that the remaining rolling losses resulted only from the tires and wheel bearings. This necessitated that the vehicle be towed up to approximately 100 km/h (60 mph) and released to coast over a carefully surveyed, segment of track.[2] This segment was 0.9 km (3,000 ft) long and had a constant grade of 0.177%. Each run was then analyzed independently using the grade, wind, tire temperature and air density data associated with the run.

The objective behind accurate road load determination is to be able to cause the dynamometer system to absorb the same aerodynamic and rolling power as would be dissipated on the road under the same set of standard conditions (i.e., some specified ambient temperature and pressure, zero wind and zero grade). Unfortunately, the standard test condition principle is often ignored in other test programs. In that event, even carefully conducted coast-down tests would yield quite different results from day to day (and especially from season to season) by virture of the variable air densities and tire temperatures. Specifying standard conditions, requires that the vehicles aerodynamic drag and rolling resistance <u>coefficients</u> be determined from the coast-down tests. The data reduction procedure by which these coefficients were determined is based on the work of White and Korst (Reference 4) which was later extended and refined at JPL by Dayman (Reference 5). With the vehicle coefficients determined, an ideal coast-down history under standardized test conditions was mathematically developed.[3] Two incremental coast periods

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[2]Coast-down testing was performed on a limited-use concrete runway at the Edwards Air Force Base near Lancaster, California. Velocity versus time data was collected by a Nucleus NC-7 Precision Speedometer (5th wheel) and recorded with an on-board HP 7100 B Strip Chart Recorder.

[3]An uncertainty analysis was applied to this complete procedure including all possible sources of human and instrumentation errors. (See Appendix B.)

(90 to 73 km/h and 32 to 16 km/h) were identified as points to be matched on JPL's Clayton twin-roll dynamometer. This particular dynamometer has been retrofitted to provide an external motoring capability. The vehicle, with half-shafts and disc brakes still removed, was first warmed up on the dynamometer by motoring at 80 km/h for 5 min and 57 km/h for 15 min. After an estimate for aerodynamic power was set into the dynamometer power absorption unit (PAU), the vehicle was motored to speed and the coast-down time from 32 km/h to 16 km/h was noted. Two variables, tire pressure and normal force,[4] were iteratively adjusted until the on-dyno coast-down time matched the predetermined ideal coast-down time.

After achieving a match at the low velocity condition, coast-downs were conducted from 90 km/h to 73 km/h. Water level was adjusted in the PAU until a match with the ideal time was reached. Some iteration was required between the high and low speed ranges until the best trade-off was reached. The dynamometer was then motored up to approximately 100 km/h (65 mph) and the vehicle-dyno system was allowed to coast-down to below 16 km/h (10 mph). Figure 3-1 shows a comparison of the coast-down history of the vehicle-dyno system with the ideal or standardized history. As a further check on the operation, the vehicle-dyno coast-down history was independently analyzed using the same numerical technique employed for the track coast-downs. The road-load power resulting from dynamometer inertia weights, bearing drag and vehicle tires was within 2% of the ideal over the whole speed range of interest. The actual road-load power (normalized by speed), and its components, absorbed by the dynamometer system is shown in Figure 3-2. Note that at higher speeds, the tire rolling resistance component actually falls off due to elevated temperature effects.

At this point, the half axles and disc-brake assemblies were reinstalled and the vehicle was ready for dynamometer testing. The ETV-1 undergoing test in the JPL Automotive Test facility is shown in Figure 3-3.

B. PROPULSION BATTERIES

The propulsion battery performance is the single largest variable in electric vehicle testing. The available capacity of a lead-acid battery does not remain constant over its lifetime and it is extremely sensitive to such things as charge procedures and temperature.

Because of this, JPL has paid special attention to the propulsion batteries. The ETV-1, as well as all other vehicles tested at JPL, has either had new batteries or batteries which were not yet on the declining portion of the capacity-age curve. These batteries were then conditioned by conducting 10 to 15 charge-discharge cycles. During the conditioning process, weak batteries were identified (and replaced) and the battery charging procedure was refined.

Conditioning was done by discharging the propulsion batteries into a bank of light bulbs which provided a near-constant resistive load. The

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[4]Normal force, or weight on the driving wheels, was altered by applying constant pressure to a pneumatic lift placed under the front of the vehicle.

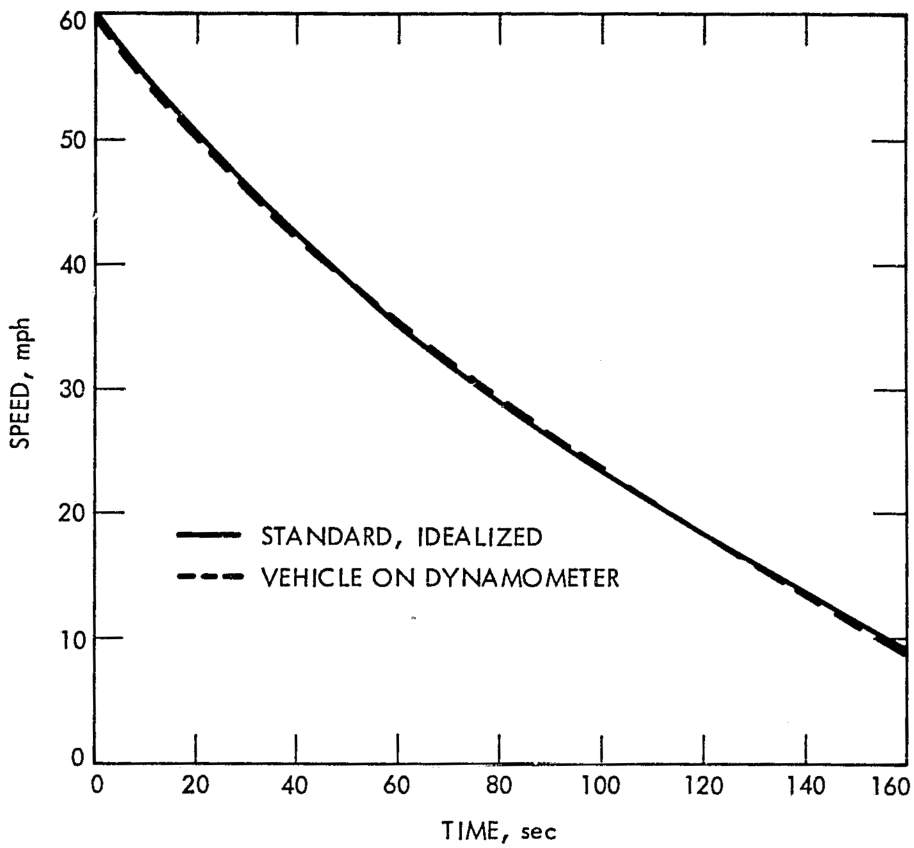

Figure 3-1. A Comparison of the ETV-1 On-Dyno Coast-Down History with the Standard Idealized Coast-History (Based on Coefficients Determined from Field Tests)

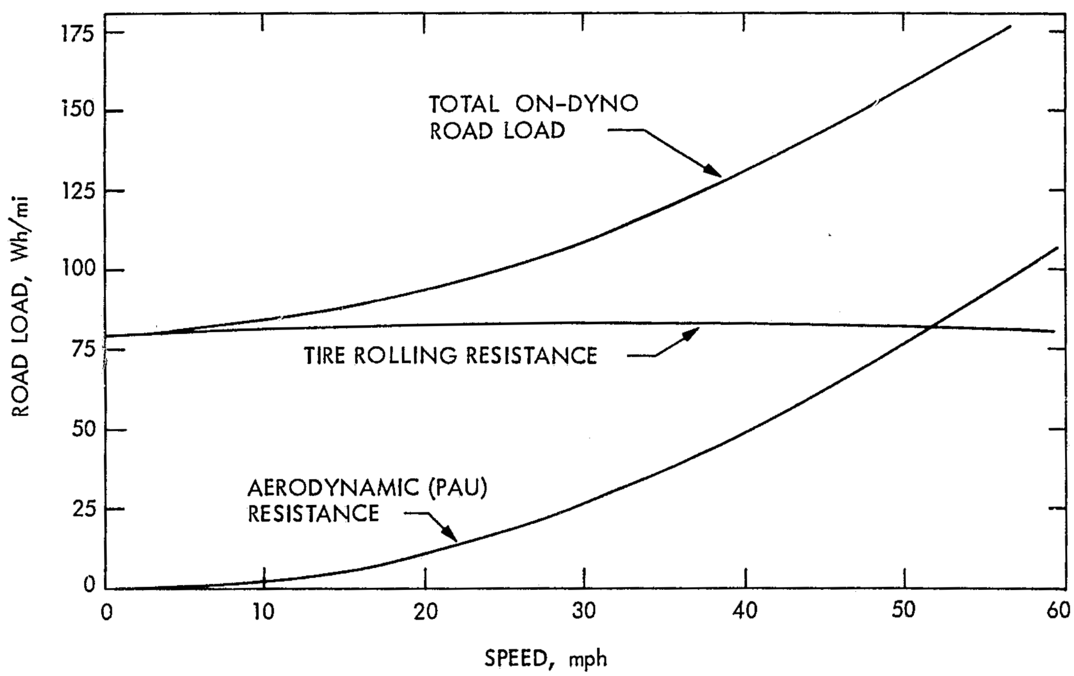

Figure 3-2. ETV-1 Road Load Power Absorbed by the Chassis Dynamometer

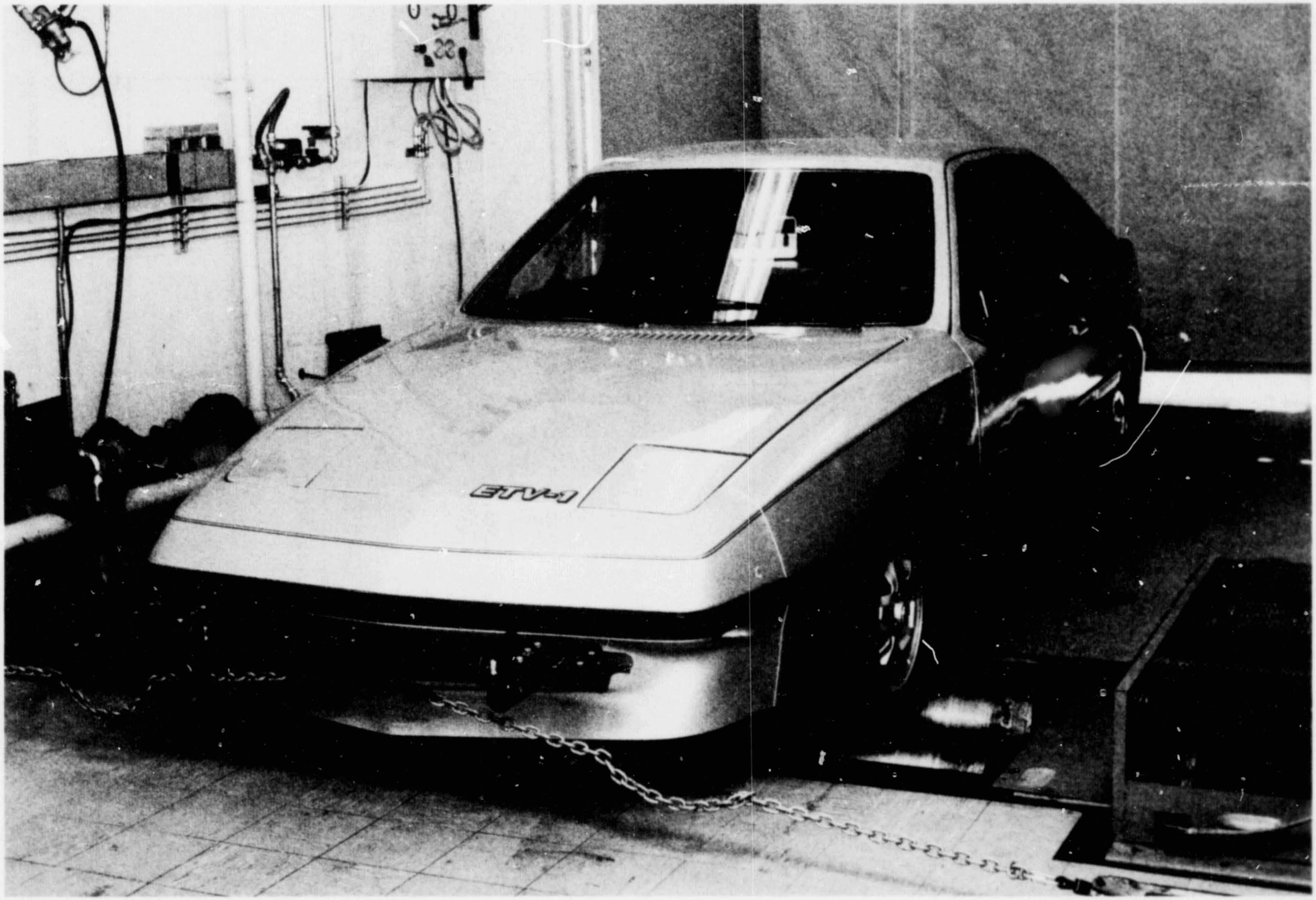

Figure 3-3. ETV-1 Under Test on the JPL Twin-Roll Clayton Dynamometer

batteries were also discharged during checkout of the instrumentation and driver familiarization with the vehicle. Both types of discharge form the conditioning process and both are important. It has been JPL's experience, although limited, that light bank discharges do not necessarily complete the conditioning process. Different rates of discharge or different types of discharge (e.g., pulsed currents) need to be incorporated into battery conditioning.

Battery charging can be a major source of variability. The charging method not only affects the subsequent discharge capacity but also battery life, heating and recharge efficiency. The ETV-1's on-board charger uses the same circuitry as the motor field chopper. Prior to delivery, the transistor in this circuitry failed under the high voltage stress of the charge cycle. A redesigned higher voltage transistor device was installed but this too failed after five or six charges. No further development activity was initiated and the vehicle was delivered with a transistor of the original design. In order to ensure the integrity of the field chopper after repair, the on-board charger has not been used.[5] Consequently, the characteristics of the ETV-1's charger and its interaction with the propulsion batteries have not been quantified. The reliability and test anomalies experienced during the Phase III activities are further addressed in Appendix C.

The DOE recommended practice adopted for the Demonstration Program states that prior to each range test the battery will be subjected to an "equalization" charge and that this charge shall continue until the specific gravity (SG) of each cell reaches a constant value. This is not a practical criterion for the ETV-1 because the tunnel arrangement prevents easy battery access. In addition, this procedure would have caused excessive battery heating. To circumvent these problems and yet ensure that the batteries were completely recharged prior to each test, a "quasi-equalization" charge was used. In place of the on-board charger, a commercially available power supply was used. This device was equipped with external controls tailored to battery charging. The charge algorithm used was as follows:

(1) Charge at a constant 25 A until a pre-set battery pack (clamping) voltage is achieved.

(2) Once the clamping voltage is reached, continue charging for 6 h while maintaining the pack voltage at the clamping value. This allows the current to taper to a lower value (nominally 4 A).

(3) The clamping voltage is automatically adjusted throughout the charge to account for the varying battery electrolyte temperature (temperature compensation - 7.2 mV/^{o}C/cell).

The clamping voltage for the battery was empirically determined during the battery conditioning process. Initial charging during conditioning was done with conservatively low clamping voltages. After each subsequent discharge/charge cycle, the voltage was increased 0.1 V per module until the

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[5] See Appendix C, continuing problem list, No. 3.

battery current, after 5 h of the timed portion of the charge was between 4 and 5 A. Figure 3-4 shows a typical charge profile. The point at which the temperature compensated clamping voltage is reached very closely corresponds to where, on a coulombic basis, 100% of the discharge amperage has been returned to the batteries. It can be seen that at this same point the battery pack has entered a less efficient charge regime as indicated by the increased battery heating rate despite rapidly decaying current. The timed portion of the charge was 6 h and resulted in a fixed overcharge in terms of ampere-hours (Ah). Because of the constant amperage overcharge, the percentage overcharge varied depending on the previous depth of discharge (DoD). Typically, overcharge varied from 15 to 20% on an Ah basis for this "quasi-equalization" charge; charge efficiency was subordinated in favor of battery repeatability.

If the battery pack is in good condition, the single largest variable related to battery capacity is battery temperature. Within the constraints of the existing SAE J227a test procedures, allowing for thermal mass considerations, it is conceivable that tests may be conducted with initial battery temperatures ranging anywhere from 16°C to 42°C. Battery capacity and the resulting vehicle range, can easily vary by 25% due solely to this parameter.

Rather than live with the variability induced by different battery temperatures, tests were conducted with an initial electrolyte temperature of 21° ±3°C. The choice of temperature is arbitrary so long as it is consistent and reasonable. This temperature was chosen since it was convenient to maintain and was not inconsistent with the EPA test procedures. To satisfy the 21°C criterion, ETV-1 testing could only be conducted every other day because

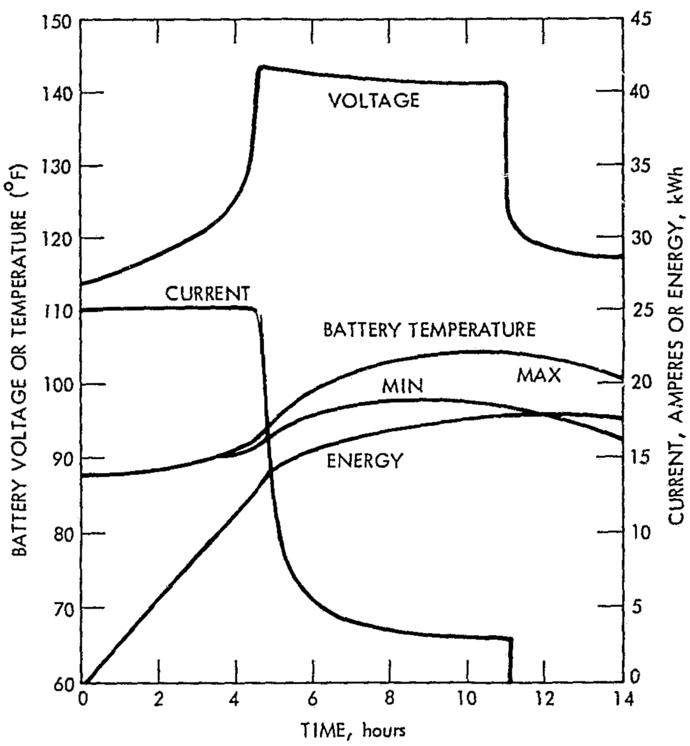

Figure 3-4. Typical Charge Profile of ETV-1 Battery

of the large thermal mass of the battery.[6] During the interim, the entire vehicle was "soaked" at 21°C. In a user environment, a controlled soak period would not be present and it is possible that the vehicle range would benefit from warm batteries just coming off the charge cycle.

C. INSTRUMENTATION

The primary measurement requirements were for a description of electrical power flow and overall vehicle performance (i.e., energy consumption and range). The electrical measurements shown in Table 3-1 are used to define the electrical power flow and the efficiencies of the major electrical power elements. Because of the chopper controllers used in todays electric

Table 3-1. ETV-1 Electrical Measurement

Basic Measurements[a]		Onboard Power Measurement Instrument (PMI)	
Parameter	Range	Parameter	Range
Battery and armature voltage	0-200 V	Battery out, armature in	0-100 kW
Battery and armature current	±500 A	Armature out, battery in[b]	0-100 kW
Field voltage	0-200 V	Field power	0-5 kW
Field current	0-25 A	Recharge power	0-10 kW
Accessory battery voltage	0-25 V		
Accessory battery current	0-25 V		
Recharge voltage	0-200 V		
Recharge current	0-50 A		

[a]Transducers connected to vehicle's electric power system.

[b]Regenerative power during braking.

[6]During track testing, the unavailability of an air-conditioned "soak room" required the use of ducted chilled air. This also allowed testing to be performed every day.

vehicles, special instrumentation is required. The wattmeters used in this testing were specifically designed for this purpose. The power (V x A) is determined in real-time with a frequency response of 50 kHz to attain a measurement accuracy of 1%. During testing, the observed dc accuracy of the wattmeters has been within 2% of reading in the range of 20 to 100% of full scale.

Figure 3-5 shows the location of the current shunts and voltage sense points needed for the power measurements. These voltage and current signals were supplied to the wideband wattmeters and provided the key parameters in the characterization of power flow. The wattmeter design was based on the unique requirements of a battery powered vehicle using armature chopping control.

Power, voltage, and current signals are isolated from the vehicle's battery potential through isolation circuits internal to the wattmeter and then directed to a digital data acquisition system. The data are all recorded on magnetic tape. Recording is done at various intervals depending on the nature of the test. For instance, during Schedule "D" tests, recording intervals are as small as 0.1 sec to allow characterization under dynamic conditions. Reduction of the data recorded on magnetic tape is accomplished on a general purpose computer on an overnight basis. Reference 6 contains the details of the complete data acquisition system from sensors through data processing. A sample of the reduced data output is shown in Appendix D.

D. TRACK TESTING

The primary objective of the Track Test Program was to establish a correlation between the major dynamometer test program and actual moving-vehicle, on-road tests. A secondary objective was to obtain quantitative measurements of vehicle performance characteristics (acceleration, braking, dynamic handling) for comparison to other electric and conventionally powered vehicles.

The track test program was conducted at the Transportation Research Center (TRC) located in East Liberty, Ohio, during June and July, 1981. In order to satisfy the primary objective, the vehicle-related parameters existent during the dynamometer tests were duplicated for the track test program wherever possible. Because of the complete on-board instrumentation and supporting equipment,[7] the vehicle test weight was approximately 1% greater than on the dyno. The front/rear weight distribution was 50/50. As specified by the JPL standardized test conditions, the entire vehicle temperature and battery electrolyte temperature were stabilized at 21°C $\pm$3°C prior to all range tests. Ambient temperatures during track testing ranged from 18°C to 27°C and winds averaged about 6 to 8 km/h.

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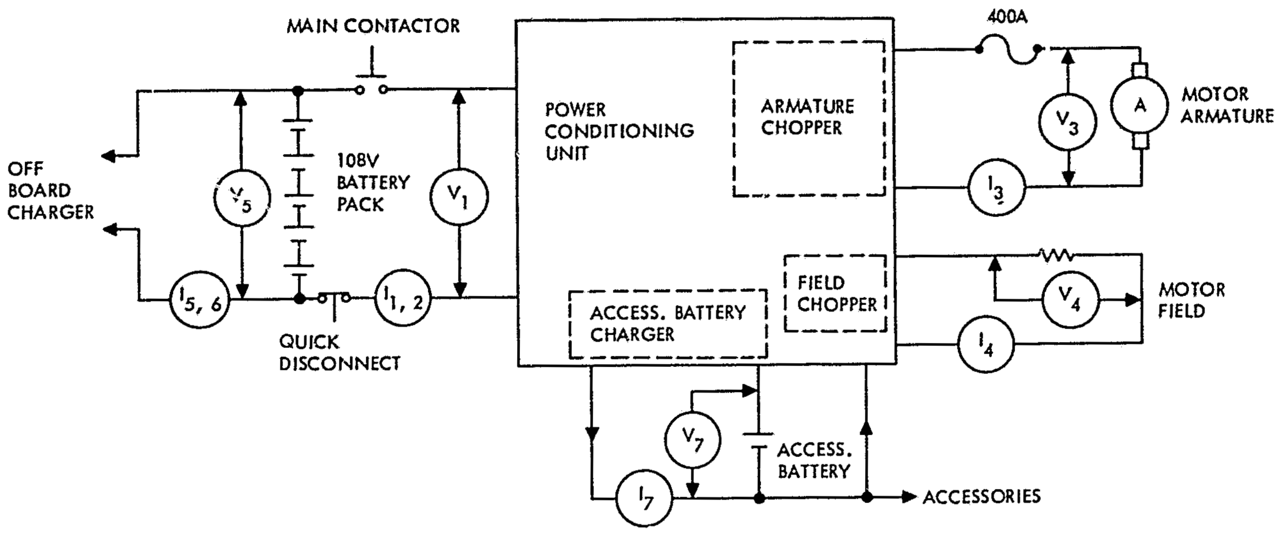
[7]This equipment consisted of the PMI (Table 3-1) and On Board Measurement System (OBMS) using a microcomputer to control and record a continuous data stream, a strip-chart recorder containing pre-recorded driving-cycle profiles and two accessory batteries to power these systems.



$V_1 \times I_1$ = ±BATTERY POWER
I_2 = ±BATTERY CURRENT
$V_3 \times I_3$ = ±ARMATURE POWER
$V_4 \times I_4$ = FIELD POWER CURRENT
$V_5 \times I_5$ = BATTERY RECHARGE POWER
I_6 = BATTERY RECHARGE
$V_7 \times I_7$ = ACCESSORY BATTERY POWER

Figure 3-5. Location of Current Shunts and Voltage Sense Points Required for Electrical Measurements

SECTION IV

ANALYSIS AND RESULTS

A. ENERGY CONSUMPTION

Although the ETV-1 embodies many of the features necessary for commercial application, it is by name and purpose a test vehicle. For that reason, it is appropriate that it be evaluated not only as a total end to end system but that the major subsystems be evaluated within the system environment as well. It is reasonable, therefore, to examine the energy efficiency of the vehicle and its components independent of the battery subsystem which powers it. In this manner, baseline vehicle energy consumption characteristics can be established (measured) and alternate battery subsystems powering the vehicle can be more easily evaluated.

The measured energy required (leaving the battery terminals) to drive the ETV-1 at constant speeds and over the SAE J227a D and EPA Urban (FTP) driving cycles on the dynamometer and in supporting track tests is presented in Figure 4-1. Energy required is normalized by distance traveled in order to compare the energy consumption of the total vehicle under various driving conditions. The track and dyno results all compare with a maximum variance of about 5%. Uncontrolled ambient conditions and a slight instrumentation weight penalty prevented the track tests from duplicating the standardized conditions

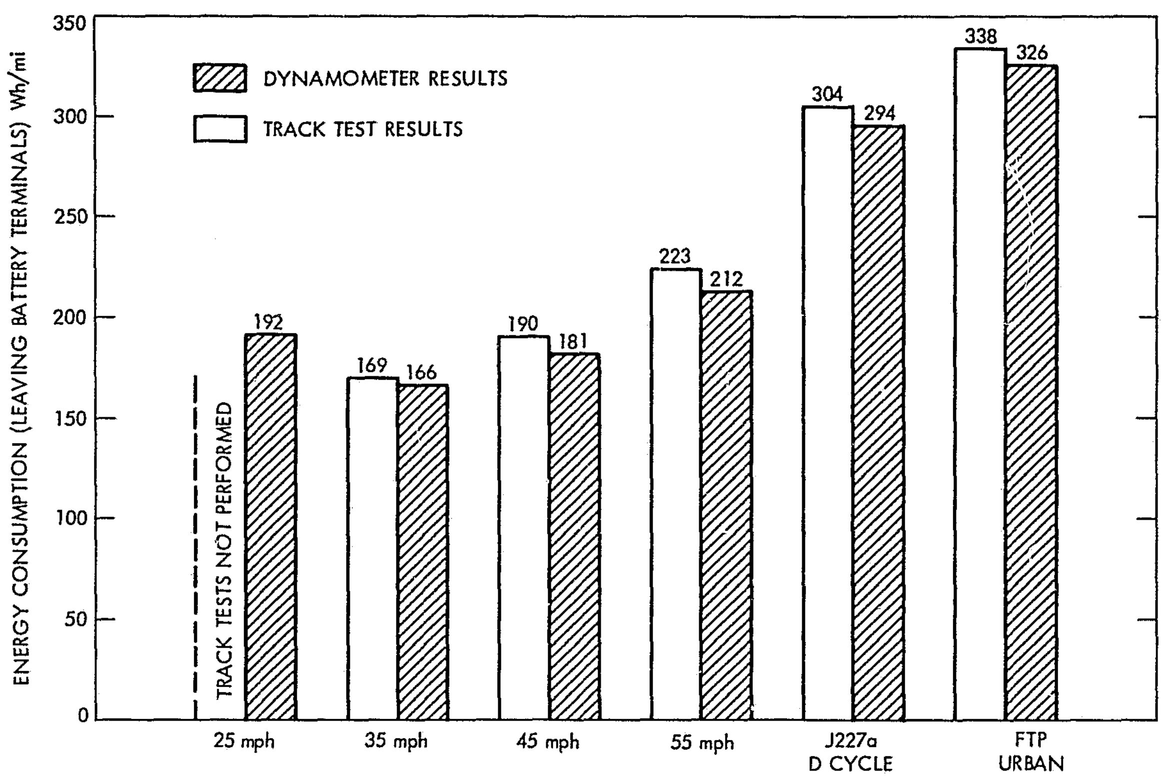


Figure 4-1. ETV-1 Energy Consumption; Correlation of Dynamometer Test Results with Track Test Results

adopted for dynamometer tests. From computer simulation, the 1% weight penalty during track tests was determined to cause a similar increase in cycle energy consumption (the effect during constant speed tests is manifested in the tire rolling resistance component and is less significant). The aerodynamic drag effect of the random ambient winds present during track tests can be estimated from a procedure developed earlier and reported in Reference 7. Air density, which has a linear effect on the aerodynamic drag component, averaged about 1% greater in the track tests than the dyno standard atmosphere conditions. All three of these effects work to increase the energy consumption measurements from track tests by 2-5% depending on the speed and cycle. Applying the appropriate corrections, the track test results move to within approximately 1% of the dyno results. This determination clearly demonstrates the validity of the JPL dynamometer calibration and set-up test procedure described earlier.

A non-monotonic relationship exists between the energy consumption and speed. This results because of the interrelationships of the various subsystems and their individual efficiency characteristics.

B. ENERGY FLOW ANALYSIS

In order to determine how the energy was apportioned and consumed among the various subsystems, an energy flow analysis was performed. For constant speed tests the analysis is straight forward and can be done with a simplified[8] power-balance equation:

$$(PBO - PACS) \times E_c \times E_m \times E_t = PRL \qquad (1)$$

where:

PBO = Battery Output Power

PACS = Auxiliary Power

E_c = Controller Efficiency

E_m = Motor Efficiency

E_t = Transaxle Efficiency

PRL = Road Load Power (Aerodynamic Drag plus Rolling Resistance)

The road load power, which in this case is the power absorbed by the dynamometer and tires, can be measured using exactly the same computational technique employed in track coast-down testing. Aerodynamic and Rolling Resistance coefficients were calculated from the "on-dyno" coast-down history

[8] A part of the auxiliary power, PACS, is used to power-up the microprocessor and provide controller housekeeping function. The simplification of Eq. 1 causes an over-estimation of the controller efficiency of no more than 1-3%.

(see Figure 1-1). These coefficients were then used to calculate the actual "road-load" power being "seen" by the rest of the vehicle[9] (torque wheels, which were unavaiable for these experiments, would provide a more direct measurement). PBO and PACS were measured directly during the testing. The controller efficiency, E_c, was directly calculated since both the motor armature and field power were continuously recorded (efficiency is defined as power out/power in). With these elements determined,[10] the power balance equation was solved for the product of the motor and transaxle efficiencies. The NASA Lewis Research Center (LeRC) has recently developed a "Road Load Simulator"(RLS) in order to evaluate various electric and hybrid vehicle candidate drive trains. An ETV-1 breadboard power train (with a torque transducer inserted between the motor and transaxle) was mated to the RLS and characterized at LeRC.[11] Those preliminary results (Reference 8) provided the necessary information to separate the losses inherent in the motor-transaxle combination and determine their relative efficiencies under various loadings. That data completed the information necessary to solve the power balance equation.

This procedure was applied to repeated constant-speed tests performed on the ETV-1 in the JPL Automotive Research Dynamometer Facility. The results of those analyses are shown in the energy flow diagrams presented in Figures 4-2 through 4-5. Auxiliary power is used to continously charge the accessory battery which, in turn, powers the cooling fans, control relays, status lamps and lighting. Note that the controller loss is negligible above 40 km/h (25 mph) (greater than 97% efficiency) where the armature chopper is bypassed and full battery voltage is applied to the motor armature. Under this condition, motor control is provided by the field chopper; the field power is very small compared to the armature power so that high controller efficiency is expected. Below base speed (approximately 43 km/h or 27 mph), the field is at full strength and motor control is provided by the armature chopper which modulates the average current and thus the power to the motor. Controller efficiency in this regime, should be lower, but is still respectable (92%) at a steady 40 km/h or 25 mph (Figure 4-2). Similarily, above base speed, the motor efficiency is over 86%. Below base speed (in the armature chopping mode) the motor efficiency drops dramatic ly to about 68%. The transaxle

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[9]Tire losses are known to increase under high torque loading. At steady speeds on a level grade the effect is insignificant.

[10]Because instaneous power readings tend to be unsteady, averages were calculated over a 3 minute period (50 points). These averages were taken at various intervals in the test to examine the effects of battery depth of discharge (DoD). Once vehicle warm-up effects are considered, little or no DoD effect was noted on the average power requirements at steady speeds. For consistency, all constant speed analyses performed in this report use the data at a 40% DoD.

[11]This effort is a part of the LeRC support to the DOE Electric and Hybrid Vehicle Program. The results of those tests (Reference 8) provide more detailed component-level data on the ETV-1 power-train. Although some of the test procedures used in the LeRC program were different, the overall results are not inconsistent with those reported herein.

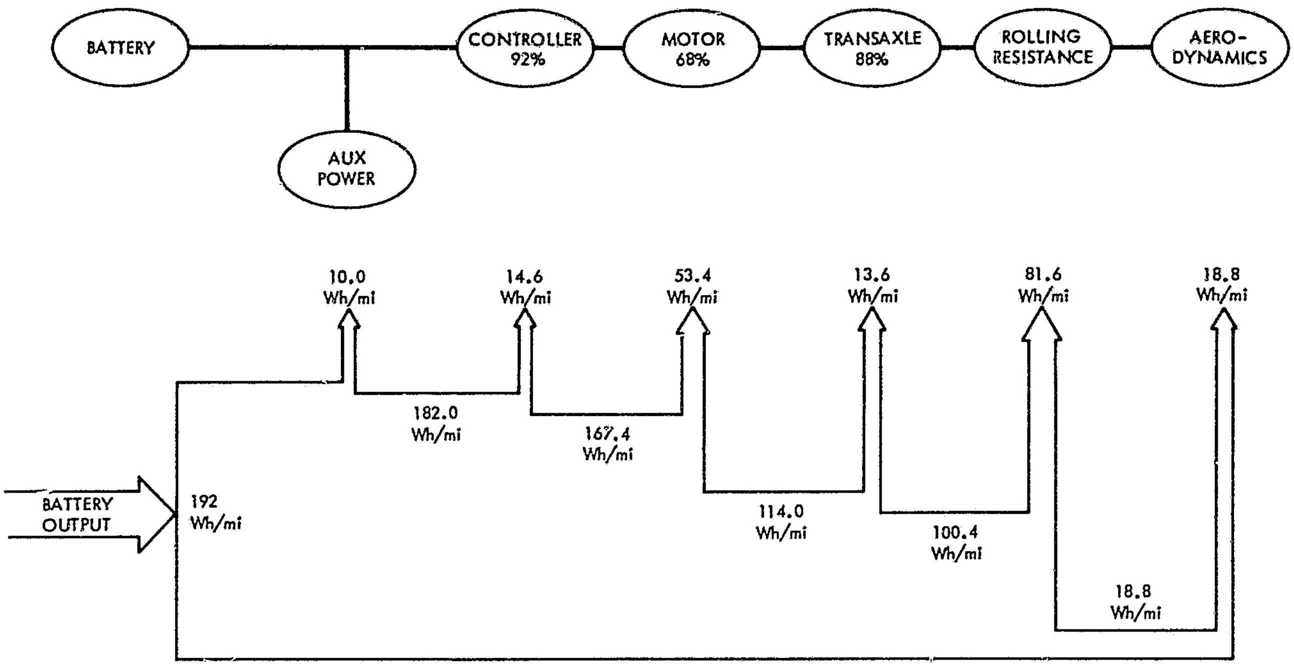

Figure 4-2. ETV-1 Energy Flow Distribution at a Steady 25 mph Speed

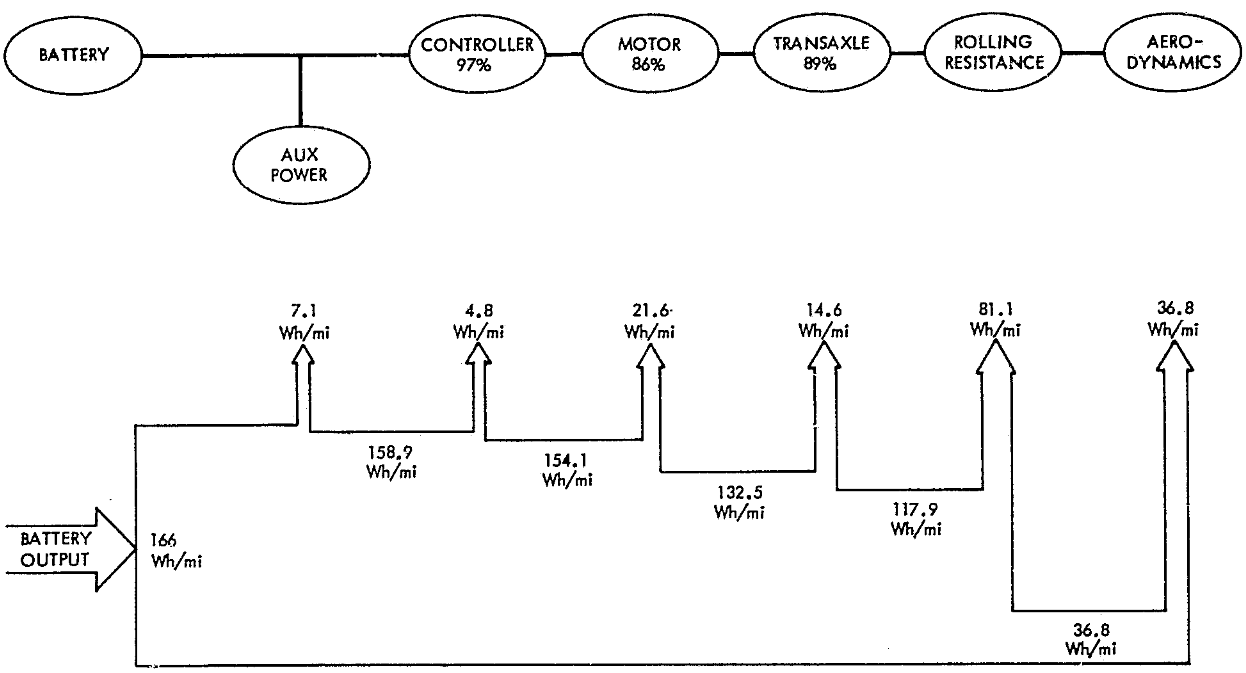

Figure 4-3. ETV-1 Energy Flow Distribution at a Steady 35 mph Speed

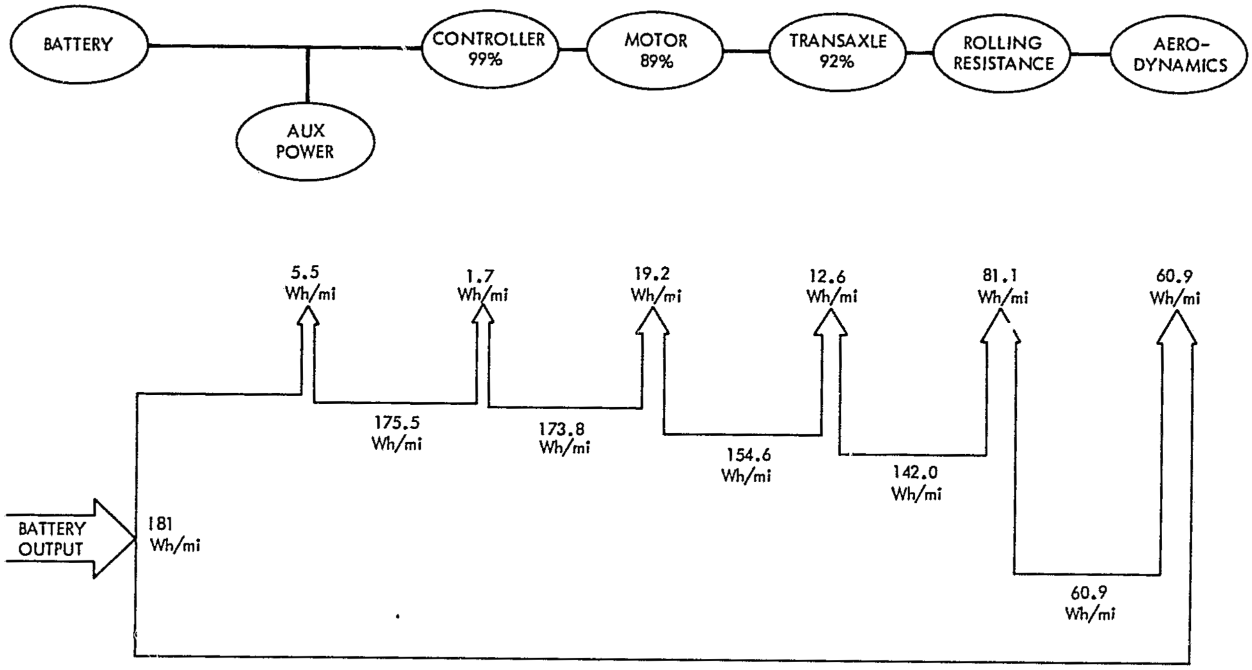

Figure 4-4. ETV-1 Energy Flow Distribution at a Steady 45 mph Speed

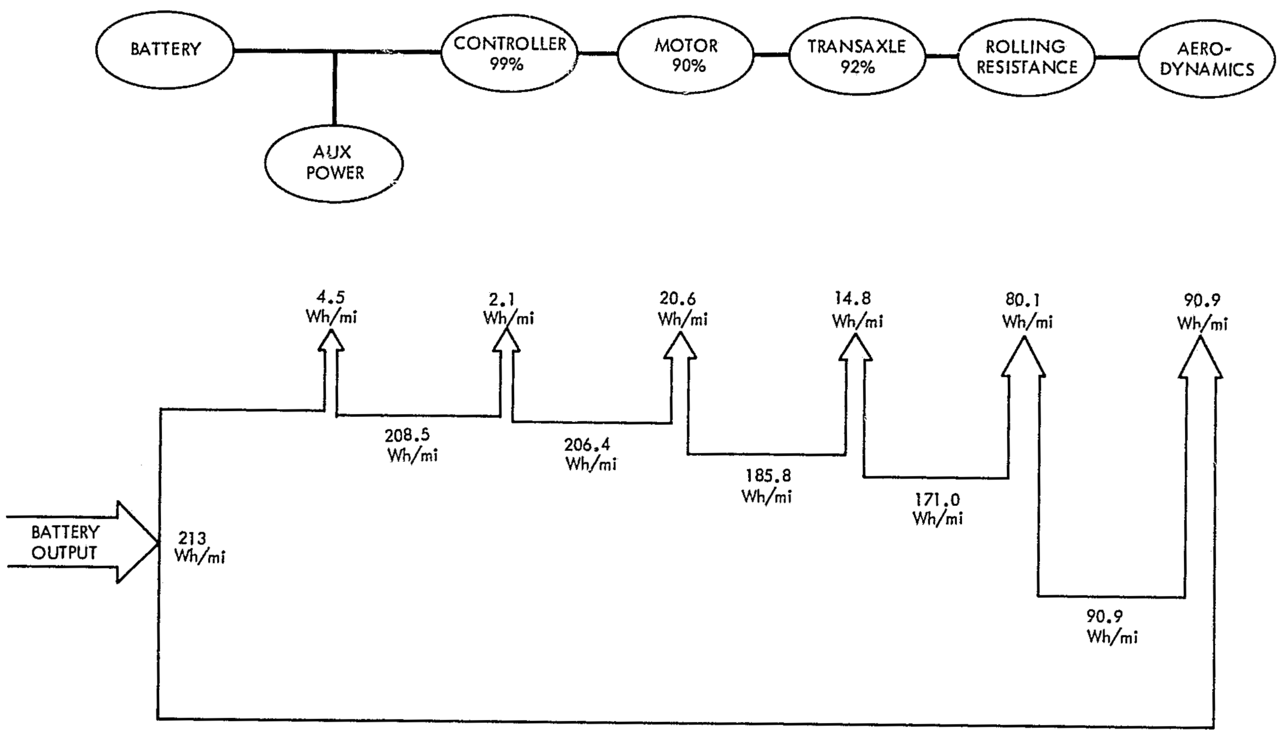

Figure 4-5. ETV-1 Energy Flow Distribution at a Steady 55 mph Speed

efficiency appears to be rather insensitive to speed variations at these low torque requirements characteristic of steady-speed running. This result is typical for a chain-reduction drive as used in the ETV-1 transaxle.

The rolling resistance and aerodynamic losses are totally dissipative and cannot be expressed in terms of efficiencies. The rolling resistance loss in Wh/mi remains virtually unchanged from 40 km/h (25 mph) to 88 km/h (55 mph). This component is composed entirely of the tire and wheel bearing loss. All other rolling losses not otherwise accounted for (e.g., disc-brake drag and half-axle bearings and seal drag) are included in the transaxle losses. Since these results are presented as energy loss per mile, which is proportional to the resistive force, it is not surprising that the rolling loss is nearly constant in this speed regime. Steel-belted radial-ply tires exhibit only a slight increase in rolling resistance with speed (up to about 100 km/h), or 60 mph and that increase is compensated for by the elevated operational temperatures of the tire at higher speeds.

As expected, the energy loss to overcome aerodynamic resistance per unit distance varies as the square of the speed (force units). The ETV-1 exhibits an exceptionally low coefficient of drag[12] and aerodynamics becomes the largest loss component only at speeds above 80 km/h (50 mph). All of the component losses are presented in Figure 4-6, as a percent of the total energy required to operate the vehicle at steady speeds.

Energy flow analysis performed over repetitive driving cycles (such as the SAE J227a D shown in Figure 4-7)[13] is more involved and requires additional information. Because of the transient nature of a driving cycle, an energy balance, rather than power balance, equation was used. The formulation is similar to Eq. 1 with the additional complexity of the regeneration energy components:

$$(EBO-EACS) \times E_c \times E_m \times E_t = ERL + ERG \qquad (2)$$

where:

EBO = Total battery output energy

EACS = Total energy required by auxilary power systems

E_c = Controller efficiency during acceleration and cruise

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[12]Full-scale wind tunnel tests (Reference 9) indicated a zero-yaw drag coefficient of 0.30 with the body at design attitude. Subsequent precision coast-down tests (See Road-Load Determination), where the ground interface is properly included, produced a drag coefficient of 0.32. The reference area is 1.84 m^2 (19.8 ft^2).

[13]The SAE J227a D cycle is defined only at certain transition points. JPL has interpreted and standardized the cycle to be consistent with acceleration and deceleration rates observed in EPA cycles (Reference 10).

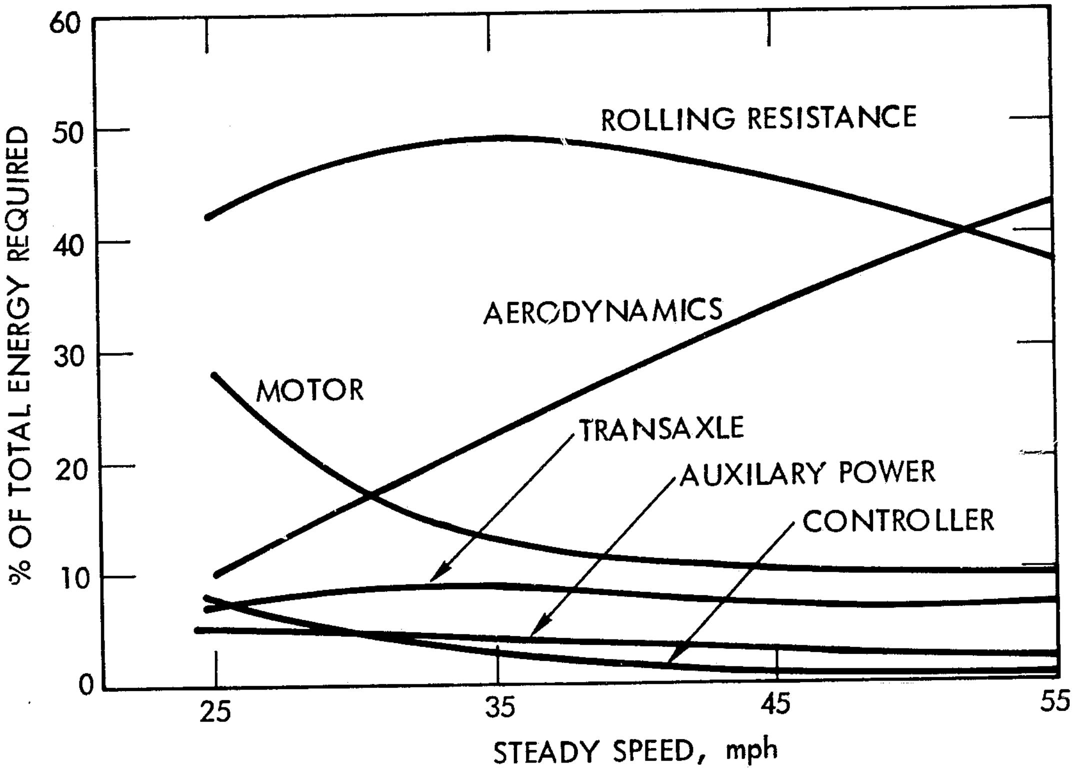

Figure 4-6. Measured Component and Subsystem Energy Requirements as a Percent of the Overall

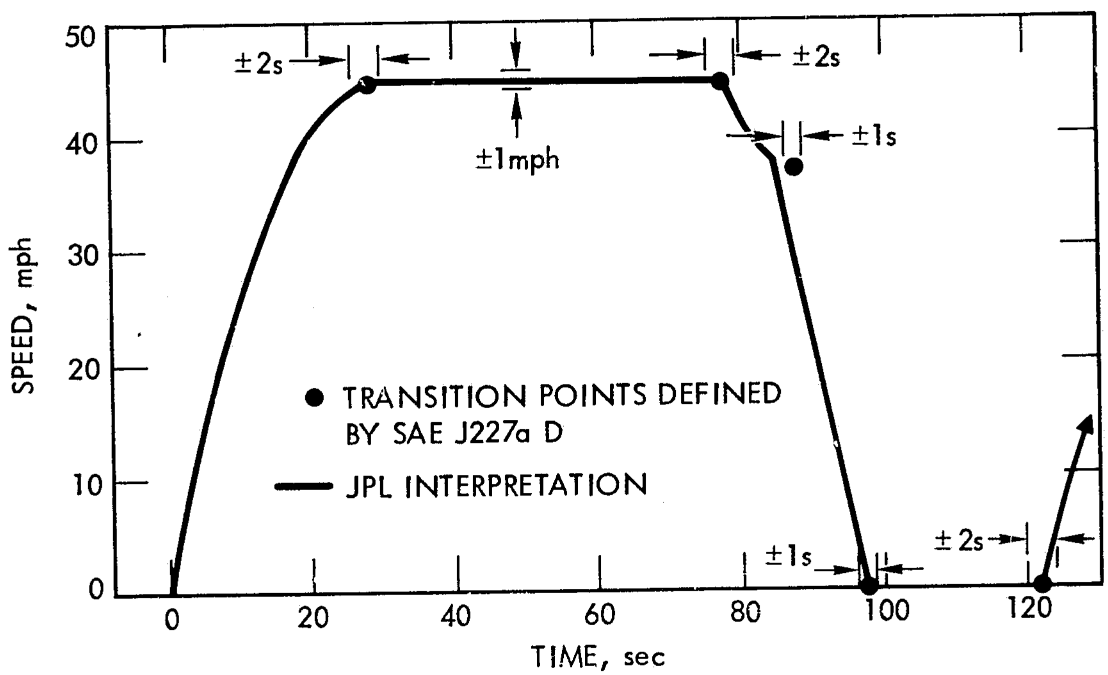

Figure 4-7. JPL Interpretation of the SAE J227a D Driving Cycle

E_m = Motor efficiency during acceleration and cruise

E_t = Transaxle efficiency during acceleration and cruise

ERL = Total road energy consumed during acceleration and cruise

ERG = Total stored kinetic energy available for regeneration ($1/2\ MV^2$ cruise)[14]

Additionally the regeneration energy, ERG, can be further analyzed, since:

$$EBI = (ERG - ERL_r - EFB) * E_{tmr} * E_{cr} \quad (3)$$

where:

EBI = Total regeneration energy arriving back at battery terminals

ERL_r = Road load energy consumed during coast and braking

EFB = Total energy consumed in friction braking

E_{mtr} = Product of motor and transaxle efficiencies during regeneration

E_{cr} = Controller efficiency during regeneration

As previously indicated, all the necessary electrical energy measurements were continuously recorded; mechanical energy flows, however, were determined by other means. The Electric Vehicle (ELVEC) computer simulator, maintained by JPL (Reference 11), was used in order to integrate the road-load requirement over the SAE J227a D cycle. That is, the simulator's road-load model was first validated by comparing ELVEC predictions with dyno test results at constant speeds. Projected aerodynamic and rolling power requirements were all within 2% of those determined from the dyno road-load analysis previously discussed. The energy consumed by aerodynamic drag and rolling resistance over the acceleration/cruise and brake/coast portions of the cycle were then determined by ELVEC.[15] The energy available for regeneration, ERG, is merely the system kinetic energy as it begins the coasting phase. The efficiency E_c is easily calculated since all energy flow into and out of the controller is recorded. Equation 2 was then solved for the product of the motor and transaxle efficiencies. The LeRC ETV-1 drive-train data at higher torques was used to aid in their separation.

Equation 3 describes the energy flow during the coast and brake portion of the cycle. The energy returning to the battery terminals, EBI, is a measured quantity. The road-load energies are inferred from ELVEC models as previously discussed; the friction braking energy, EFB, is inferred from the

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[14] M is the effective mass of the vehicle - dynamometer system rotational inertia.

[15] Due to torque effects which are not included, ELVEC may underestimate the tire loss during the acceleration portion of the cycle.

ELVEC model as well by using the same brake-blending algorithm as in the ETV-1 microprocessor itself. The controller efficiency during regeneration is calculated using direct energy measurements. Equation 3 is then solved for the product of the transaxle and motor efficiencies during regeneration. No attempt was made in this case to separate the two (motor and transaxle efficiencies are expected to be different when the direction of energy flow is reversed).

The result of this analysis is shown in Figure 4-8. Here again, the energy consumed has been normalized by distance traveled in order to have compatible units with the previously developed constant-speed energy distributions. Both the controller and motor-transaxle combination are significantly less efficient during regeneration. Over 42% of the kinetic energy stored in the vehicle during cruise makes its way back to the battery terminals. Although the benefit of regeneration is generally accepted, the resulting range increase is open to question. The Argonne National Laboratory (ANL) has conducted a series of programmed dc load cyclic experiments and concluded that for lead-acid batteries, 98% of the energy returned by regeneration becomes available for increased range (Reference 12). Planned experiments to quantify the effect by disabling the regeneration circuit were eliminated when it was determined that major alterations to the microprocessor would be required. For these reasons, Figure 4-8 avoids the issue of "net energy" from the battery showing merely the total energy leaving the battery terminals (294 Wh/mi) and the total returned by way of regeneration (44 Wh/mi).

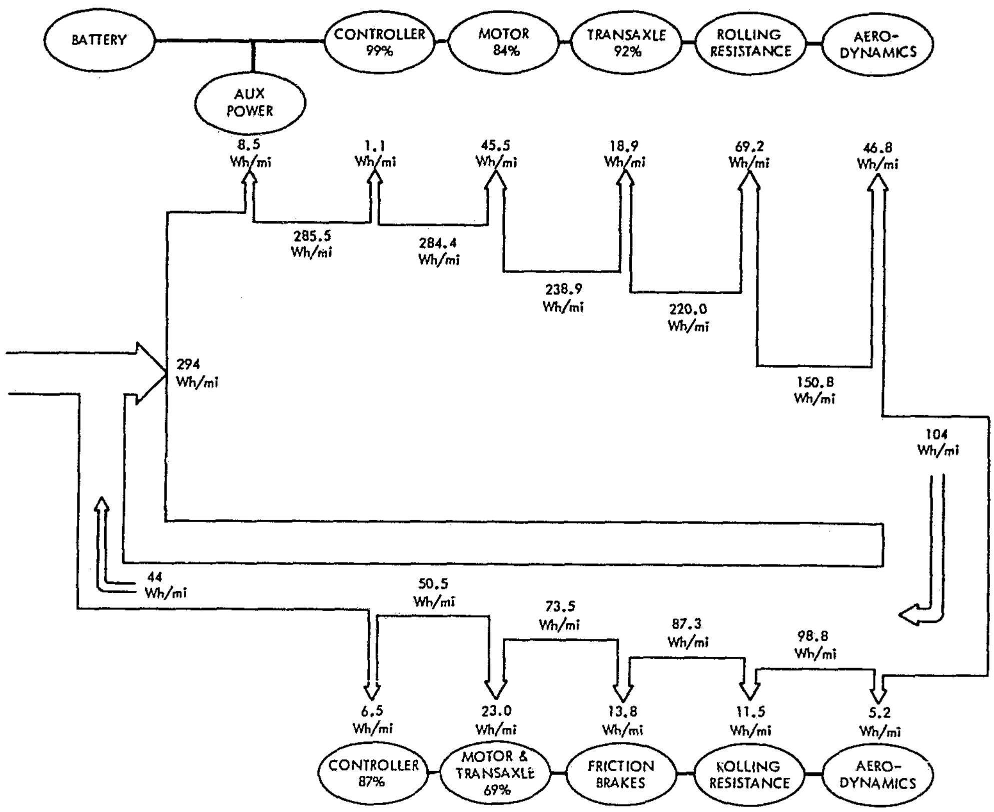

Figure 4-8. ETV-1 Energy Flow Distribution over the SAE J227a D Driving Cycle

C. RANGE

Discussion of the range performance or energy consumption at the wall plug of the ETV-1 has been purposely avoided. The characteristics of the battery system which power the vehicle are much more inconsistent than any other subsystem or component. A battery's potential for producing power and energy are sensitive, and somewhat unknown, functions of such variables as:

(1) Charging procedures.

(2) Age.

(3) Temperature.

(4) Previous discharge history.

(5) Discharge rates.

Some of these variables can be controlled in a testing environment by strictly regulating the procedures. A private or fleet user, however, could not be expected to consistently maintain such controls. Therefore, statements regarding range performance, under some particular (standard) set of circumstances, are of questionable value. This situation is similar to EPA fuel economy ratings for internal combustion (IC) engine automobiles. Unlike the relatively consistent fuel energy content of an IC vehicle gas tank, however, the energy available from an electric vehicle battery pack introduces major additional uncertainties.

Nevertheless, the range and corresponding battery performance experienced in dynamometer and track tests are presented in Figures 4-9 and 4-10.[16] Testing to battery depletion at 40 km/h (25 mph) was prevented because of motor and controller overheating in the armature chopping mode.[17] If these range results seem less than inspiring, recall that the test conditions were not designed to maximize range. For instance, requiring batteries to cool down to 21°C before initiating tests significantly reduces their energy capacity below that available immediately following charge when battery electrolyte temperatures can be above 40°C. Increasing evidence indicates that lead-acid battery capacity may be increased by about 1% per °C in these

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[16] Two different batteries are represented. The original batteries delivered with the vehicle (EV2-13, 048 Series) were replaced for dyno testing with Globe EV1000 prototype modules (commercial prototype based on EV2-13 design). A new set of EV1000 commercial modules was installed and characterized prior to the track testing.

[17] At 40 km/h (25 mph) which is just below base speed, the armature chopper is on nearly continuously and inadequate cooling results. In an attempt to perform this test, the PCU temperature reached 63°C (146°F) and the motor temperature reached 127°C (261°F).

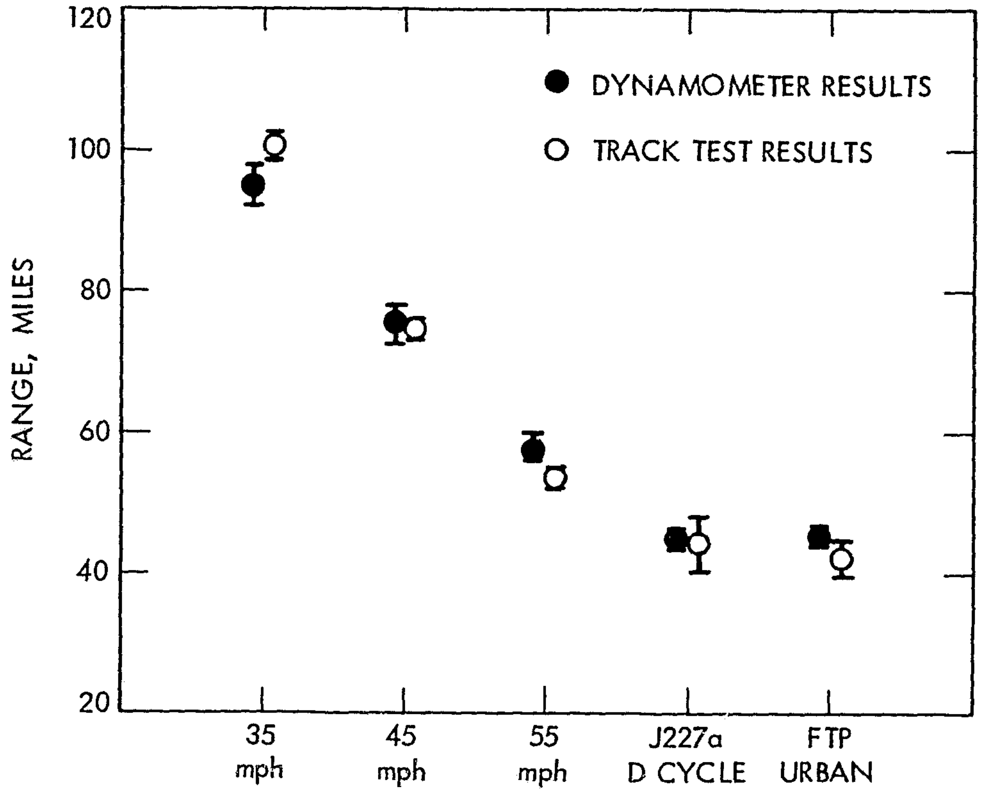

Figure 4-9. ETV-1 Range Performance Experienced During Dynamometer and Track Testing

temperature ranges.[18] In addition, vehicle test weight is defined as curb weight plus a 273 kg (600 lb) payload, bringing the ETV-1 test weight to 1795 kg (3,950 lb). The incremental nature of Clayton dynamometer inertia weights required the use of 1818 kg (4,000 lb). All these tests were terminated when a low-voltage criterion of 1.65 V per cell for constant speed tests and 1.3 V per cell during acceleration for cyclic tests was reached.[19]

The ETV-1 was previously reported to have demonstrated a range of 74.2 mi over the J227a D cycle. These track tests were performed by Chrysler at their Chelsea Proving Grounds (Reference 14) before delivery to DOE and JPL.

Following concerns raised by JPL, DOE requested JPL to lead a working group activity whose task would be to unravel the discrepancies between the General Electric (GE)/Chrysler ETV-1 track test results (74 mi) and the JPL dynamometer ETV-1 test results (45 mi). The primary focus of this group was on the performance of the two series of batteries involved. However, knowledge of the vehicle environment required an investigation of variances between the other vehicle subsystems as well. Group participants included representatives from Johnson Controls (Globe Battery Division), General Electric CRD, Lewis Research Center, Argonne National Laboratory and JPL.

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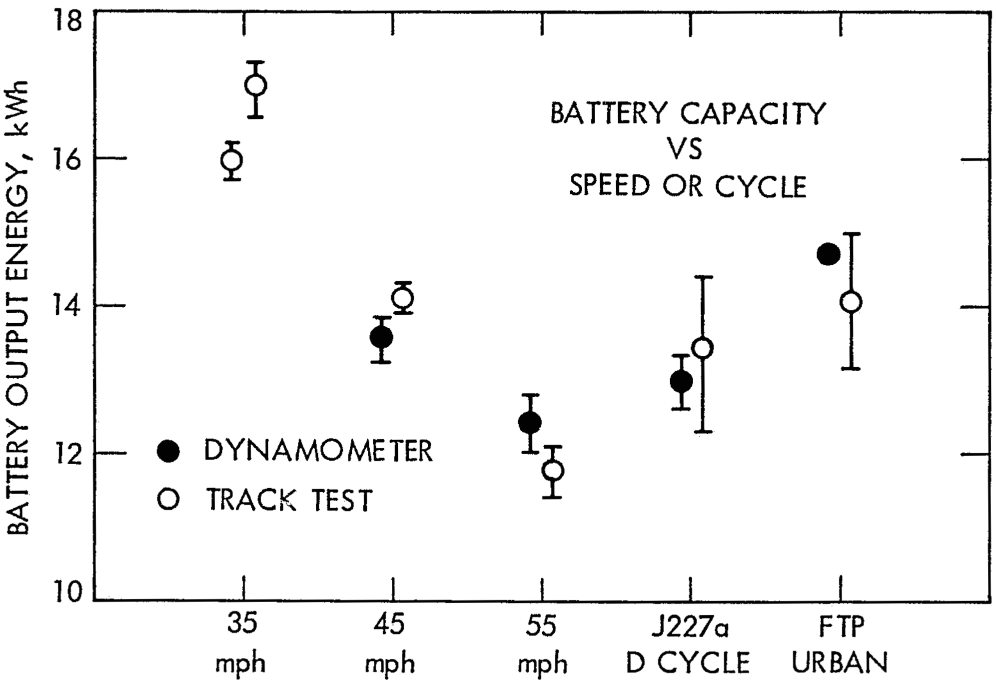
[18]Results from recently completed tests of the ETV-1 at JPL with 18 lead-acid modules contained in a thermally controlled box (Reference 13). The results were corroborated in ad-hoc tests performed by Argonne National Laboratory.

[19]In fact, the 1.3 V termination criterion was always reached on the same cycle that the acceleration criterion (Figure 4-7) could not be met.



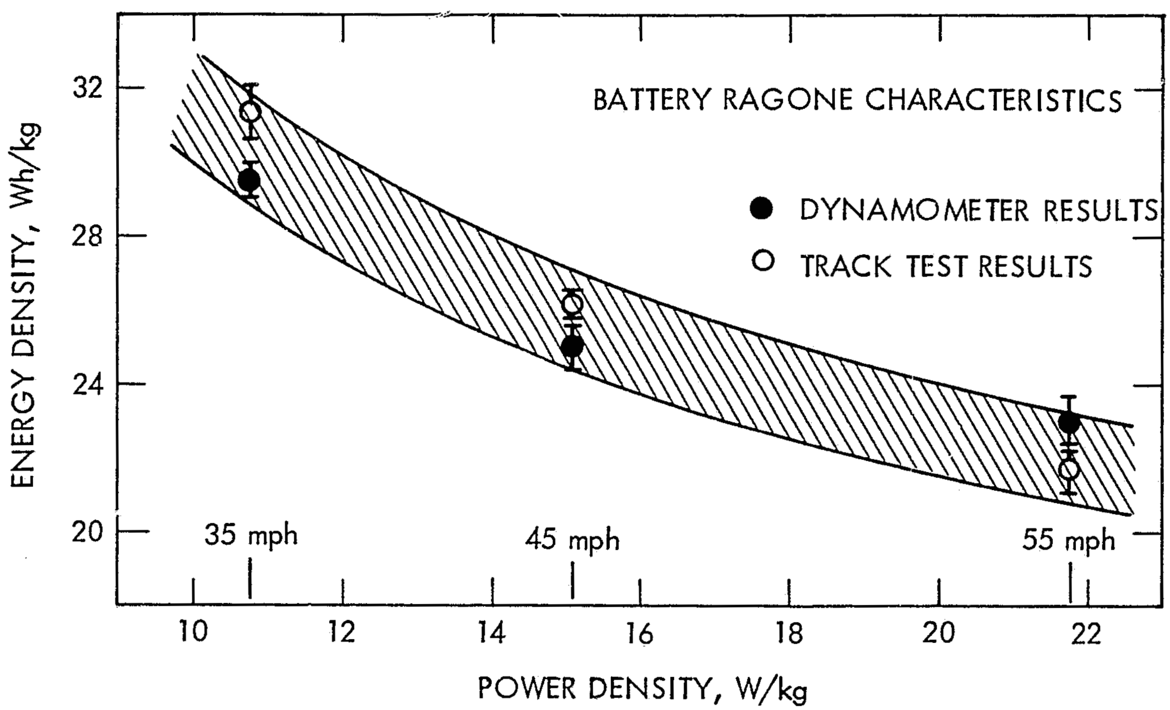


Figure 4-10. Battery Performance Experienced During Dynamometer and Track Test

The track tests which were run for GE at the Chrysler Chelsea Proving Grounds during August and September 1979 were performed on the No. 1 prototype vehicle (ETV-1-1) with Globe-Union 048 Series EV2-13 battery modules installed. The JPL dynamometer tests were performed with the No. 2 prototype vehicle (ETV-1-2) powered by Globe's EV1000 prototype battery modules (commercial prototype based on EV2-13 design).[20]

The ultimate objective of the working group was to understand the operation and results from the ETV-1 test programs and develop a consensus among the group participants regarding the cause of the apparent discrepancies (Appendix E).

The approach adopted was to first review the details of the Chrysler and JPL test procedures and results, identify the sources of variance, and then focus attention on the performance of the two series of batteries in these and other test programs. As anticipated, these discussions resulted in the need for further information. A series of special tests was devised subject to the availability of representative battery modules.

Power profiles were empirically derived (from a combination of special dyno tests and computer simulations) representing the two separate J227a D cycle tests. Certain parameters were known to be different. In addition to the fact that two different vehicles were involved:

(1) The ETV-1-1 Chelsea track test payload consisted of the driver and only minimal instrumentation (total test weight of 1,645 kg); JPL dyno testing was performed with a test weight specification of 1,795 kg. (DOE range goals were based on a payload of 273 kg).

(2) Since only the transition points are defined on the J227a D cycle, the GE and JPL interpretations of the acceleration and deceleration profiles were different.[21]

As a result, the GE-track cycle energy requirement was 285 Wh/mi from the battery terminals with 48 Wh/mi returning through regeneration. The JPL-dyno cycle required 294 Wh/mi and returned 44 Wh/mi.

In an effort to quantify what part the two battery types played in the test discrepancy, a test program was initiated at the National Battery Test Laboratory (NBTL) which is a part of the Argonne National Laboratory. Representative EV2-13 and EV1000 battery modules were subjected to the two empirical power profiles at ambient and a number of elevated electrolyte

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[20]Following the Chelsea tests, the No. 1 prototype vehicle underwent costing studies at Chrysler while the No. 2 vehicle was finished and delivered to JPL for the Phase III Test Activity. Since over a year elapsed between delivery of the EV2-13 batteries from Globe and the initiation of the JPL test activity (during which time, little maintenance was performed) the original batteries were replaced with the EV1000 prototype.

[21]GE chose to optimize the acceleration profile in order to maximize the efficiency of their controller.

temperatures (The Chelsea test was performed at some unknown elevated electrolyte temperature following a 19 h, non-temperature-compensated, charge).

The conclusion, and final group concensus, reached at the close of these ad-hoc activities were:

(1) The Globe 048 series batteries used in the Chelsea tests had a 6-10% greater energy capacity than the Globe EV1000 prototype batteries used during the JPL tests.

(2) The differences in payload, driving profile interpretation and vehicles resulted in 8% more range during D-cycle tests at Chelsea than during JPL dyno testing.

(3) There is an uncertainty of at least 5% in simulating track tests in the laboratory with dynamometer-generated power profiles.

(4) D-cycle range increases with battery electrolyte temperature at a rate of 1.1% per $^{\circ}$C.

(5) The largest factor affecting range (and the one having the greatest uncertainty) is electrolyte temperature. It would not be unreasonable, however, to expect that the electrolyte temperature of the batteries used during the Chelsea test was at least 50°C. Since the JPL dyno tests were performed with an average electrolyte temperature of about 26°C, one would expect a range difference of 25-30% from this parameter alone.

(6) A combination of these effects and uncertainties provides the basis for a reasonable explanation of the range difference.

(7) Reporting EV range is of questionable value because of the many arbitrary operational parameters which have first order effects on the results.

As an additional check on the scenario, a special road test was performed with the ETV-1-2 while it was at the TRC track. In an effort to duplicate the Chelsea test, weight was removed from the vehicle and the starting battery electrolyte temperature was raised significantly. The average range, resulting from two GE-type D-cycle tests with electrolyte temperatures around 57°C, was 71.6 mi. It should be noted that these tests could not exactly reproduce all the original Chelsea test parameters so 74.2 mi was not expected. There were several important differences:

(1) Different vehicles (probably a small and perhaps negligible effect).

(2) Different batteries. (This effect was quantified in the ANL tests to be about -8%.)

(3) Different test weights. (The special JPL tests were performed with the PMI system aboard to record data.) The additional 78 kg should have had a -4% impact on the D-cycle range.

(4) An estimate was made that the Chelsea electrolyte temperature was "around" 51°C. The charge procedure used to elevate the temperature for these special tests turned out to be too aggressive leaving the average electrolyte temperature at about 57°C. (This effect was quantified by the ANL tests to be about + 6%.)

Combining these effects, (geometrically) one would have expected the vehicle to have 6% less range in the special JPL tests than in the original Chelsea test. Or, more specifically, if the above scenario were correct, the vehicle should have gone 69.7 mi in the JPL tests compared to 74.2 mi in the original Chelsea test. The agreement is within 3%. Had the Chelsea battery temperature been assumed to be 48°C instead of 51°C (just as reasonable), the agreement would have been nearly perfect.

D. TRACK PERFORMANCE

The primary objective of the track test program was to corroborate the dynamometer results. Attempts were also made to evaluate various performance and handling characteristics in the road environment. Specifically, acceleration and braking tests were performed. Planned dynamic handling tests such as skid-pad and high speed slalom maneuvers were unsuccessful because of significant tire/wheelhouse interference. Although sagging springs may have contributed to the vehicle's inability to negotiate a 30 m (100 ft) radius skid-pad at speeds greater than 50 km/h (30 mph), the real problem was found to be a front-end manufacturing flaw which prevented full suspension travel except in straight ahead running. This situation is not uncommon in non-production hardware. The second ETV-1 vehicle was later found to have significantly more wheelhouse clearance and would probably have a much higher speed threshold before interference problems set-in.

Maximum acceleration tests were planned for two vehicle payloads (195 kg and 316 kg) and a range of battery depths of discharge. Unfortunately, high quality acceleration data was virtually impossible to generate on this vehicle. Motor over-current protection circuitry prevents simple full-throttle application.[22] Many practice runs were required in order for the driver to "sense" the main contactor drop-out threshold. As a consequence, acceleration times were rather unrepeatable and lacked the accuracy required to assess the specific effects of DoD with any confidence. No clear monotonic trend with DoD emerged with the exception of the last runs where the battery was clearly depleted. Top speeds in excess of the DOE goal (97 km/h, 60 mph) were easily achieved.

Table 4-1 presents the results of these maximum acceleration tests for the two payload cases and compares them with the DOE Program goals.

Although neither payload (test driver and instrumentation) package was identical to the 273 kg payload specified in the DOE performance goals, they

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[22]Controller software limits the armature current to 400 A. The current sensor a (temperature-sensitive Hall-effect device) drifts causing an erroneous over-current signal which breaks the main contactor.

Table 4-1. Results of Acceleration Tests

(Average Performance at 0 to 80% DoD)

	ETV-1 Track Performance		DOE Goal
	Payload 195 kg	Payload 316 kg	Payload 273 kg
0-48 km/h (0-30 mph)	8.6	8.8	9.0
0-80 km/h (0-50 mph)	20.2	21.3	-
40-88 km/h (25-55 mph)	18.4	19.6	18.0

bracket that value. It appears that the zero-to-48 km/h (30 mph) acceleration goal of 9.0 sec was met, but that the 40 to 88 km/h (25 to 55 mph) passing acceleration goal of 18.0 sec could not be met even at the reduced weight. The zero-to 80 km/h (50 mph) time is shown for completeness since this is becoming an un-official acceleration measure for conventional vehicles. It would appear that the ETV-1 has acceleration performance similar to many non-turbocharged diesel automobiles now in production.

Several types of straight-line braking tests were performed with the vehicle at its standard track-test weight of 1,835 kg. Braking distances to stop from approximately 48 km/h (30 mph) and 96 km/h (60 mph) were measured and repeated three times after cool-down periods. Brake pedal effort was limited to an average of 673 N (150 lb). The results shown in Table 4-2 indicate the consistency of these tests. A brief review of road tests from the automotive press indicates that these braking distances are representative of typical American sedans and are approximately 20% greater than the best production "sports" machines. Brake fade tests were also performed by measuring braking distance from 96 km/h to zero following both six and ten repetitive 1/2-g braking efforts. These distances, shown in Table 4-2, indicate an increase of less than 7% in the worst case and therefore suggests that brake fade is not a serious problem.

Summaries of the major output variables from each individual dynamometer and track test are included in Appendix F.

Table 4-2. Results of Braking Tests

	Cool Brake Tests Distance to Stop (m)			
	Test 1	Test 2	Test 3	Test 4
48 km/h to 0 (30 mph to 0)	13.59	13.20	13.32	13.38
96 km/h to 0 (60 mhp to 0)	48.52	48.98	48.83	48.78

	Brake Fade Tests Distance to Stop (m) Following:	
	6--1/2 g Braking Efforts	10--1/2 g Braking Efforts
96 km/h to 0 (60 mph to 0)	51.85	50.29

SECTION V

CONCLUDING REMARKS

The ETV-1 Electric Test Vehicle represents a significant step forward in the development of a viable electric passenger vehicle. Developed by using a total system design approach, the various electrical and mechanical subsystems have been properly integrated to produce an aesthetically pleasing vehicle having outstanding energy economy.[23] Much of that success is due to the low road-load energy requirement and the aerodynamic design in particular. Aerodynamics was involved, from the outset, as an integral design parameter. As a result, the energy required to overcome aerodynamic drag is approximately 30% lower than could be expected by converting the best of the current production sub-compacts.

The electrical drive components, armature and field choppers, traction motor, power conditioning and controller logic all work together as a near optimum system (Reference 15).

The battery subsystem still remains the weak link to continued development and public acceptance. Although lead-acid battery technology is more than a century old, significant improvement may still be available. For example, feed-back control charging procedures and thermal management are two areas where potentially substantial benefits could be derived.

A significant point about electric vehicle test procedures and specifically range results needs further emphasis. It is quite difficult to perform credible tests on a system as complex as an automobile. Furthermore, unlike the energy content of an IC vehicle fuel tank, the energy available from an electric vehicle's battery pack introduces major additional uncertainties. Normal consumer operation of the ETV-1, within the varying seasonal climates across this country, could reflect urban range performances that vary by a factor of three or more. Even two serious testing organizations (JPL and GE/Chrysler) observed vastly different range results. Without thermal control, lead-acid battery capacity is so variable that any corresponding range results must be accompanied by very specific qualifications or it is relatively useless. The "proper" battery temperature at which to perform testing, if reasonable and constant, is arbitrary (and, hence, the range as well). Cycle-life testing at a range of battery operating temperatures will provide the missing information to conduct the necessary performance and economic trade-offs required to establish the "proper" battery environment.

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[23] The DOE ETV-1 energy consumption (Wh/mi leaving the battery terminals) is approximately 20% less than that required by the South Coast Technology (SCT) converted Rabbit over a D cycle (Reference 10).

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APPENDIX A

ETV-1 SUBSYSTEM DESCRIPTIONS

A. CHASSIS

The ETV-1 (Figure A-1) is a four passenger electric car which was developed as a total system. Packaging and structural studies led to the incorporation of a front wheel drive system with transversely mounted motor and transaxle, and a central longitudinal battery tunnel which is a fully integrated element of the unibody construction.

Aerodynamic design was recognized as an important design parameter at the outset. A major drag reduction program was initiated and coordinated with the styling activities yielding a drag-area product (C_DA) approximately 30% lower than current conventional subcompact cars.

High-strength low-alloy steel is used in several locations to obtain a high strength-to-weight ratio. External body panels such as the doors, hood and fenders are heat treated aluminum. Additional weight savings were achieved by using a polycarbonate resin, Lexan®, for the side and rear windows. The ETV-1 meets all applicable Federal Motor Vehicle Safety Standards (FMVSS) that were in effect at contract initiation (April, 1977). The sole exception was the Lexan® the side and rear window glazing which was expected to be acceptable in the mid-1980 time frame.

Chassis specifications are shown in Table A-1.

B. DRIVE TRAIN

The prime mover is a General Electric four pole, separately-excited dc motor. It is transversely mounted ahead of the front wheels and transmits power to a differential through a double reduction chain drive. Specifications are shown in Table A-2.

C. ELECTRONICS

The separately excited dc motor is controlled by transistor armature and field choppers which are in turn commanded by the propulsion control microcomputer. Based on the Intel 8080A, the microprocessor is the interface between driver demands and the electronic components. The drive subsystem is shown schematically in Figure A-2.

The control strategy calls for armature control for vehicle speeds from 0 to 43 km/h (27 mph) and field control beyond. In the armature control mode, the average motor armature voltage is varied between 0 and 108 V (nominally) by the duty cycle of the armature chopper while the field current is held constant by the field chopper. During the field control mode, the field current is reduced and the armature sees the full battery voltage through an armature chopper bypass contactor.

Figure A-1. The DOE ETV-1 Electric Test Vehicle

Table A-1. Chassis Specifications

4-Passenger, central backbone unit-body	
Curb weight	1,522 kg (3,350 lb)
Wheelbase	249 cm (98.0 in.)
Overall length	430.3 cm (169.4 in.)
Overall height	131.1 cm (51.6 in.)
Overall width	166.9 cm (65.7 in.) at B-Pillar
Tread, front	142.2 cm (56.0 in.)
Tread, rear	141.2 cm (55.6 in.)
Fully independent suspension	
Front	McPherson strut (Omni)
Rear	Trailing arm, spring over shock
Brakes	Blended hydraulic and dynamic regenerative
Front	Discs (Omni)
Rear	Drum (Omni)
Tires	Goodyear extra load P175/75R13
Front	29 psi
Rear	42 psi
Drag coefficient	0.32 (nominal)[a] at zero yaw
Frontal area	1.84 m^2 (19.8 ft^2)

[a]Open windows and headlights cause an 11% and 13% drag penalty, respectively (Reference 7).

Table A-2. Drive Train Specifications

Motor	
Continuous rating	15 kW (20.1 HP), 96 V 175 A
Force-ventilated	59 l/s (125 cfm)
Maxiumum speed	5000 RPM
Shunt field	330 turns/pole
Approximate weight	100 kg (200 lbs)
Transmission	
Double reduction morse "HY-VO" chain, fixed ratio	
Differential	
Modified production Omni	
Overall final drive ratio	5.48:1

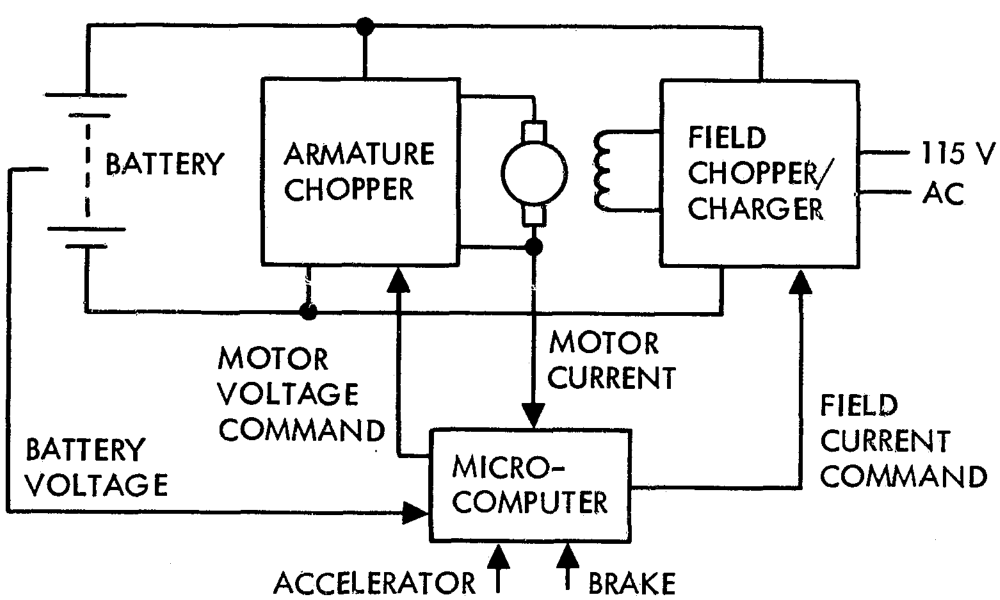

Figure A-2. ETV-1 dc Drive Subsystem (Reference 15)

When the vehicle is stationary, the field chopper circuit can be used as an on-board battery charger using a 115 V 50 Hz ac power line. Electronic specifications are shown in Table A-3.

Table A-3. Electronic Specifications

Armature Chopper	
Continuous rating	
Motoring	+200 A
Generating	-100 A
Transient rating	(1 min)
Motoring	+400 A
Generating	-200 A
Field Chopper/Charger	
Continuous rating	
Field supply	10.6 A, 53 V
Switching frequency	9.5 kHz
Charging	24 A, 132 V (30 A Line) 8 A, 132 V (15 A Line)
Switching frequency	5-15 kHz

D. BATTERY SUBSYSTEM

The propulsion battery was specifically designed for the ETV-1 by Johnson Controls, Globe Battery Division (previously Globe-Union). The eighteen modules making up the battery incorporate the following features:

(1) Radial grid plate design (13 plates/cell).

(2) Low aspect-ratio plates (90° rotation from conventional).

(3) Single point watering system.

(4) Right and left hand terminal design to minimize cabling losses.

The battery specifications are shown in Table A-4.

Table A-4. Battery Specifications

6 V Modules, 108 V nominal pack voltage	
Energy Density	37.5 Wh/kg (17 Wh/lb) 3 h rate
Power Density	181 W/kg (82 W/lb) peak
Life	500 cycles to 70% DoD (design goal)
Approximate weight	495 kg (1,090 lb) 18 module pack
Module size	
Length	26.4 cm (10.4 in.)
Width	18.3 cm (7.2 in.)
Height	28.3 cm (11.1 in.)

APPENDIX B

THE IMPROVEMENT OF DYNAMOMETER RESULT ESTIMATION THROUGH UNCERTAINTY ANALYSIS

The objective of performing an analysis of this type is two-fold:

(1) To quantify the influence of error propagation on the results of JPL EHV dynamometer testing.

(2) To gain insight for refining the test techniques, where applicable, in order to minimize uncertainty.

The vehicle-dynamometer system is iteratively adjusted until the system coast-down history approximates the ideal-standardized mathematical history derived from track coast-down tests. Although that match can be within a percent or two, the accuracy of the ideal-mathematical expression is still open to question. The following analysis quantifies the probable error in that expression from the true value.

The governing equation for a vehicle coasting down over a fixed grade is:

$$M \frac{dV}{dt} = \Sigma \text{ Forces} = \text{Road Load} \qquad (1)$$

or

$$\frac{W}{g} \frac{V}{t} = \underbrace{\frac{1}{2} \rho V^2 C_D A}_{\text{Aero Drag}} - \underbrace{W(C_{R_o} + C_{R_v} V)}_{\text{Rolling Resist.}} \underbrace{\pm W\theta}_{\text{Grade Force}} \qquad (2)$$

where,

W = Vehicle Weight

g = Acceleration Constant

ΔV = Dyno-Match Speed Increment 16 km/h (10 mph)

Δt = Dyno-Match Time Increment

ρ = Air Density

V = Instantaneous Vehicle Speed

C_D = Aerodynamic Drag Coefficient

A = Vehicle Frontal Area

C_{R_o} = Rolling Resistance Constant Coefficient

C_{R_v} = Rolling Resistance Speed-Dependent Coefficient

θ = Grade Slope

Dealing with the left-hand expression from Eq. 2, the average road load acting on a vehicle as it coasts-down from one speed to another is:

$$\text{Road Load, (RL)} = \frac{W}{g}\,\frac{\Delta V}{\Delta t} \tag{3}$$

The Combined Road Load Sample Standard Deviation, $S_{\bar{RL}}$ is defined:

$$S_{\bar{RL}}^{\;2} = \left(\frac{\partial \bar{RL}}{\partial W}\right)^2 S_W^{\;2} + \left(\frac{\partial \bar{RL}}{\partial \Delta V}\right)^2 S_{\Delta V}^{\;2} + \left(\frac{\partial \bar{RL}}{\partial g}\right)^2 S_g^{\;2} + \left(\frac{\partial \bar{RL}}{\Delta t}\right)^2 S_{\Delta t}^{\;2} \tag{4}$$

And the Precision Index, $PI_{\bar{RL}}$, in percent is simply:

$$PI_{\bar{RL}}(\%) = \frac{S_{\bar{RL}}}{\bar{RL}} = \sqrt{\frac{S_W^{\;2}}{W^2} + \frac{S_{\Delta V}^{\;2}}{\Delta V^2} + \frac{S_g^{\;2}}{g^2} + \frac{S_{\Delta t}^{\;2}}{\Delta t^2}} \tag{5}$$

From fifteen repeated track coast-down tests, the element sample standard deviations and norms were determined to be:

Sample Standard Deviations	Norms
S_W = 21 kg	W = 1,795 kg
$S_{\Delta V}$ = 0.061 m/s	ΔV = 4.48 m/s
$S_{\Delta t}$ = (32 to 16 km/h) = 1.25 sec	Δt (32 to 16 km/h) = 42.97 sec
$S_{\Delta t}$ = (90 to 73 km/h) = 0.49 sec	ΔT (90 to 73 km/h) = 22.60 sec

Evaluating Eq. 5 with the above values for both low and high speed regimes yields:

Low Speed:

$$PI_{\bar{RL}} = \sqrt{\left(\frac{21}{1,795}\right)^2 + \left(\frac{0.061}{4.48}\right)^2 + \left(\frac{1.25}{42.97}\right)^2} = \pm 3.42\%$$

and

High Speed:

$$PI_{\bar{RL}} = \sqrt{\left(\frac{21}{1,795}\right)^2 + \left(\frac{0.061}{4.48}\right)^2 + \left(\frac{0.49}{22.60}\right)^2} = \pm 2.81\%$$

With a sample size of 15, the students T statistic is 2.13 for 95% containment. Therefore, there's a 95% probability that the true road load value is within $\pm$7.28% and $\pm$5.99% of the norm at the low and high speed regimes respectively.

Equation 2 shows that the Road Load can be represented by the expression on the right side of the equation. By making an independent estimate of the road load from component test results, the "combined uncertainty interval" principle can be used. Simply stated, if the true value lies within each independent uncertainty interval, it also falls within the combined interval (A union B).

Equation 4 can be rewritten for the right side of Eq. 2:

$$S_{\bar{RL}}{}^2 = \left(\frac{\partial \bar{RL}}{\partial C_D A}\right)^2 S_{C_D A}{}^2 + \left(\frac{\partial \bar{RL}}{\partial C_{R_o}}\right)^2 S_{C_{R_o}}{}^2 + \left(\frac{\partial \bar{RL}}{\partial C_{R_v}}\right)^2 S_{C_{R_v}}{}^2 + \left(\frac{\partial \bar{RL}}{\partial \theta}\right)^2 S_\theta^2$$

The Precision Index, $PI_{\bar{RL}}$ is again $S_{\bar{RL}}/RL$ but now cannot be reduced to the form shown in Eq. 5.

The following sample standard deviations (Table B-1) were determined from wind tunnel tests (Reference 8), special tire tests (private communication with Goodyear) and careful grade surveys of the runways. The precision Index from these independent estimates is $\pm 3.01\%$ and 1.64% for the low and high speed regimes. Since the sample size is much greater in this case (high sample rates in the wind tunnel and tire facilities), a normal distribution may be assumed. The 95% containment interval then occurs at 1.96σ.

Table B-2 shows the resulting Road Load confidence interval at the low and high speed regimes for the two independent estimates.

Table B-1. Sample standard Deviations and Norms

Sample Standard Deviations	Norms
$S_{C_D A} = 0.0055\ m^2$	$C_D A = 0.552\ m^2$
$S_{C_{R_o}} = 0.00021$ N/N	$C_{R_o} = 0.0095$ N/N
$S_{C_{R_v}} = 0.00000045\ \frac{N\text{-}sec}{N\text{-}m}$	$C_{R_v} = 0.0000112\ \frac{N\text{-}sec}{N\text{-}m}$
$S_\theta = 0.0013\%$	$\theta = 0.1776\%$

Table B-2. Road Load Confidence Interval

	Speed km/h	Nominal Road Load N	95% Confidence Interval N
Coast-Down Testing	Low (32-16)	186.7	173.1 - 200.3
	High (90-73)	354.9	333.6 - 376.2
Component Testing	Low (32-16)	190.9	179.6 - 202.2
	High (90-73)	359.2	347.1 - 370.7

Note that there is indeed an interval overlap in the two estimate approaches. If some minimum overlap had not been found, it would indicate that

(1) There was an instrumentation error.

(2) There were data reduction errors.

(3) There is some yet unidentified error source.

However, significant overlap exists. The centroid of that overlap is the new nominal road load value and the boundaries represent the 95% confidence band.

In summary, there is a 95% probability that the true low speed road load is 189.9 N $\pm$5.4% and the high speed road load is 358.6 N $\pm$3.2% for the standard conditions defined (zero wind, zero grade, standard test atmosphere).

APPENDIX C

ETV-1 RELIABILITY DURING TEST PROGRAM

The ETV-1 is a highly advanced vehicle. Because of the nature of the contract timing and final assembly delays, the vehicle was delivered to JPL with very little operational experience. As a result, the JPL test program was often interrupted and delayed by many "failures" and test anomalies. The following history indicates the frequency and diversity of the problems with brief comments. A complete and detailed log book was also kept (as with all vehicles tested by JPL) which documents all repair and service activities. After addressing several minor and a few major deficiences, the ETV-1 has become a reliable test vehicle.

PROBLEM/FAILURE HISTORY AT JPL

Vehicle received on October 2, 1979
Accessory battery charger not operational on delivery.

October 10, 11 - GE personnel at JPL to repair accessory battery charger. (Repair required lowering charger current to 17 A to eliminate overheating.

October 29 - Vehicle will not start.
(Accessory battery was discharged - constant 1.5 A drain from reversing relays in motor temperature circuitry.[1])

The vehicle had no major failure other than several chopper contactor drop outs for the month of November.
(This abnormality seems to occur during acceleration with the accelerator pedal to the floor.)

December 4 - Transmission case cracked and PCU damaged while performing coastdowns on the dynamometer. (A logic error in the microprocessor allowed a buildup of field current with the key switch off at 100 km/h. This condition further induced the very high transcient torque which cracked the transmission case. PCU regeneration and motoring modules found to be shorted out.)

December 12 - PCU sent to GE for repair. JPL to fabricate new more durable transmission case.

Remainder of January and part of February used for preparing vehicle for dynamometer testing, (e.g., shunts installed) and coastdown test at Edwards Air Force Base (e.g., half-axles removed, fifth wheel installed).

February 14 1980 - Microprocessor software reprogrammed, PCU repaired and returned to JPL. Transmission case fabrication still in process.

Coastdown testing performed at ETS (March 17 - April 21).

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[1] See continuing problem list at the end of this Appendix (No. 1).

April 29 -Battery pack removed from vehicle to replace batteries 1, 2, 3, 4 and 9 due to low capacity.
(Battery pack and frame were very corroded because of electrolyte leakage from the watering system.)
April 30 - Installed new transmission case.

May 9 - First formal dyno test - 55 mph
Range = 59.5 mi
Energy Battery Out = 12.776 kWh

May 12 - "D" cycles
Range = 32.6 mi
Energy Battery Out = 14.542 kWh

May 19 - 45 mph
Range = 78.2 mi
Energy Battery Out = 14.542 kWh

May 21 - 35 mph (Test terminated due to QD cut out, reason unknown)
Range = 62.6 mi
Energy Battery Out = 10.670 kWh

May 22 - Attempted FTP
Test terminated when main contactor continued cutting out in deceleration mode.

May 27 - Determined that the cut out problem was due to drift in the armature current sensor of the PCU. Decision was made to replace the original (year-old, plus) battery pack.

June 3 - GE at JPL to address current offset problem[2] -- severe arcing damage found inside PCU.
(Returned PCU to GE for investigation repair.)

June 23 - PCU returned to JPL from GE. Solder splashes on circuit boards responsible for arcing.

July 28 - Shutdown during FTP test caused by PCU overheat due to air duct failure. (Air duct redesigned and replaced by JPL).

October 9 - Shutdown during first 25 mph constant speed test due to Oscillation in 10 volt logic power supply. (Minor circuit modifications to the low voltage power supply required the addition of a capacitor to the Schmitt trigger and resistor and transistor changes in the preregulator).

29 October - Shutdown during D cycles or when warm.
Ten-volt logic power supply now rises to fault gate with temperature.
(Replacing the 11 V regulating Zener diode with a 10 V Zener maintains the voltage between 9.6 and 10.2 V).

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[2]See continuing problem list at the end of this Appendix (No. 2).

The ETV-1 has continued to operate in a reasonably reliable fashion since November, 1980. Several actions still need attention but are in the area of nuisance concerns:

Continuing Problems

1. Problem. As presently configured, there is a continuous current drain of approximately 1.5 A to power-up reversing relays in the motor temperature circuitry. This is sufficient to completely discharge the accessory battery in 24-36 h. The present procedure is to disconnect the accessory line when not in use.

   Solution. Implement a design which will disconnect the accessory battery when the keyswitch is in the off position.

2. Problem. Drift in the armature current sensor causes the PCU to command shutdown in the coast mode. The sensor is a Hall-effect device which has significant temperature sensitivity. Present procedure is to frequently re-set sensor.

   Solution. Replacement of one-turn pots with ten-turn pots has improved the re-set frequency. A new circuit, which is less temperature sensitive, is still required.

3. Problem. The on-board battery charger is not being used because of the high possibility of failure of the field module transistor with which it is integrated. In order to insure that the test program not be further interrupted, the current procedure is to use an off-board charger exclusively.

   Solution. Develop and install a very high quality transistor in the field module which will stand up to the high voltage stress induced during the charge mode.

APPENDIX D

OUTPUT DATA SAMPLE FROM ETV-1 TESTING

A sample of the tabulated data output from a dynamometer test is presented in order to demonstrate the number and types of data that are recorded and analyzed by IDAC[1] on every test. The example shown is a reduced data slice from the acceleration period of a J227a D cycle test with the battery at approximately 40% DoD. Because of the magnitude of the data channels and column limitations, data output is presented in three groups:

(1) General Parameters.

(2) Energy and Power Parameters.

(3) Voltages, Currents and Temperatures.

Table D-1 contains the abbreviations used for column headings. Included are the equations used for the calculated data. Complete data summaries (including some analysis) from all dynamometer and track tests are presented in Appendix F.

Table D-1. Abbreviations for Column Headings

Column	The column number, from the left, in which the abbreviation occurs.
Symbol	The column heading symbol, or abbreviation.
Plot	Equals YES if this is a default plot parameter. Note that all parameters can be plotted.
Code	Equals I if IDAC data; equals C if a calculated parameter.
Description	Gives a description of column contents, including equations if this is a calculated parameter.

[1]Integrated Data Acquisition and Control System.

PART 1

GENERAL PARAMETERS

COLUMN	SYMBOL	PLOT	CODE	DESCRIPTION
1	RUN	No	I	Test run number
2	EB	No	I	Emission bench number. Equals 0 for electric-only cars
3	TIME	Yes	I	Elapsed time since start of recording
4	VEL	Yes	I	Vehicle velocity
5	DIST	Yes	I	Distance traveled
6	HPDYNO	Yes	I	Dyno absorbed power
7	HPROAD	Yes	C	Road load powers; = HPAERO + HPROLL
8	HPIW	Yes	I	Inertia weight power
9	HPAERO	Yes	C, I	Aero hp = $(VEL/50)^3$ x hp aero @ 50 mph if given, else = HPDYNO
10	TPOS	No	I	Carburetor throttle position, not used
11	APOS	No	I	Accelerator pedal position, not used
12	DSS	Yes	I	Drive shaft or half axle speed
13	PBO	No	I	Battery power out, hp
14	HPROLL	Yes	C	Rolling load, = RDL50 + (RDL15 - RDL50) $\frac{(VEL-50)}{(15-50)}$; where RDL50 = rolling load at 50 mph, lb RDL15 = rolling load at 15 mph, lb
15	DTEFF	Yes	C	Drive train efficiency = HPRO HPROAD/PBO * 100
16	%AERO	Yes	C	HPAERO/HPROAD * 100
17	%ROLL	Yes	C	HPROLL/HPROAD * 100

PART 2

ENERGY AND POWER PARAMETERS

COLUMN	SYMBOL	PLOT	CODE	DESCRIPTION
1	RUN	No	I	Test run number
2	TIME	Yes	I	Elapsed time since start of recording
3	VEL	Yes	I	Vehicle Velocity
4	EBO	Yes	I	Energy out of battery
5	EBI	Yes	I	Energy into battery
6	EMAI	Yes	I	Energy into motor armature
7	EMAO	Yes	I	Energy out of motor armature
8	EMF	Yes	I	Energy into motor field
9a	BTAMPO	No	I	Total Ah out of battery
10a	BTAMPI	No	I	Total Ah into battery
11a	BCHGP	No	I	Charging power into battery
12	PBO	Yes	I	Power out of battery
13	PBI	Yes	I	Power into battery
14	PMAI	Yes	I	Power into motor armature
15	PMAO	Yes	I	Power out of motor armature
16	PMF	Yes	I	Power into motor field
17	MSPD	Yes	I	Electric motor speed
18	GRATM	Yes	C	Motor speed/DSS

a - not operational

PART 3

VOLTAGES, CURRENTS, AND TEMPERATURES

COLUMN	SYMBOL	PLOT	CODE	DESCRIPTION
1	RUN	No	I	Test run number
2	TIME	Yes	I	Elapsed time since start of recording
3	VEL	Yes	I	Vehicle velocity
4a	BCHGV	No	I	Charging voltage to battery
5	BV	Yes	I	Battery voltage
6	MAV	Yes	I	Motor armature voltage
7	MFV	Yes	I	Motor field voltage
8	BCHGA	No	I	Charging current to battery
9	BA	Yes	I	Battery current
10	MAA	Yes	I	Motor armature current
11	MFA	Yes	I	Motor field current
12	TBAT1	Yes	I	Battery module temperature #1
13	TBAT2	Yes	I	Battery module temperature #2
14	TBAT3	Yes	I	Battery module temperature #3
15	TBAT4	Yes	I	Battery module temperature #4
16	TBAT5	Yes	I	Battery module temperature #5
17	TCONT	Yes	I	Controller temperature
18	TEM1	Yes	I	Electric motor temperature #1 (external)
19	TEM2	Yes	I	Electric motor temperature #2 (external)
20	TEM3	Yes	I	Electric motor temperature #3 (external)
21	ABV	Yes	I	Accessory battery voltage

a - not operational

TABULATED OUTPUT
Part I General Parameters

IDAC TAPE L843 TEST NO. 11 DAY 217 10:23:28 SITE NO.=4.0 IDAC SITE= 4
TAMB = 72.879 DEG F PAMB = 13.907 PSIA TEST DATA START 10:23:33 REL HUM = ***** IN.WGHT.= 4000.

RUN	EB	TIME SEC	VEL MPH	DIST MI	HPDYNO HP	HPROAD HP	HPIW HP	HPAERO HP	TPOS %	APOS %	DSS RPM	PBO HP	HPROLL HP	DTEFF %	%AERO	%ROLL
3	0	2175.80	32.98	16.850	2.13	5.06	20.13	1.49	.0	.0	2649.2	33.06	3.57	76.22	29.49	70.51
3	0	2175.97	33.17	16.852	2.13	5.11	19.14	1.52	.0	.0	2681.8	32.38	3.59	74.90	29.72	70.28
3	0	2176.14	33.38	16.853	2.18	5.16	20.07	1.55	.0	.0	2680.1	31.96	3.61	78.95	29.97	70.03
3	0	2176.31	33.67	16.855	2.19	5.24	22.19	1.59	.0	.0	2719.4	32.12	3.65	85.40	30.32	69.68
3	0	2176.48	33.85	16.856	2.20	5.28	21.08	1.61	.0	.0	2726.3	32.81	3.67	80.35	30.54	69.46
3	0	2176.65	34.09	16.858	2.33	5.35	21.92	1.65	.0	.0	2734.9	33.35	3.70	81.75	30.83	69.17
3	0	2176.82	34.32	16.860	2.30	5.41	22.16	1.68	.0	.0	2765.7	33.77	3.72	81.63	31.11	68.89
3	0	2176.99	34.52	16.861	2.33	5.46	20.86	1.71	.0	.0	2776.0	33.82	3.75	77.81	31.35	68.65
3	0	2177.16	34.74	16.863	2.33	5.52	21.55	1.74	.0	.0	2810.2	33.90	3.77	79.85	31.62	68.38
3	0	2177.33	35.08	16.865	2.36	5.61	26.04	1.80	.0	.0	2810.2	33.77	3.81	93.72	32.02	67.98
3	0	2177.50	35.24	16.866	2.36	5.65	22.71	1.82	.0	.0	2853.0	33.74	3.83	84.06	32.20	67.80
3	0	2177.67	35.43	16.868	2.49	5.71	21.61	1.85	.0	.0	2847.9	33.52	3.85	81.49	32.44	67.56
3	0	2177.84	35.61	16.870	2.53	5.75	19.71	1.88	.0	.0	2791.4	33.51	3.88	76.01	32.65	67.35
3	0	2178.01	35.82	16.872	2.51	5.81	19.63	1.91	.0	.0	2842.7	33.69	3.90	75.52	32.90	67.10
3	0	2178.18	36.04	16.873	2.54	5.87	20.77	1.95	.0	.0	2762.3	33.93	3.93	78.52	33.16	66.84
3	0	2178.35	36.25	16.876	2.54	5.93	21.58	1.98	.0	.0	2777.7	34.25	3.95	80.31	33.41	66.59
3	0	2178.52	36.60	16.877	2.58	6.03	27.57	2.04	.0	.0	2767.4	34.59	3.99	97.15	33.82	66.18
3	0	2178.69	36.79	16.878	2.59	6.08	25.32	2.07	.0	.0	2806.8	34.48	4.01	91.07	34.04	65.96
3	0	2178.86	36.96	16.880	2.63	6.13	22.45	2.10	.0	.0	2799.9	34.22	4.03	83.53	34.24	65.76
3	0	2179.03	37.13	16.882	2.80	6.18	20.01	2.13	.0	.0	2851.3	34.12	4.05	76.75	34.44	65.56
3	0	2179.20	37.30	16.883	2.78	6.23	18.24	2.16	.0	.0	2969.5	33.97	4.07	72.05	34.64	65.36
3	0	2179.37	37.47	16.885	2.80	6.28	18.07	2.19	.0	.0	2996.9	34.08	4.09	71.45	34.84	65.16
3	0	2179.54	37.68	16.887	2.81	6.34	19.75	2.22	.0	.0	3031.1	34.09	4.12	76.54	35.08	64.92
3	0	2179.71	37.87	16.889	2.84	6.40	20.41	2.26	.0	.0	3058.5	33.92	4.14	79.04	35.30	64.70
3	0	2179.88	38.13	16.890	2.91	6.48	23.94	2.31	.0	.0	3061.9	33.78	4.17	90.05	35.61	64.39
3	0	2180.05	38.34	16.892	2.95	6.54	24.02	2.34	.0	.0	3087.6	33.66	4.20	90.81	35.84	64.16
3	0	2180.22	38.50	16.895	2.96	6.59	21.59	2.37	.0	.0	3091.1	33.31	4.22	84.62	36.03	63.97
3	0	2180.39	38.62	16.896	2.99	6.63	17.95	2.40	.0	.0	3115.0	32.70	4.23	75.17	36.17	63.83
3	0	2180.56	38.76	16.898	3.08	6.67	15.70	2.42	.0	.0	3060.2	32.13	4.25	69.63	36.32	63.68
3	0	2180.73	38.90	16.900	3.07	6.71	15.07	2.45	.0	.0	3020.9	31.56	4.26	69.01	36.48	63.52
3	0	2180.90	39.03	16.901	3.13	6.75	14.75	2.47	.0	.0	2976.3	30.86	4.28	69.68	36.63	63.37
3	0	2181.07	39.16	16.903	3.10	6.79	14.97	2.50	.0	.0	3000.3	30.4[illegible]	4.29	71.43	36.78	63.22
3	0	2181.24	39.32	16.905	3.15	6.84	16.09	2.53	.0	.0	3002.0	31.14	4.31	73.64	36.96	63.04
3	0	2181.41	39.64	16.909	3.19	6.94	24.10	2.59	.0	.0	3000.3	32.50	4.35	95.51	37.32	62.68
3	0	2181.58	39.89	16.909	3.20	7.02	26.94	2.64	.0	.0	3053.4	33.40	4.38	100.00	37.60	62.40
3	0	2181.75	40.04	16.911	3.21	7.07	24.57	2.67	.0	.0	3053.4	33.89	4.40	93.36	37.78	62.22
3	0	2181.92	40.22	16.913	3.26	7.13	22.78	2.71	.0	.0	3051.7	34.22	4.42	87.39	37.98	62.02
3	0	2182.09	40.39	16.914	3.35	7.18	20.09	2.74	.0	.0	3087.6	34.44	4.44	79.19	38.16	61.84
3	0	2182.26	40.58	16.916	3.47	7.24	20.24	2.78	.0	.0	3097.9	34.39	4.46	79.91	38.37	61.6[illegible]
3	0	2182.43	40.72	16.919	3.49	7.29	19.05	2.81	.0	.0	3185.2	34.53	4.48	76.28	38.54	61.46
3	0	2182.60	40.92	16.920	3.48	7.36	20.69	2.85	.0	.0	3276.0	34.51	4.50	81.28	38.76	61.24
3	0	2182.77	41.06	16.922	3.46	7.40	18.92	2.88	.0	.0	3298.3	34.59	4.52	76.11	38.91	61.09
3	0	2182.94	41.25	16.924	3.48	7.46	19.96	2.92	.0	.0	3320.5	34.25	4.54	80.08	39.12	60.88
3	0	2183.11	41.39	16.927	3.57	7.51	18.97	2.95	.0	.0	3344.5	33.29	4.56	79.54	39.28	60.72
3	0	2183.28	41.53	16.928	3.62	7.56	17.51	2.98	.0	.0	3288.0	32.67	4.58	76.72	39.43	60.57
3	0	2183.45	41.65	16.930	3.67	7.60	16.38	3.01	.0	.0	3325.7	31.99	4.59	74.95	39.56	60.44
3	0	2183.62	41.77	16.932	3.68	7.64	14.89	3.03	.0	.0	3221.2	31.92	4.61	70.55	39.69	60.31
3	0	2183.79	41.93	16.934	3.67	7.69	16.31	3.07	.0	.0	3200.7	31.92	4.62	75.18	39.87	60.13
3	0	2183.96	42.16	16.936	3.70	7.77	21.27	3.12	.0	.0	3217.8	31.55	4.65	92.07	40.12	59.88

TABULATED OUTPUT
Part II Energy and Power Parameters

IDAC TAPE L843 TEST NO. 11 DAY 217 10:23:28 SITE NO.=4.0 IDAC SITE= 4

RUN	TIME SEC	VEL MPH	EBO WH	EBI WH	EMAI WH	EMAO WH	EMF WH	DSS RPM	TXM-IN RPM	DSTRQ FT-LB	PBO KW	PBI KW	PMAI KW	PMAO KW	PMF KW	MSPD RPM	GRATM
3	2175.8	32.98	5026.6	740.4	4703.8	848.0	89.4	2649.2	149.1	426.57	24.65	.00	24.02	.00	.0828	2667.2	1.01
3	2176.0	33.17	5028.0	740.4	4705.1	848.0	89.4	2681.8	149.1	426.57	24.14	.00	23.49	.00	.0866	2681.2	1.00
3	2176.1	33.38	5029.3	740.4	4706.4	848.0	89.4	2680.1	149.1	426.57	23.83	.00	23.20	.00	.0819	2699.7	1.01
3	2176.3	33.67	5030.6	740.4	4707.7	848.0	89.4	2719.4	149.1	426.57	23.95	.00	23.32	.00	.0812	2717.5	1.00
3	2176.5	33.85	5031.3	740.4	4708.3	848.0	89.4	2726.3	149.1	426.57	24.47	.00	23.84	.00	.0734	2736.9	1.00
3	2176.6	34.09	5032.7	740.4	4709.7	848.0	89.4	2734.9	149.1	426.57	24.87	.00	24.18	.00	.0744	2757.8	1.01
3	2176.8	34.32	5034.1	740.4	4711.0	848.0	89.4	2765.7	149.1	426.57	25.18	.00	24.49	.00	.0747	2775.6	1.00
3	2177.0	34.52	5034.8	740.4	4711.7	848.0	89.4	2776.0	149.1	426.57	25.22	.00	24.56	.00	.0703	2795.3	1.01
3	2177.2	34.74	5036.2	740.4	4713.1	848.0	89.5	2810.2	149.1	426.57	25.28	.00	24.62	.00	.0691	2812.5	1.00
3	2177.3	35.08	5037.6	740.4	4714.4	848.0	89.5	2810.2	149.1	426.57	25.18	.00	24.52	.00	.0694	2830.3	1.01
3	2177.5	35.24	5038.3	740.4	4715.1	848.0	89.5	2853.0	149.1	426.57	25.16	.00	24.51	.00	.0687	2847.2	1.00
3	2177.7	35.43	5039.7	740.4	4716.5	848.0	89.5	2847.9	149.1	426.57	24.99	.00	24.32	.00	.0666	2864.1	1.01
3	2177.8	35.61	5041.0	740.4	4717.8	848.0	89.5	2791.4	149.1	426.57	24.99	.00	24.34	.00	.0631	2881.2	1.03
3	2178.0	35.82	5042.4	740.4	4719.2	848.0	89.5	2842.7	149.1	426.57	25.12	.00	24.46	.00	.0603	2899.7	1.02
3	2178.2	36.04	5043.1	740.4	4719.9	848.0	89.5	2762.3	149.1	426.57	25.30	.00	24.62	.00	.0625	2916.2	1.06
3	2178.3	36.25	5044.6	740.4	4721.3	848.0	89.5	2777.7	149.1	426.57	25.54	.00	24.88	.00	.0597	2935.6	1.06
3	2178.5	36.60	5046.0	740.4	4722.6	848.0	89.5	2767.4	149.1	426.57	25.79	.00	25.11	.00	.0609	2952.5	1.07
3	2178.7	36.79	5046.7	740.4	4723.3	848.0	89.5	2806.8	149.1	426.57	25.71	.00	25.06	.00	.0566	2970.3	1.06
3	2178.9	36.96	5048.1	740.4	4724.7	848.0	89.5	2799.9	149.1	426.57	25.52	.00	24.87	.00	.0561	2985.3	1.07
3	2179.0	37.13	5049.5	740.4	4726.1	848.0	89.5	2851.3	149.1	426.57	25.44	.00	24.80	.00	.0578	3002.2	1.05
3	2179.2	37.30	5050.2	740.4	4726.8	848.0	89.5	2969.5	149.1	426.57	25.33	.00	24.69	.00	.0531	3016.6	1.02
3	2179.4	37.47	5051.7	740.4	4728.2	848.0	89.5	2996.9	149.1	426.57	25.41	.00	24.76	.00	.0553	3033.4	1.01
3	2179.5	37.68	5053.1	740.4	4729.5	848.0	89.5	3031.1	149.1	426.57	25.42	.00	24.75	.00	.0547	3050.0	1.01
3	2179.7	37.87	5054.5	740.4	4730.9	848.0	89.5	3058.5	149.1	426.57	25.29	.00	24.66	.00	.0541	3065.0	1.00
3	2179.9	38.13	5055.2	740.4	4731.6	848.0	89.5	3061.9	149.1	426.57	25.19	.00	24.56	.00	.0537	3080.9	1.01
3	2180.0	38.34	5056.6	740.4	4733.0	848.0	89.5	3087.6	149.1	426.57	25.10	.00	24.47	.00	.0513	3095.0	1.00
3	2180.2	38.50	5058.0	740.4	4734.3	848.0	89.5	3091.1	149.1	426.57	24.84	.00	24.19	.00	.0528	3110.0	1.01
3	2180.4	38.62	5058.6	740.4	4735.0	848.0	89.5	3115.0	149.1	426.57	24.38	.00	23.75	.00	.0509	3122.2	1.00
3	2180.6	38.76	5060.0	740.4	4736.3	848.0	89.5	3060.2	149.1	426.57	23.96	.00	23.32	.00	.0534	3135.0	1.02
3	2180.7	38.90	5061.3	740.4	4737.6	848.0	89.5	3020.9	149.1	426.57	23.54	.00	22.92	.00	.0534	3147.8	1.04
3	2180.9	39.03	5061.9	740.4	4738.2	848.0	89.5	2976.3	149.1	426.57	23.01	.00	22.42	.00	.0525	3158.4	1.06
3	2181.1	39.16	5063.2	740.4	4739.4	848.0	89.5	3000.3	149.1	426.57	22.72	.00	22.17	.00	.0481	3170.3	1.06
3	2181.2	39.32	5064.5	740.4	4740.7	848.0	89.5	3002.0	149.1	426.57	23.22	.00	22.62	.00	.0462	3185.6	1.06
3	2181.4	39.64	5065.8	740.4	4742.0	848.0	89.5	3000.3	149.1	426.57	24.24	.00	23.59	.00	.0475	3202.5	1.07
3	2181.6	39.89	5066.5	740.4	4742.6	848.0	89.5	3053.4	149.1	426.57	24.91	.00	24.27	.00	.0453	3219.7	1.05
3	2181.7	40.04	5067.9	740.4	4744.0	848.0	89.5	3053.4	149.1	426.57	25.27	.00	24.64	.00	.0444	3236.2	1.06
3	2181.9	40.22	5069.3	740.4	4745.4	848.0	89.5	3051.7	149.1	426.57	25.52	.00	24.91	.00	.0422	3252.2	1.07
3	2182.1	40.39	5070.0	740.4	4746.1	848.0	89.5	3087.6	149.1	426.57	25.68	.00	25.01	.00	.0434	3266.9	1.06
3	2182.3	40.58	5071.5	740.4	4747.5	848.0	89.5	3097.9	149.1	426.57	25.64	.00	24.99	.00	.0422	3280.9	1.06
3	2182.4	40.72	5072.9	740.4	4748.9	848.0	89.5	3185.2	149.1	426.57	25.75	.00	25.11	.01	.0422	3295.6	1.03
3	2182.6	40.92	5073.6	740.4	4749.5	848.0	89.5	3276.0	149.1	426.57	25.73	.00	25.07	.00	.0416	3309.4	1.01
3	2182.8	41.06	5075.0	740.4	4750.9	848.0	89.5	3298.3	149.1	426.57	25.79	.00	25.14	.00	.0412	3324.4	1.01
3	2182.9	41.25	5076.5	740.4	4752.3	848.0	89.5	3320.5	149.1	426.57	25.54	.00	24.92	.00	.0400	3336.9	1.00
3	2183.1	41.39	5077.9	740.4	4753.7	848.0	89.5	3344.5	149.1	426.57	24.82	.00	24.21	.00	.0428	3348.4	1.00
3	2183.3	41.53	5078.5	740.4	4754.4	848.0	89.5	3288.0	149.1	426.57	24.36	.00	23.77	.01	.0422	3360.0	1.02
3	2183.4	41.65	5079.9	740.4	4755.7	848.0	89.5	3325.7	149.1	426.57	23.86	.00	23.25	.00	.0403	3370.0	1.01
3	2183.6	41.77	5081.2	740.4	4756.9	848.0	89.5	3221.2	149.1	426.57	23.81	.00	23.17	.00	.0412	3382.2	1.05
3	2183.8	41.93	5081.8	740.4	4757.6	848.0	89.5	3200.7	149.1	426.57	23.81	.00	23.21	.00	.0409	3393.7	1.06
3	2184.0	42.16	5083.2	740.4	4758.9	848.0	89.5	3217.8	149.1	426.57	23.52	.00	22.94	.00	.0394	3404.7	1.06

TABULATED OUTPUT
Part III Voltages, Currents and Temperatures

IDAC TAPE L843 TEST NO. 11 DAY 217 10:23:28 SITE NO.=4.0 IDAC SITE= 4

RUN	TIME SEC	VEL MPH	BCHGV VOLT	BV VOLT	MAV VOLT	MFV VOLT	BCHGA AMP	BA AMP	MAA AMP	MFA AMP	TBAT1 DEGF	TBAT2 DEGF	TBAT3 DEGF	TBAT4 DEGF	TBAT5 DEGF	TCONT DEGF	TEM1 DEGF	TEM2 DEGF	TEM3 DEGF	ABV VOLT
3	2175.8	32.98	97.2	96.0	95.9	19.9	.1	257.9	250.9	4.17	77.4	77.1	78.1	78.8	74.5	69.2	99.5	113.1	149.1	426.57
3	2176.0	33.17	97.6	96.4	96.4	20.1	.1	250.6	244.1	4.15	77.4	77.2	78.2	78.7	74.7	69.2	99.8	112.9	149.1	426.57
3	2176.1	33.38	97.7	96.7	96.6	19.5	.1	246.6	240.6	4.11	77.4	77.3	78.1	78.7	74.6	69.1	99.6	112.6	149.1	426.57
3	2176.3	33.67	97.8	96.8	96.7	18.9	.1	246.0	240.7	4.05	77.5	77.2	78.2	78.7	74.7	69.2	99.6	113.8	149.1	426.57
3	2176.5	33.85	97.5	96.6	96.5	18.2	.1	252.5	247.9	3.97	77.3	77.1	78.3	78.6	74.5	69.1	99.6	113.4	149.1	426.57
3	2176.6	34.09	97.3	96.3	96.1	18.9	.1	258.7	253.6	3.88	77.2	77.2	78.1	78.8	74.6	69.2	99.6	113.5	149.1	426.57
3	2176.8	34.32	97.1	96.1	95.9	18.7	.1	261.8	256.7	3.85	77.5	77.2	78.2	78.8	74.5	69.2	99.6	113.0	149.1	426.57
3	2177.0	34.52	97.0	96.0	95.8	18.2	.1	262.8	257.5	3.80	77.4	77.1	78.2	78.8	74.6	69.1	99.7	113.1	149.1	426.57
3	2177.2	34.74	97.0	96.0	95.8	18.3	.1	263.8	258.4	3.76	77.4	77.3	78.1	78.8	74.7	69.1	99.7	112.9	149.1	426.57
3	2177.3	35.08	97.0	95.9	95.7	18.3	.1	263.9	258.1	3.75	77.3	77.3	78.1	78.7	74.6	69.2	99.7	113.8	149.1	426.57
3	2177.5	35.24	97.1	96.0	95.9	17.4	.1	261.2	255.5	3.70	77.3	77.2	78.2	78.7	74.6	69.1	99.7	113.7	149.1	426.57
3	2177.7	35.43	97.1	96.0	95.9	17.8	.1	260.9	255.1	3.68	77.4	77.3	78.2	78.7	74.6	69.2	99.6	113.4	149.1	426.57
3	2177.8	35.61	97.2	96.1	95.9	17.3	.1	259.8	254.2	3.65	77.2	77.2	78.2	78.8	74.6	69.1	99.5	113.2	149.1	426.57
3	2178.0	35.82	97.1	96.0	95.9	16.8	.1	261.0	255.8	3.60	77.4	77.2	78.1	78.8	74.5	69.1	99.5	113.1	149.1	426.57
3	2178.2	36.04	97.0	96.0	95.8	17.5	.1	264.0	258.8	3.55	77.5	77.2	78.1	78.7	74.7	69.1	99.8	113.0	149.1	426.57
3	2178.3	36.25	96.8	95.8	95.6	17.0	.1	267.1	262.1	3.50	77.3	77.2	78.1	78.7	74.7	69.1	99.7	112.8	149.1	426.57
3	2178.5	36.60	96.7	95.7	95.5	17.1	.1	269.2	264.0	3.46	77.4	77.2	78.1	76.7	74.6	69.2	99.7	113.8	149.1	426.57
3	2178.7	36.79	96.7	95.7	95.4	16.6	.1	269.2	263.8	3.45	77.3	77.3	78.3	78.6	74.6	69.2	99.7	113.9	149.1	426.57
3	2178.9	36.96	96.7	95.6	95.5	16.6	.1	267.3	261.2	3.42	77.3	77.3	78.3	78.7	74.6	69.1	99.5	113.5	149.1	426.57
3	2179.0	37.13	96.8	95.6	95.6	16.3	.1	265.7	260.1	3.40	77.3	77.1	78.1	76.7	74.5	69.1	99.6	113.4	149.1	426.57
3	2179.2	37.30	96.9	95.6	95.6	16.4	.1	265.2	259.7	3.37	77.4	77.1	78.2	78.9	74.6	69.1	99.6	113.4	149.1	426.57
3	2179.4	37.47	96.9	95.9	95.7	16.2	.1	265.0	259.7	3.34	77.6	77.2	78.2	78.8	74.7	69.1	99.6	113.2	149.1	426.57
3	2179.5	37.68	96.9	95.8	95.6	16.2	.1	265.2	259.8	3.31	77.4	77.2	78.2	78.8	74.7	69.1	99.9	113.1	149.1	426.57
3	2179.7	37.87	96.9	95.8	95.6	16.2	.1	264.8	259.2	3.28	77.3	77.3	76.1	78.7	74.7	69.0	99.8	112.9	149.1	426.57
3	2179.9	38.13	97.0	95.9	95.7	15.8	.1	262.4	256.9	3.26	77.3	77.3	78.2	78.7	74.6	69.1	99.7	113.1	149.1	426.57
3	2180.0	38.34	97.0	95.9	95.7	15.8	.1	262.1	256.5	3.23	77.3	77.2	78.2	78.7	74.6	69.2	99.6	114.0	149.1	426.57
3	2180.2	38.50	97.1	96.0	95.9	15.9	.1	259.2	253.2	3.22	77.3	77.3	78.3	78.7	74.6	69.1	99.7	113.9	149.1	426.57
3	2180.4	38.62	97.3	96.2	96.1	15.9	.1	254.5	248.3	3.22	77.3	77.2	78.2	78.7	74.6	69.1	99.6	113.5	149.1	426.57
3	2180.6	38.76	97.6	96.5	96.4	16.0	.1	248.6	242.6	3.20	77.4	77.2	78.2	78.8	74.6	69.0	99.7	113.3	149.1	426.57
3	2180.7	38.90	97.8	96.7	96.7	15.8	.1	243.4	237.7	3.21	77.4	77.3	76.1	78.7	74.6	69.2	99.6	113.1	149.1	426.57
3	2180.9	39.03	98.0	96.8	96.9	15.8	.1	238.3	232.1	3.21	77.4	77.2	78.1	78.7	74.6	69.1	99.7	113.2	149.1	426.57
3	2161.1	39.16	98.3	97.2	97.2	14.7	.1	233.1	227.4	3.21	77.4	77.3	78.1	78.7	74.8	69.2	99.8	113.0	149.1	426.57
3	2181.2	39.32	98.1	97.2	97.1	14.8	.1	237.8	233.5	3.15	77.4	77.3	78.2	78.8	74.7	69.2	99.7	113.1	149.1	426.57
3	2181.4	39.64	97.6	96.7	96.5	14.8	.1	249.6	246.0	3.05	77.4	77.2	78.1	78.7	74.6	69.1	99.6	113.6	149.1	426.57
3	2161.6	39.89	97.1	96.2	96.0	14.6	.1	258.5	254.0	3.03	77.5	77.2	78.2	78.7	74.7	69.3	99.7	114.1	149.1	426.57
3	2181.7	40.04	96.9	95.9	95.8	14.5	.1	263.3	258.6	3.00	77.3	77.3	78.3	78.7	74.7	69.1	99.6	113.9	149.1	426.57
3	2181.9	40.22	96.8	95.8	95.7	13.9	.1	265.1	260.1	2.99	77.3	77.2	78.2	78.7	74.7	69.2	99.7	113.5	149.1	426.57
3	2182.1	40.39	96.7	95.6	95.4	14.8	.1	268.9	263.7	2.95	77.3	77.3	78.3	78.7	74.6	69.2	99.7	113.9	149.1	426.57
3	2182.3	40.58	96.7	95.6	95.4	14.5	.1	268.8	263.4	2.93	77.3	77.1	78.2	78.7	74.6	69.0	99.5	113.6	149.1	426.57
3	2162.4	40.72	96.7	95.6	95.4	14.4	.1	269.5	264.3	2.91	77.3	77.2	78.2	78.9	74.6	69.1	99.6	113.6	149.1	426.57
3	2182.6	40.92	96.7	95.6	95.4	14.5	.1	269.5	264.3	2.88	77.5	77.2	78.2	78.9	74.6	69.1	99.6	113.4	149.1	426.57
3	2162.8	41.06	96.7	95.6	95.4	14.0	.1	269.0	263.9	2.87	77.6	77.2	78.2	78.7	74.6	69.2	99.6	113.5	149.1	426.57
3	2182.9	41.25	96.6	95.5	95.3	14.1	.1	268.4	262.7	2.87	77.5	77.3	78.2	78.7	74.6	69.2	99.7	113.2	149.1	426.57
3	2183.1	41.39	97.0	95.7	95.6	14.3	.1	260.5	254.0	2.89	77.4	77.2	78.1	78.7	74.5	69.1	99.9	113.3	149.1	426.57
3	2183.3	41.53	97.3	96.2	96.2	14.1	.1	252.5	246.5	2.87	77.4	77.3	78.2	78.7	74.7	69.1	99.8	113.3	149.1	426.57
3	2183.4	41.65	97.6	96.5	96.4	14.2	.1	247.7	242.0	2.88	77.4	77.4	78.1	78.8	74.7	69.1	99.7	113.1	149.1	426.57
3	2183.6	41.77	97.7	96.7	96.6	14.2	.1	246.3	241.2	2.85	77.4	77.3	76.1	78.8	74.8	69.2	99.8	113.1	149.1	426.57
3	2183.8	41.93	97.6	96.6	96.5	14.0	.1	246.2	241.1	2.84	77.5	77.4	78.1	76.8	74.7	69.1	99.6	113.1	149.1	426.57
3	2184.0	42.16	97.7	96.6	96.5	13.9	.1	244.4	238.7	2.85	77.4	77.2	78.1	78.7	74.7	69.1	99.7	113.5	149.1	426.57

APPENDIX E

ETV-1 AD-HOC BATTERY WORKING GROUP

The purpose of the ETV-1 Ad-Hoc Battery Working Group was to investigate the causes for the differences in ETV-1 range reported by General Electric before delivery and that observed during the Phase III testing at JPL. The group was made up of representatives from JPL, Johnson Controls (Globe Battery Division), General Electric (Corporate Research and Development), NASA's Lewis Research Center, and the Argonne National Laboratory.

The first meeting convened at JPL on January 20, 1981. The approach adopted for these investigations was to review the details of the GE/Chrysler and JPL test procedures and results, identify the sources of variance, and then focus attention on the performance of the two series of battery modules involved (Globe EV2-13's and EV1000 prototypes).

These discussions resulted in the need for some special tests and detailed analysis. Representative battery modules from the two series were located and baselined (at Globe and JPL) and subjected to very carefully determined ETV-1 power profiles under laboratory conditions.[1] Of particular interest (and first-order significance) was the battery electrolyte temperature under which the Chelsea (Chrysler Proving Grounds) test had been run. Since there had been no significant on-board instrumentation, this vital information had to be estimated by inference. The Chelsea charge profile had been documented but was open to some question. Nevertheless, several duplicate charge profiles were performed on a similar EV2-13 battery pack at JPL (over two years old) in the hope that it might produce the same temperature/charge characteristic. Unfortunately, significant antimony transfer over the years allowed a thermal run-away condition during this duplicate non-compensated charge and little useful information could be extracted.

The Lewis Research Center also performed several ETV-1 profiles on their Road Load Simulator in order to quantify the difference in net cycle energy between the Chelsea track and JPL dyno test profiles.

The second and final group meeting was held at the Argonne National Laboratory on June 9, 1981. The purpose of this gathering was to review the results of the various test activities assigned at the previous meeting, and to arrive at an understanding regarding the vehicle and battery subsystem operation during the two vehicle test series. The group consensus, as listed in the text, provides a reasonable explanation for the range differences and points out that reporting EV range has questional value because of the many arbitrary operational parameters which have first order effects on the results.

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[1]Power profiles were developed from JPL-generated dyno data and were programmed into the battery cycler at Argonne's National Battery Test Laboratory.

APPENDIX F

DYNAMOMETER AND TRACK TEST SUMMARIES

The following tabular summary presents the individual results from all the dynamometer and track testing performed in support of the final ETV-1 testing phase at JPL. As indicated in the text, three different battery packs were installed in the vehicle during the course of this testing. The Globe EV2-13 battery was developed under the ETV-1 contract and was delivered with the vehicle in 1979. The EV1000A battery was a pre-production prototype of the commercial EV2-13. The EV1000B was the first EV2-13 built by the Globe production division with the commercial name EV1000. The EV1000A was installed during the bulk of the dynamometer testing. The EV1000B was installed for the track testing but was characterized on the dynamometer prior to leaving for the track.

Controller efficiency was here defined to be simply the sum of the armature input and field energies divided by the battery output energy. Battery recharge efficiencies are the battery output energy or amperage divided by the respective recharge values.

E T V - 1 T E S T D A T A S U M M A R Y

TEST NUMBERS	1	2	3	4	5	6	7	8
TEST DATE	05/09/80	05/12/80	05/19/80	05/21/80	07/17/80	07/21/80	07/24/80	07/28/80
TEST TYPE	55MPH	D	45MPH	35MPH	55MPH	D	45MPH	FTP
BATTERY TYPE	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	EV2-13	EV2-13	EV2-13	EV2-13	EV-1000A	EV-1000A	EV-1000A	EV-1000A
BATTERY ENERGY ECONOMY (MI/KWH)	4.66	3.33	5.38	5.87	4.72	3.37	5.45	3.16
RANGE (MILES)	59.52	*32.62	78.20	*62.65	56.72	43.40	75.59	*44.05
ELAPSED TIME (MINUTES)	67.9	67.7	105.9	112.4	64.3	89.9	103.3	187.4
BATTERY DISCHARGE ENERGY (KWH)	12.78	*9.80	14.542	*10.67	12.02	12.89	13.86	*13.92
BATTERY REGEN. ENERGY (KWH)	0.0718	1.59	0.0	0.0	0.078	1.789	0.059	1.591
BATTERY REGEN. ENERGY (%)	0.56	16.2	0.0	0.0	0.65	13.88	0.43	11.43
BATTERY DISCHARGE (AMP - HOURS)	126.3	*97.99	141.9	*101.42	120.9	135.0	N.A.	N.A.
BATTERY REGEN. (AMP - HOURS)	0.583	12.77	0.009	0.0	0.655	15.04	N.A.	N.A.
BATTERY REGEN. AMPERAGE (%)	0.46	13.0	0.0	0.0	0.54	11.14	N.A.	N.A.
ARMATURE INPUT ENERGY (KWH)	12.31	9.26	13.68	9.6	11.84	12.36	13.39	12.57
ARMATURE REGEN. OUTPUT (KWH)	0.0	1.813	0.0	0.0	0.087	2.076	0.066	2.204
ARMATURE REGEN. OUTPUT (%)	0.0	19.6	0.0	0.0	0.74	16.79	0.49	17.53
FIELD ENERGY (KWH)	0.0372	0.176	0.0736	0.171	0.0327	0.2428	0.0643	1.036
CONTROLLER EFFICIENCY (%)	96.64	96.25	94.56	91.6	98.82	97.80	97.02	97.76

ORIGINAL PAGE IS OF POOR QUALITY

ODOMETER READING (MILES)	315.0	373.0	405.0	481.0	742.0	827.0	873.0	946.0
BATTERY RECHARGE ENERGY EFFICIENCY(%)	65.05	66.87	69.10	N.A.	67.07	70.71	63.70	N.A.
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	79.62	83.47	63.03	N.A.	84.20	92.41	74.62	N.A.
BATTERY TEMP. BEFORE (DEG F)	73.4	70.2	74.4	71.6	75.4	71.6	73.4	72.4
BATTERY TEMP. AFTER (DEG F)	84.4	82.6	82.6	75.8	85.2	91.2	81.8	90.0

* COMMENTS

TEST NO. 1: VEHICLE TEST WITH 13 RECEIVED BATTERIES PLUS 5 JPL SPARES

TEST NO. 2: INVALID RANGE TEST - WRONG TERMINATION CRITERIA USED

TEST NO. 4: INVALID RANGE TEST - TEST TERMINATED EARLY (O.D. CUT-OUT)

TEST NO. 5: FIRST TEST WITH ALL NEW BATTERIES

TEST NO. 6: INVALID RANGE TEST - TEST TERMINATED EARLY BECAUSE OF HIGH PCU TEMPS

E T V - 1 T E S T D A T A S U M M A R Y

TEST NUMBERS	9	10	11	12	13	14	15	16
TEST DATE	07/30/80	08/01/80	08/04/80	08/07/80	08/12/80	08/22/80	08/25/80	09/02/80
TEST TYPE	FTP	VAR	C	45MPH	45MPH	D	45MPH	45MPH
BATTERY TYPE	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	EV-1000A	EV-1000A	EV-1000A	EV-1000A	EV-1000A	EV-1000A	EV-1000A	EV-1000A
BATTERY ENERGY ECONOMY (MI/KWH)	3.07	5.15	3.41	5.62	5.53	3.39	5.56	5.36
RANGE (MILES)	*45.31	*52.25	*43.42	76.99	86.1	45.53	75.67	71.78
ELAPSED TIME (MINUTES)	201.0	82.3	94.2	104.4	116.1	94.5	102.4	97.5
BATTERY DISCHARGE ENERGY (KWH)	*14.76	*10.14	*12.71	13.69	15.55	13.40	13.61	13.39
BATTERY REGEN. ENERGY (KWH)	1.763	0.0623	1.874	0.0565	0.0574	2.013	0.0539	0.051
BATTERY REGEN. ENERGY (%)	11.95	0.61	14.74	0.41	0.36	15.02	0.39	0.38
BATTERY DISCHARGE (AMP - HOURS)	*153.5	*99.43	*133.2	136.6	150.4	140.2	132.8	131.0
BATTERY REGEN. (AMP - HOURS)	13.35	0.525	15.45	0.476	0.489	16.97	0.468	0.427
BATTERY REGEN. AMPERAGE (%)	8.70	0.52	11.60	0.34	0.32	12.10	0.35	0.32
ARMATURE INPUT ENERGY (KWH)	13.16	9.089	11.91	12.83	14.66	12.75	12.76	12.56
ARMATURE REGEN. OUTPUT (KWH)	2.129	0.074	2.143	0.0634	0.0647	2.318	0.061	0.0578
ARMATURE REGEN. OUTPUT (%)	16.15	0.81	17.99	0.49	0.44	18.18	0.47	0.46
FIELD ENERGY (KWH)	1.042	0.4317	0.2313	0.0617	0.0611	0.2439	0.544	0.0579
CONTROLLER EFFICIENCY (%)	96.30	93.92	95.54	94.17	94.65	96.93	94.19	94.25

ODOMETER READING (MILES)	990.0	1034.0	1085.0	1131.0	1206.0	1329.0	1374.0	1870.0
BATTERY RECHARGE ENERGY EFFICIENCY(%)	61.83	N.A.	66.83	62.66	64.50	70.94	62.28	N.A.
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	81.51	N.A.	88.66	79.10	78.07	91.85	76.19	N.A.
BATTERY TEMP. BEFORE (DEG F)	75.0	74.8	72.0	71.2	74.0	74.6	71.6	71.4
BATTERY TEMP. AFTER (DEG F)	93.4	81.0	89.4	79.8	82.6	91.6	79.0	77.8

* COMMENTS

TEST NO. 9: 10 MIN. SOAK EVERY 7.5 MILES

TEST NO. 10: NOT A RANGE TEST - ENGINEERING DATA ONLY

TEST NO. 11: 3 MIN, 42 SEC DELAY BETWEEN CYCLES 26 & 27

TEST NO. 13: FIRST TEST AFTER BATTERY FLATTENING

E T V - 1   T E S T   D A T A   S U M M A R Y

TEST NUMBERS	17	19	20	21	22	23	24	25
TEST DATE	09/03/80	10/06/80	10/09/80	10/15/80	10/16/80	10/20/80	10/22/80	10/22/80
TEST TYPE	D	45MPH	25MPH	35MPH	35MPH	45MPH	35MPH	25MPH
BATTERY TYPE	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	EV-1000A	EV-1000A	EV-1000A	EV-1000A	EV-1000A	EV-1000A	EV-1000A	EV-1000A
BATTERY ENERGY ECONOMY (MI/KWH)	3.42	5.33	4.93	5.91	5.98	5.46	6.06	5.04
RANGE (MILES)	*58.58	78.96	*58.33	*93.35	96.9	72.7	97.5	*22.8
ELAPSED TIME (MINUTES)	122.5	107.1	113.0	161.7	167.9	98.5	168.5	56.8
BATTERY DISCHARGE ENERGY (KWH)	*17.08	14.79	*11.82	*15.79	16.20	13.31	16.09	*4.53
BATTERY REGEN. ENERGY (KWH)	3.157	0.038	0.0	0.024	0.03	0.04	0.02	0.01
BATTERY REGEN. ENERGY (%)	18.47	0.25	0.0	0.15	0.18	0.30	0.14	0.22
BATTERY DISCHARGE (AMP - HOURS)	*173.9	142.8	*110.3	*151.8	156.8	129.8	156.7	*42.5
BATTERY REGEN. (AMP - HOURS)	26.66	0.326	0.0	0.212	0.3	0.4	0.2	0.1
BATTERY REGEN. AMPERAGE (%)	15.32	0.22	0.0	0.13	0.2	0.3	0.1	0.2
ARMATURE INPUT ENERGY (KWH)	16.15	13.91	8.305	14.36	14.85	12.67	14.85	3.37
ARMATURE REGEN. OUTPUT (KWH)	3.627	0.0444	0.0	0.033	0.04	0.05	0.02	0.02
ARMATURE REGEN. OUTPUT (%)	22.46	0.31	0.0	0.22	0.2	0.4	0.2	0.6
FIELD ENERGY (KWH)	0.346	0.0729	1.899	0.2307	0.233	0.057	0.234	0.605
CONTROLLER EFFICIENCY (%)	96.53	94.51	86.30	92.41	93.1	95.6	93.7	87.78

ODOMETER READING (MILES)	1908.0	2081.0	2150.0	2215.0	2307.0	2401.0	2472.0	2567.0
BATTERY RECHARGE ENERGY EFFICIENCY(%)	N.A.	57.08	N.A.	57.51	56.18	61.41	69.31	N.A.
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	N.A.	71.20	N.A.	71.43	71.4	76.9	85.0	N.A.
BATTERY TEMP. BEFORE (DEG F)	105.2	71.2	72.2	69.2	69.4	70.6	74.2	69.5
BATTERY TEMP. AFTER (DEG F)	120.0	81.0	77.2	77.8	76.4	80.2	82.6	71.4

* COMMENTS

TEST NO. 17: SIMULATION OF CHRYSLER D CYCLE TEST - GE PROFILE, BATTERY TEMP = 108 DEG F., CAR=3625 LBS.

TEST NO. 19: FIRST TEST AFTER SEVERAL BATTERY CONDITIONING CYCLES

TEST NO. 20: INVALID RANGE TEST - TEST TERMINATED EARLY (Q.D. CUT-OUT)

TEST NO. 21: INVALID RANGE TEST - TERMINATED EARLY BECAUSE OF LOW INDIVIDUAL BATTERY VOLTAGE

TEST NO. 25: INVALID RANGE TEST - TEST ABORTED DUE TO EXCESSIVE MOTOR TEMP. CAUSED BY CONTINUOUS ARMATURE CHOPPING

ETV-1 TEST DATA SUMMARY

TEST NUMBERS	30	31	70	71	72	73	74	75
TEST DATE	11/12/80	11/14/80	05/11/81	05/11/81	05/13/81	05/15/81	05/18/81	05/20/81
TEST TYPE	D	55MPH	45MPH	45MPH	45MPH	D	55MPH	45MPH
BATTERY TYPE	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	EV-1000A	EV-1000A	EV-1000B	EV-1000B	EV-1000B	EV-1000B	EV-1000B	EV-1000B
BATTERY ENERGY ECONOMY (MI/KWH)	3.30	4.50	5.38	5.38	5.35	3.35	4.62	5.32
RANGE (MILES)	*27.67	36.85	84.8	84.1	82.8	46.4	55.8	79.2
ELAPSED TIME (MINUTES)	58.3	41.4	114.6	113.4	112.0	96.0	62.1	107.7
BATTERY DISCHARGE ENERGY (KWH)	*8.37	8.181	15.75	15.61	15.48	13.85	12.08	14.87
BATTERY REGEN. ENERGY (KWH)	1.104	0.062	0.05	0.05	0.52	1.93	0.08	0.06
BATTERY REGEN. ENERGY (%)	13.18	0.75	0.31	0.32	3.35	13.9	0.7	0.4
BATTERY DISCHARGE (AMP - HOURS)	*86.25	80.71	154.0	152.9	151.0	140.1	119.1	145.3
BATTERY REGEN. (AMP - HOURS)	9.111	0.508	0.4	0.4	0.5	16.0	0.7	0.5
BATTERY REGEN. AMPERAGE (%)	10.56	0.62	0.3	0.3	0.3	11.4	0.6	0.3
ARMATURE INPUT ENERGY (KWH)	7.928	7.865	14.81	14.65	14.46	12.94	11.59	13.88
ARMATURE REGEN. OUTPUT (KWH)	1.285	0.0703	0.06	0.06	0.06	2.25	0.09	0.07
ARMATURE REGEN. OUTPUT (%)	16.20	0.89	0.4	0.4	0.4	17.4	0.8	0.5
FIELD ENERGY (KWH)	0.1432	0.0184	0.069	0.069	0.071	0.243	0.022	0.006
CONTROLLER EFFICIENCY (%)	96.41	96.36	94.46	94.29	93.86	95.2	96.1	93.3

ODOMETER READING (MILES)	3029.0	3056.0	5760.0	5842.0	5924.0	6015.0	6064.0	6174.0
BATTERY RECHARGE ENERGY EFFICIENCY(%)	31.48	57.06	56.44	68.40	69.19	72.36	64.44	70.12
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	44.91	73.77	71.1	84.2	84.8	92.5	81.1	85.7
BATTERY TEMP. BEFORE (DEG F)	68.8	71.4	72.8	72.8	75.2	74.4	70.8	74.4
BATTERY TEMP. AFTER (DEG F)	79.8	76.8	81.2	81.2	83.4	89.6	80.4	82.4

* COMMENTS

TEST NO. 30: BATTERY WAS DAMAGED BY CHARGING WITHOUT TEMPERATURE COMPENSATION

TEST NO. 70: FIRST TEST WITH NEW BATTERIES, PRETEST AH OVERCHARGE = 40%

TEST NO. 71: PRETEST AH OVERCHARGE = 40%

TEST NO. 72: PRETEST OVERCHARGE BACK TO NOMINAL 20%

E T V - 1 T E S T D A T A S U M M A R Y

TEST NUMBERS	76	77	78	79	80	81	82	83
TEST DATE	06/07/81	07/10/81	06/11/81	06/12/81	06/13/81	06/15/81	06/16/81	06/17/81
TEST TYPE	45MPH	D	35MPH	D	D	FTP	45MPH	45MPH
BATTERY TYPE	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	EV-1000B	EV-1000B	EV-1000B	EV-1000B	EV-1000B	EV-1000B	EV-1000B	EV-1000B
BATTERY ENERGY ECONOMY (MI/KWH)	5.05	3.22	5.92	3.52	3.30	2.87	5.31	5.24
RANGE (MILES)	74.25	39.76	102.75	48.36	44.45	15.41	76.00	73.18
ELAPSED TIME (MINUTES)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
BATTERY DISCHARGE ENERGY (KWH)	14.700	12.350	17.350	14.510	13.460	5.360	14.320	13.960
BATTERY REGEN. ENERGY (KWH)	0.0500	1.6700	0.0300	2.0300	1.8300	0.8500	0.0600	0.0500
BATTERY REGEN. ENERGY (%)	0.34	13.5	0.17	13.9	13.6	15.85	0.42	0.36
BATTERY DISCHARGE (AMP - HOURS)	0.00	125.25	166.35	147.55	136.80	51.80	138.55	135.15
BATTERY REGEN. (AMP - HOURS)	0.000	14.1	0.300	17.1	15.3	1.200	0.500	0.500
BATTERY REGEN. AMPERAGE (%)	0.00	11.3	0.18	11.58	11.18	2.32	0.36	0.37
ARMATURE INPUT ENERGY (KWH)	13.840	11.580	15.760	13.640	12.580	4.620	13.460	13.180
ARMATURE REGEN. OUTPUT (KWH)	0.0600	1.9400	0.0400	2.3500	2.1300	1.1100	0.0600	0.0600
ARMATURE REGEN. OUTPUT (%)	0.43	16.75	0.25	17.22	16.93	24.02	0.45	0.46
FIELD ENERGY (KWH)	0.0590	0.2075	0.2200	0.2520	0.2280	0.3180	0.0570	0.5600
CONTROLLER EFFICIENCY (%)	94.55	95.44	92.22	95.74	95.16	92.13	94.39	98.42

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ODOMETER READING (MILES)	6311.0	6392.0	6437.0	6540.0	6592.0	6637.0	6659.0	6741.0
BATTERY RECHARGE ENERGY EFFICIENCY(%)	52.60	58.46	65.77	65.72	60.03	N.A.	62.34	61.47
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	N.A.	76.59	78.18	83.75	82.90	N.A.	76.06	75.49
BATTERY TEMP. BEFORE (DEG F)	74.0	71.2	74.8	74.6	73.6	73.6	72.2	69.6
BATTERY TEMP. AFTER (DEG F)	78.8	86.4	83.0	90.0	90.8	84.0	85.2	84.6

* COMMENTS

TEST NO. 76: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB

TEST NO. 77: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030LBS

TEST NO. 78: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB. PRETEST CHARGE TO NOMINAL 40% AH OVERCHARGE (IE 2HR + 10HR)

TEST NO. 79: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB. PRETEST CHARGE TO NOMINAL 30% AH OVERCHARGE (IE 2HR + 8HR)

TEST NO. 80: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB

TEST NO. 81: INVALID RANGE TEST - OD OPENED, TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB

TEST NO. 82: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB

TEST NO. 83: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB

E T V - 1   T E S T   D A T A   S U M M A R Y

TEST NUMBERS	84	85	86	87	88	89	90	91
TEST DATE	06/18/81	06/19/81	06/20/81	06/21/81	06/25/81	07/08/81	07/10/81	07/13/81
TEST TYPE	55MPH	35MPH	55MPH	55MPH	FTP	FTP	FTP	45MPH
BATTERY TYPE	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	EV-1000B	EV-1000B	EV-1000B	EV-1000B	EV-1000B	EV-1000B	EV-1000B	EV-1000B
BATTERY ENERGY ECONOMY (MI/KWH)	4.51	5.96	6.44	4.52	2.95	N.A.	2.96	5.68
RANGE (MILES)	51.54	98.84	53.46	51.97	44.23	41.18	38.80	95.35
ELAPSED TIME (MINUTES)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
BATTERY DISCHARGE ENERGY (KWH)	11.420	16.580	12.060	11.500	14.970	N.A.	13.090	16.790
BATTERY REGEN. ENERGY (KWH)	0.0800	0.0200	1.0900	0.0800	2.4300	N.A.	2.0600	0.0600
BATTERY REGEN. ENERGY (%)	0.70	0.12	0.90	0.70	16.23	0.00	15.7	0.36
BATTERY DISCHARGE (AMP - HOURS)	111.70	160.55	117.90	111.70	158.20	N.A.	136.70	162.25
BATTERY REGEN. (AMP - HOURS)	0.750	0.200	0.800	0.700	20.100	N.A.	17.100	0.500
BATTERY REGEN. AMPERAGE (%)	0.67	0.12	0.68	0.63	12.70	0.00	12.5	0.31
ARMATURE INPUT ENERGY (KWH)	10.940	14.930	11.600	10.940	13.040	11.920	11.520	15.800
ARMATURE REGEN. OUTPUT (KWH)	0.1000	0.0300	0.1000	0.0900	3.0700	2.7600	2.5800	0.0700
ARMATURE REGEN. OUTPUT (%)	0.91	0.20	0.86	0.82	23.54	23.15	22.39	0.44
FIELD ENERGY (KWH)	0.0230	0.2155	0.0230	0.0180	0.9320	0.8985	0.7900	0.0690
CONTROLLER EFFICIENCY (%)	96.00	93.34	9.68	95.29	93.33	N.A.	94.04	94.51

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ODOMETER READING (MILES)	6815.0	6866.0	6970.0	7029.0	7105.0	7188.0	7232.0	7279.0
BATTERY RECHARGE ENERGY EFFICIENCY(%)	57.36	66.04	58.70	58.15	66.89	N.A.	63.39	60.53
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	71.88	78.43	73.11	72.17	86.59	N.A.	79.66	N.A.
BATTERY TEMP. BEFORE (DEG F)	68.6	71.8	74.4	72.6	75.4	76.0	74.6	87.4
BATTERY TEMP. AFTER (DEG F)	76.2	75.4	85.0	82.8	92.2	90.8	91.2	95.4

* COMMENTS

TEST NO. 84: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB

TEST NO. 85: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB

TEST NO. 86: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB

TEST NO. 87: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB

TEST NO. 88: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB - HIGH WINDS, CONTROLLER ERRATIC

TEST NO. 89: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB

TEST NO. 90: TRACK TEST AT TRC - VEHICLE WEIGHT = 4030 LB

TEST NO. 91: TRACK TEST, DIAGNOSTIC TEST ONLY ,PREPARATION FOR GE LOOK ALIKE D, VEHICLE WEIGHT = 3780 LBS

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ETV-1 TEST DATA SUMMARY

TEST NUMBERS	92	93	94	95	96
TEST DATE	07/14/81	07/15/81	07/16/81	07/18/81	09/09/81
TEST TYPE	GE-D	45MPH	GE-D	D	45MPH
BATTERY TYPE	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	EV-1000B	EV-1000B	EV-1000B	EV-1000B	ISOA-2
BATTERY ENERGY ECONOMY (MI/KWH)	3.49	5.76	3.47	3.56	5.61
RANGE (MILES)	73.77	95.64	69.43	49.35	109.71
ELAPSED TIME (MINUTES)	N.A.	N.A.	N.A.	N.A.	149.7
BATTERY DISCHARGE ENERGY (KWH)	21.140	16.590	19.980	13.860	19.540
BATTERY REGEN. ENERGY (KWH)	3.9200	0.0600	3.6200	1.9900	0.0583
BATTERY REGEN. ENERGY (%)	18.5	0.36	18.11	14.35	0.30
BATTERY DISCHARGE (AMP - HOURS)	209.80	158.60	197.65	145.90	213.47
BATTERY REGEN. (AMP - HOURS)	32.450	0.500	29.95	16.60	0.559
BATTERY REGEN. AMPERAGE (%)	15.46	0.32	15.15	11.37	0.26
ARMATURE INPUT ENERGY (KWH)	19.780	15.550	18.680	12.920	18.582
ARMATURE REGEN. OUTPUT (KWH)	4.4300	0.0600	4.1000	2.2900	0.0655
ARMATURE REGEN. OUTPUT (%)	22.39	0.39	21.94	17.72	0.35
FIELD ENERGY (KWH)	0.4050	0.0745	0.3750	0.2510	0.0812
CONTROLLER EFFICIENCY (%)	95.46	94.18	95.37	95.03	95.51

ODOMETER READING (MILES)	7375.0	7449.0	7545.0	7620.0	7901.0
BATTERY RECHARGE ENERGY EFFICIENCY(%)	77.81	56.85	77.69	67.03	53.15
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	95.68	68.71	95.12	87.94	41.14
BATTERY TEMP. BEFORE (DEG F)	135.0	81.4	131.2	73.2	75.0
BATTERY TEMP. AFTER (DEG F)	128.0	79.6	134.4	85.6	84.8

* COMMENTS

TEST NO. 92: TRACK TEST, GE LOOK ALIKE ,PRETEST CHARGE MODIFIED TO HEAT BATTERY TO 135 DEGREES, WEIGHT = 3780 LB

TEST NO. 93: TRACK TEST, DIAGNOSTIC TEST ONLY ,PREPARATION FOR GE LOOK ALIKE D, VEHICLE WEIGHT = 3780 LB.

TEST NO. 94: TRACK TEST, GE LOOK ALIKE ,PRETEST CHARGE MODIFIED TO HEAT BATTERY TO 135 DEGREES, WEIGHT = 3780 LB.

TEST NO. 95: TRACK TEST, JPL D WITH LOW WEIGHT ,PRETEST OVERCHARGE RETURNED TO NOMINAL 30% AH - WEIGHT = 3780 LB

TEST NO. 96: FIRST DYNO TEST AFTER TRACK