NOTICE

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NASA TM-81574

A LABORATORY FACILITY FOR ELECTRIC VEHICLE PROPULSION SYSTEM TESTING

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Prepared for
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Introduction

Significant Department of Energy (DOE) emphasis has been placed on early commercialization of electric and hybrid vehicles. NASA LeRC's role for DOE is in project management of propulsion system development and has resulted in industry contracts in technical areas that range from drivetrain components and buffer systems to prototype propulsion systems. In support of this work, a Road Load Simulator (RLS) Facility has been constructed at the LeRC to allow an independent government assessment under accurate and repeatable test conditions of the industry developed technology.

Most development testing has been conducted in vehicles on test tracks or on chassis dynamometers. These test methods place serious constraints on the ability to adequately instrument these systems and to control test conditions over the long term. The RLS facility has the advantage of providing a stable yet flexible laboratory environment in which to test and optimize a propulsion system concept prior to costly and labor intensive integration of that system into a vehicle. This paper will describe the details of the facility construction with discussion of the selection philosophy for its key components.

Road Load Simulator Facility System

The primary requirement of the RLS is to apply to the propulsion system a combination of forces made up of tire losses, aerodynamic drag, road grade and vehicle inertial effects. A block diagram and photograph of this simulator system is shown in Figures 1 and 2 respectively. Not shown in the figures are the instrumentation, control systems and power sources. Both a high speed and low speed input shaft are provided to test vehicle components and total propulsion systems. The three torque producing components are the inertia wheels, the hydroviscous absorber and the combined clutch and drive motor. To visualize the need or philosophy behind the selection of these components requires a look at the road load equation.

A vehicle traveling on a roadway is impeded in its forward progress by a number of motion resistances which interact to produce a net force on the vehicle drive axle. In essence, the function of the RLS is to mechanically simulate the effect of these forces in a controlled test environment. This composite road load torque is the arithmetic sum of the tire resistance, aerodynamic drag, vehicle inertia, and road grade; the equation is written:

$$T_{net} = K_1 + K_2 v + K_3 v^2 + K_4\, dv/dt + K_5 \sin\theta$$

where

T_{net} - net torque

v - velocity

θ - road grade

t - time

Coefficients K_1 and K_2 represent the terms relating to tire friction; K_3 is related to frontal area and drag coefficient; K_4 is related to the inertial torque associated with a change in velocity; and K_5 is related to the road grade which may be positive or negative. In downhill operation where the grade is negative, the $K_5 \sin\theta$ term can be large enough that the net torque is negative. To develop negative net torque a clutch and constant speed ac motor is provided as part of the simulator.

The Road Load Simulator

To evaluate the energy flow in an experimental vehicle system under transient conditions such as the SAE J227a "D" cycle requires an accurate and repeatable method of producing the inertial torque. A very fast response time for the inertial simulation is required, especially when testing propulsion systems utilizing battery switching concepts since the inertial torques change rapidly. Rapid response is also required when testing the smoothness of transmission shift points as these shift points will likely be integrated into the vehicle controller itself. The dynamics of the torque control system of the dynamometer must not interact with the dynamics of the speed control system of the experiment. Because of the instantaneous response characteristics a mechanical inertia wheel package was chosen over the electrical dc dynamometer. The inertia wheel package consists of a series of nine removeable flywheels on a shaft. By selecting the appropriate combination of wheels, vehicle weights from 450 kilograms (1000 pounds) to 3400 kilograms (7500 pounds) in 57 kilogram (125 pound) increments can be simulated. At the low speed input shaft a 1.7 gear box was chosen to couple the low speed input shaft to the simulator shaft. This reduces the weight of the inertia flywheel package and provides a better match to the absorber and clutch/drive motor components. The facility characteristics are summarized in Figure 3.

A hydroviscous absorber is used to provide the road losses due to grade, rolling resistance, and aerodynamic drag. The hydroviscous absorber and clutch are each composed of a set of discs free to move axially immersed in hydraulic oil (shown in Figure 4) (Ref. 1). The oil provides viscous coupling which varies with the controlled thickness of the oil film between the discs. Viscous coupling is increased by forcing the disc pack closer together. A hydraulic system (not shown) controls the disc spacing. This hydroviscous absorber and clutch/drive motor are the key elements of the simulator system and were chosen over the eddy current absorbers because they have a greater capability to absorb high torques at low speed and provide increased torque response. The speed-torque operating regions for each type dynamometer system are compared in Figure 5. The eddy current absorber shown in the upper curve is limited in the low speed high torque regime by the maximum exitation current that can be applied to the field of the absorber. (The absorber must be capable of providing the maximum grade torque component at zero speed.) This necessitates a servo disc brake be added to absorb the extra torque.

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The lower curve shows that the hydroviscous absorber satisfies the high torque-low speed condition required for maximum grade torque at zero speed, without any increase in size. In comparing the system losses or drag of these two systems, it should be noted that the hydroviscous absorber does have a higher parasitic drag due to the viscous coupling. This parasitic drag of the hydroviscous absorber does require that the control blend in the clutch/drive motor at low torque to balance these losses. In addition to providing better low speed torque, the hydroviscous absorber system is a simpler, lower cost, and more versatile machine.

Torque control of the RLS is accomplished by means of the closed loop control system depicted in Figure 6. Inputs to the torque function generator, which solves the torque equation, are from the "K"-factor inputs and the vehicle velocity obtained from the simulator shaft speed transducer. The "K"-factor inputs are manually dialed in by means of thumbwheel switches on the simulator console. The range of allowable "K"-factors is derived from the simulated vehicle characteristics shown in Figure 7. The summing of these inputs in the function generator produces a torque command. This command signal is compared with the actual feedback torque from the load cell and the error signal is applied simultaneously to the absorber control and the clutch control. The parasitic losses of the absorber are balanced by overlapping the action of the absorber and the clutch/drive motor.

Experiment Control Options

Control of the propulsion system experiment may be in either the manual or automatic mode. In the manual mode, speed control or torque control of the absorber may be selected. The manual control mode is used primarily for steady state testing such as component efficiency characterization or steady speed range testing.

For dynamic tests, automatic control of the experiment is used to command the accelerator and brake controls of the test propulsion system to maintain consistent repeatability of the desired transient operation. The input command to the experiment can be provided from two sources. The first is a programmable waveform generator that will output any repetitive driving cycle such as the SAE J227a cycles or the FUDC. The second is a tape input that could be taken from the fifth wheel of an actual vehicle mission. This would allow a vehicle to be driven on the road or track, then brought into the test cell, instrumented and tested under nearly the same identical conditions.

The Battery Simulator

A battery simulator consisting of a motor-generator set with a capacitive filter network has been developed to provide a stable power source for those tests involving component mapping and long-term testing. For these tests the battery simulator has the advantage of simulating the battery source impedance while eliminating the normal variations caused by state of charge and temperature or long term effects such as age and battery module replacement. The constant output provided by the battery simulator is an important tool in separating combined effects on propulsion system efficiency such as battery state-of-charge and component temperature.

The Instrumentation & Data Acquisition System

To characterize a propulsion system in terms of power flow and component efficiency requires that the system components be isolated from each other by instrumentation. Isolation of mechanical components is achieved by the use of speed-torque transducers. Electronic wattmeters are employed for the electrical power measurements (ref. 2). These wattmeters derive their inputs from voltage-current pairs taking care to preserve each pairs phase relationship in order to measure the true power. These primary measurements in addition to average voltage, current and temperature data are recorded on the Lewis Research Center central data system. The data system is of an interactive nature so that the experimenter can select appropriate blocks of data and perform calculations on a real-time basis as the experiment is progressing. A block diagram of this data system is shown in Figure 8.

Signals from the transducers on the experiment package are conditioned and sent to the Remote Acquisition Micro Processor to be digitized. This digitized data is then converted to engineering units which may be displayed along with simple calculations from these data on the operator's display. This display is updated once every second and is used primarily to provide information needed to control the experiment.

The data are also transmitted to the central minicomputer where additonal computation takes place to be sent to the research display on a five second update basis. The experimenter may select from any of 10 predetermined display options depending on the information he requires. This allows the research engineer to continually review calculated data in essentially final form that provides a maximum amount of information on a real time basis.

Concluding Remarks

The RLS facility is now fully operational and the "Near Term Electric Vehicle" propulsion system is under test. From the test data acquired, an assessment of the design effort and facility effectiveness may be made. Once the simulator has been programmed with a particular set of vehicle characteristics, the proper road load is automatically maintained as a function of speed. The operator then has only to concern himself with "driving the car" as the control system solves the torque equation and provides the road load while the flywheels provide the inertia. Simplicity of control has freed the operator to concentrate attention on the experiment rather than on facility operation.

The ability to make accurate electrical power measurements under the influence of armature chopper and field chopper operation has been demonstrated. The data system provides continuous measurement and real-time calculation and display of engineering data allowing timely assessment of the experiment. All facility support systems are operational including the battery simulator. Exploratory tests performed using the battery simulator show that separation of battery effects on the propulsion system from other propulsion system effects (produced by temperature for example) are possible.

It is expected that the RLS will provide the government with the capability to continually assess the advancing state-of-the-art in E&HV propulsion system technology. This early insight should greatly enhance our ability to direct the R&D effort and to provide the information industry requires to reduce the risk, cost, and time required for a successful E&HV commercialization effort.

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2. Lesco, D., Wattmeter Evaluation, NASA TM-81545, 1980.

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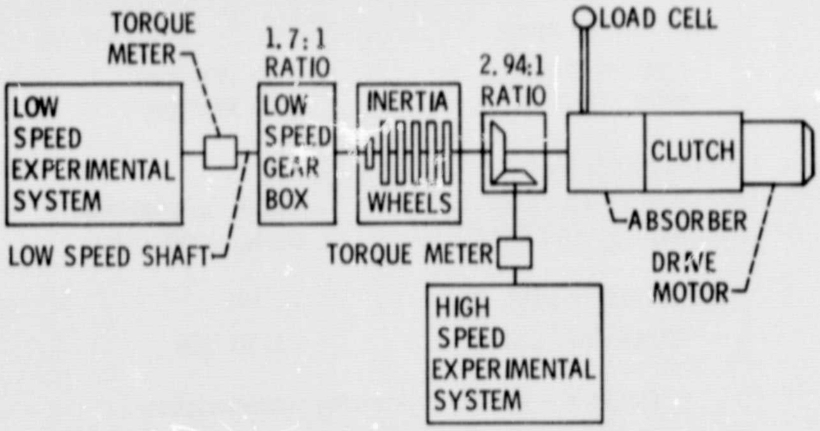


Figure 1. - Road load simulator components.

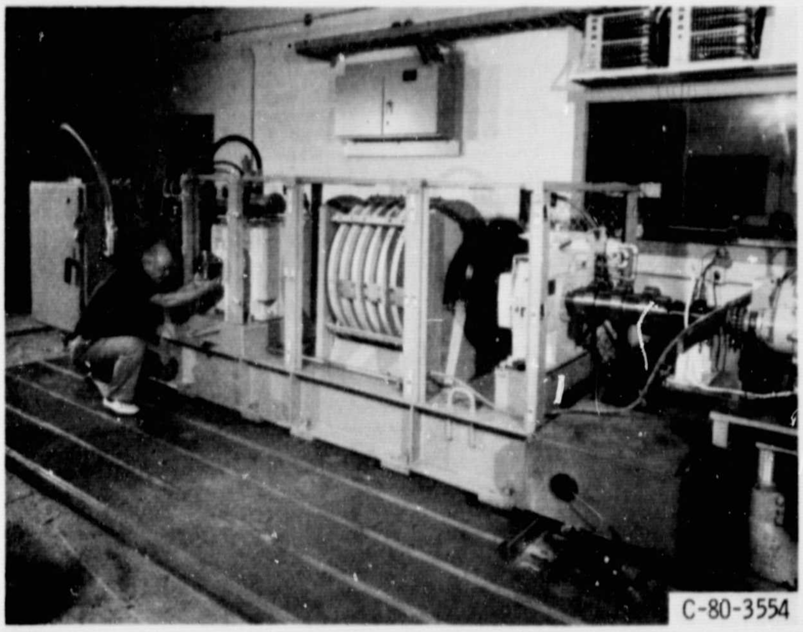


Figure 2. - Road load simulator.

SHAFT SPEED INPUT:	
LOW SPEED RANGE	0 TO 1000 rpm
HIGH SPEED RANGE	0 TO 5000 rpm
INPUT TORQUE LIMIT	
LOW SPEED RANGE	3400 N. m (2500 ft-lb)
HIGH SPEED RANGE	680 N. m (500 ft-lb)
ABSORBER POWER	112 kW
GRADE CAPABILITY	+30 TO -15%

Figure 3. - Facility engineering characteristics.

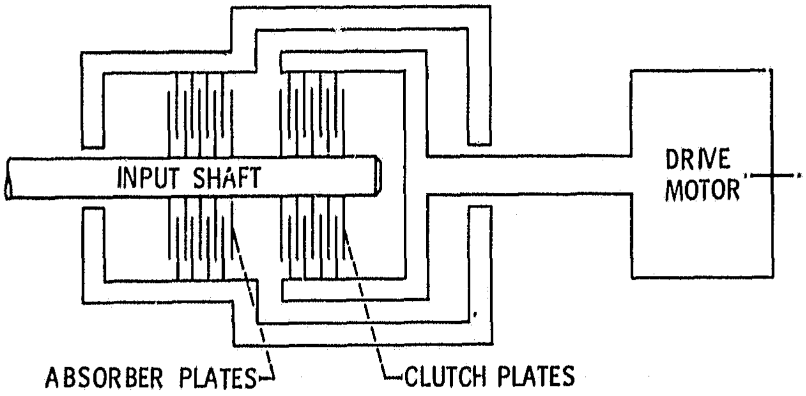
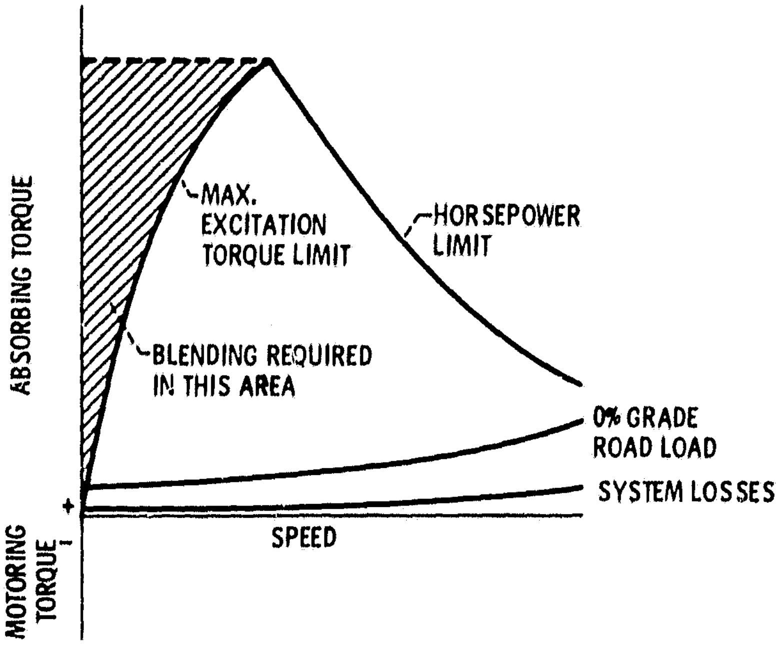
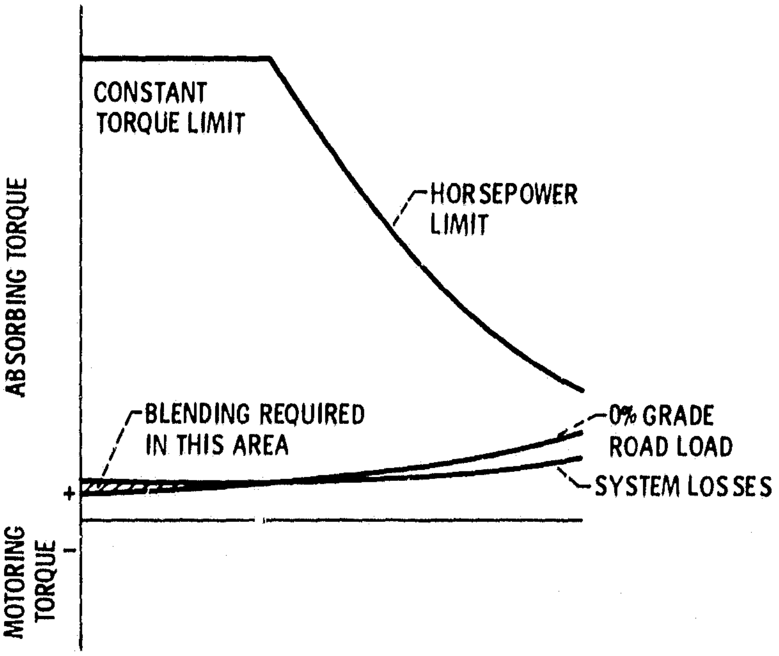


Figure 4. - Absorber and clutch.



(a) Eddy current absorber.



(b) Hydroviscous absorber.

Figure 5. - Absorber characteristics.

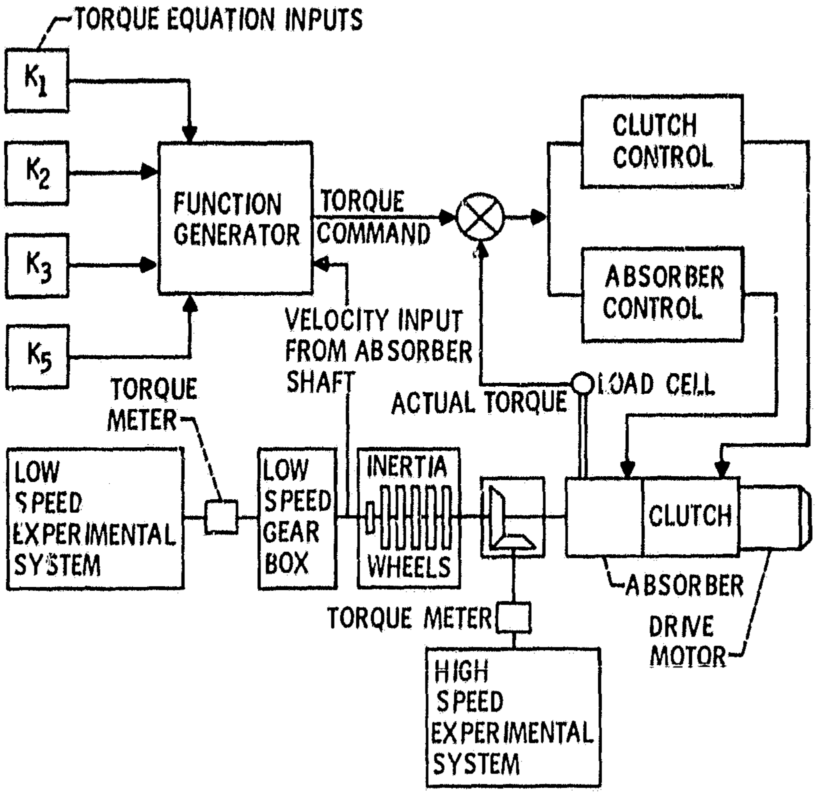


Figure 6. - Road load simulator control system.

WEIGHT	450 TO 3400 kg (1000 TO 7500 lb)
TIRE RADIUS	0.25 TO 0.45 m (10 TO 18 in)
FRONTAL AREA	1.1 TO 3.7 m^2 (12 TO 40 ft^2)
TIRE FRICTION COEFFICIENT	0.005 TO 0.016
AERODYNAMIC DRAG COEFFICIENT	0.2 TO 0.8

Figure 7. - Simulated vehicle characteristics.

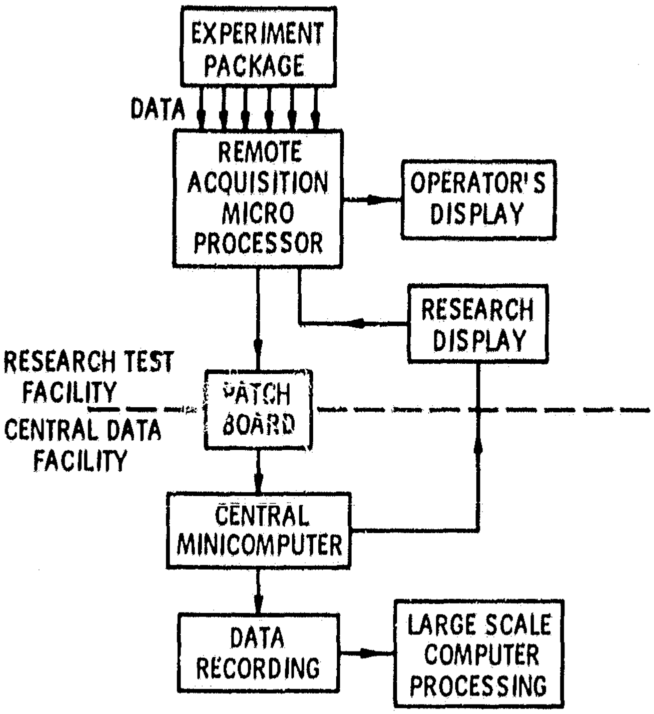


Figure 8. - Data system block diagram.

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16. Abstract

This paper describes the Road Load Simulator Facility located at the NASA Lewis Research Center in Cleveland, Ohio. This facility enables a propulsion system or any of its components to be evaluated under realistic vehicle inertia and road loads. The load is applied to the system under test according to the road load equation: $F_{net} = K_1F_1 + K_2F_2V + K_3V^2 + K_4 (dv/dt) + K_5 \sin \theta$. The coefficient of each term in the equation can be varied over a wide range with vehicle inertia representative of vehicles up to 7500 pounds simulated by means of flywheels. The required torque is applied by the flywheels, a hydroviscous absorber and clutch, and a drive motor integrated by a closed loop control system to produce a smooth, continuous load of up to 150 horsepower.

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