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Office of Vehicle and Engine R&D

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ROLLING RESISTANCE OF ELECTRIC VEHICLE TIRES FROM TRACK TESTS

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SUMMARY

Two sets of low-rolling-resistance tires were track tested to obtain realistic tire characteristics for use in programming the Road Load Simulator, a special dynamometer facility located at the NASA Lewis Research Center. One set was specially made by Goodyear Tire and Rubber Company for DOE's ETV-1 electric vehicle, and the other was a set of standard commercial automotive tires. The tests were conducted over an ambient temperature range of 15° to 32° C (59° to 89° F) and with tire pressures of 207 and 276 kPa (30 and 40 psi).

Both sets of tires had very low rolling resistance. The commercial tires, which were manufactured approximately 3 years after the electric vehicle tires, exhibited lower rolling resistance than the electric vehicle tires. This is a result of the continuing effort by the tire manufacturers to reduce rolling resistance in order to improve fuel economy. At a contained-air temperature of 38° C (100° F) and a pressure of 207 kPa (30 psi), the resistance of the electric vehicle tires was 0.0102 kilogram per kilogram of vehicle weight and the resistance of the commercial tires was 0.0088 kilogram per kilogram of vehicle weight. At a contained-air temperature of 38° C (100° F) and a pressure of 276 kPa (40 psi), the resistance of the electric vehicle tires was 0.009 kilogram per kilogram of vehicle weight and the resistance of the commercial tires was 0.0074 kilogram per kilogram of vehicle weight. The average time for the tires to reach an equilibrium temperature after startup was 20 minutes for the constant-speed tests regardless of vehicle speed and 27 minutes for the SAE J227a Schedule D driving cycle tests. The average change in rolling resistance from startup to final equilibrium value was 5 percent for all tests. There was very little heating of the tires from velocity-dependent losses. The predominant heating source for these tires was radiation heating from the Sun.

INTRODUCTION

A test facility located at NASA's Lewis Research Center is used for test and evaluation of electric vehicle propulsion systems that result from the Department of Energy's (DOE) Electric Vehicle Program. This facility, the Road Load Simulator (RLS) (ref. 1) provides a means for testing propulsion systems under road load conditions that the system would experience in a vehicle. To obtain realistic performance characteristics of propulsion systems, it is important to program the RLS with accurate aerodynamic and tire rolling resistance values.

Many independent tire tests have been carried out to determine the rolling resistance of bias-ply, bias-belted, and radial-belted tires under controlled laboratory conditions (refs. 2 to 7). These references indicate

that rolling resistance decreases of more than 50 percent could be expected during the first 30 minutes of operation. However, high rolling resistance during those first few minutes of operation can greatly affect the operating range of an electric vehicle.

Special low-rolling-resistance tires were made by Goodyear Tire and Rubber Company for the Electric Test Vehicle - One (ETV-1), an electric vehicle built by the General Electric Company and the Chrysler Corporation for DOE. These tires were tested by NASA's Lewis Research Center to acquire data for realistically programming the RLS. Tests were also conducted on a set of standard commercial automotive tires. These were Goodyear's Viva tires. Both sets of tires were tested under actual operating conditions on the test track at the Transportation Research Center of Ohio.

U.S. customary units were used for recording experimental data. The units were converted to the International System of Units (SI) for presentation in this report. U.S. customary units are presented in parentheses.

TEST PROCEDURE

The tests were conducted between April 28, 1981, and August 26, 1981, at the State of Ohio's Transportation Research Center. The Center is located 72 km (45 miles) northwest of Columbus along U.S. Route 33 near East Liberty, Ohio. A layout of the track is shown in figure 1.

Test Vehicle

A 1981 Chevette with automatic transmission was used as the test vehicle. The vehicle weight was adjusted by adding sandbag ballast until the gross vehicle weight including instrumentation and driver was brought up to 1402 kg (3090 lb). The gross vehicle weight was divided evenly between the front and rear axles.

Test Tires

Rolling resistance tests were conducted on two sets of size P175/75R13 radial tires. The first set was specially made in 1978 by Goodyear for General Electric to be used on the ETV-1. These tires are steel belted and use a special low-loss compound. The other set, Goodyear Viva tires, have two fiberglass and one polyester tread belt and one polyester sidewall ply. This tire, a standard commercial tire used on passenger cars, is load rated for 505 kg (1113 lb) at 240 kPa (35 psi).

Instrumentation

One rear tire was instrumented for temperature and the other for pressure. A thermocouple mounted in a passthrough in the rim was located in the center of the tire to measure the contained-air temperature of the tire. Slip rings used to remove the signal from the wheel are shown in figure 2. A rotating union was used on the other rear wheel to take the tire pressure from the rotating wheel to a pressure transducer in the vehicle (fig. 3). It was not possible to mount the slip ring and rotating union to the same wheel. Both variables were recorded on strip-chart

recorders within the vehicle. During the driving, test vehicle speed was recorded from a fifth wheel mounted on a rear bumper bracket. A dc-to-ac inverter was used to power the recorder and the instrumentation electronics.

A load cell was used between the test vehicle and a towing vehicle to measure the force required to tow the test vehicle. The force signal was filtered with a 0.05-Hz-time-constant, second-order response filter before recording.

Procedure

The tires were first broken in by driving 650 km (400 miles) at 80 km/hr (50 mph) prior to the test program.

Because the road load could not be measured directly during the driving tests, it was determined in two steps. Contained-air temperature in the tire as a function of time was found during the driving tests. Then the relationship between the contained-air temperature and the tire rolling resistance was found by towing the vehicle. This procedure is explained in more detail as follows: First the vehicle was driven either at constant speed or over a driving cycle, starting with the tires as close to ambient temperature as possible. Tire contained-air temperature as a function of time was recorded during this test. An example test record is shown in figure 4. The temperature trace has been retraced from another recorded chart to get the temperature, pressure, and speed traces on one chart. The tests were run at constant speeds of 24, 56, 72, and 88 km/hr (15, 35, 45, and 55 mph) and over the SAE J227a Schedules B, C, and D (ref. 8). The tests and test conditions are tabulated in table I. The initial tire pressure was set at 21° C (70° F).

The second set of data were taken while towing the test vehicle with another vehicle for approximately 1.6 km (1 mile) at about 5 km/hr (3 mph) and measuring the force required to tow the vehicle, the contained-air temperature of the tire, and the pressure of the opposite tire. These tests were conducted with initial tire pressures of 207 and 276 kPa (30 and 40 psi) and over a range of stabilized contained-air temperatures of 21° to 47° C (70° to 116° F). The force measurement was done by attaching a load cell to the front bumper of the test vehicle, as shown in figure 5. The towing vehicle was then connected to the test vehicle with a light wire, as shown in figure 6. Care was taken to keep the wire level and in line with the direction of travel. To protect the load cell, the wire size was selected to break or untwist from the load cell if the load became excessive. A sample trace of the recorded force is shown in figure 7. The filter inserted in the load-cell signal conditioner reduced the large undulations present in the force trace. These undulations are a result of the small slope changes in the test track surface. Small variations in track surface cause large changes in the force required to tow the vehicle. The engine of the test vehicle was left idling and the transmission was left in neutral during the tests. It was found that, when both rear wheels were lifted from the ground, there was enough torque transmitted through the transmission to just keep the wheels turning. Thus, the contributions to the road load from the rear brakes, the differential, and the transmission were cancelled out and only the tire rolling resistance was measured during

the towing tests. The contributions from the front wheel bearings and front disk brakes are still in the test results but are small.

DATA REDUCTION

The tire rolling resistance as a function of time while driving a vehicle at constant speeds over driving cycles was determined in three steps:

(1) The tire contained-air temperature was measured as a function of time for each driving mode during the driving tests. The tests were repeated for a range of ambient temperatures and at two initial tire pressures.

(2) The rolling resistance was determined as a function of tire contained-air temperature by slowly towing the test vehicle and measuring the force required to maintain a fixed speed.

(3) From these two sets of data the tire rolling resistance as a function of time was determined. The assumption was made that the change in rolling resistance is due to the change in tire pressure and the tire material temperature and that the resistance is not affected by the speed of the vehicle. These assumptions are substantiated by laboratory tests described in references 2, 3, 5, 6, and 7.

Driving Tests

The tire contained-air temperature data for a particular run, as shown in figure 8, were fitted with a second-order curve by means of a least-squares fit. The curve ends where the temperature began to drop in value. It was assumed that the temperature reached equilibrium at this point. Actually the temperature continued to increase and decrease in an undulating manner throughout the test for reasons that are discussed later under TEST RESULTS.

Towing Tests

A smooth curve was drawn through the force trace, as shown in figure 9, as an average force. In most cases only the last 10-minute portion of the trace was used to assure that the temperature had reached equilibrium. Depending on the time of day and the position of the Sun, the temperature did not always reach equilibrium. The tests were run in both directions on the track, and the force due to the average slope was added to or subtracted from the force values depending on the direction of the tow. The values determined from both directions were then averaged.

TEST RESULTS

Rolling Resistance as a Function of Temperature

The towing test data were used to plot rolling resistance as a function of tire contained-air temperature. This relationship is shown for the special electric vehicle tires in figure 10 and for the Viva tires in figure 11; curves for 207 and 276 kPa (30 and 40 psi) are shown.

Goodyear ran rolling resistance tests on P195/75R14 tires made of the same material as the special electric vehicle tires on a 170.8-cm (67.23-in.) drum tire test facility. The results of their tests are also plotted in figure 10. A correction factor specified by Goodyear was applied to their experimental data to correct for the curvature of the drum. The Goodyear tests were performed with a cold inflation pressure of 179 kPa (26 psi).

Contained-Air Temperatures as a Function of Time

The results of the tests to determine the contained-air temperature as a function of time for constant-speed tests on both the special electric vehicle tires and the Viva tires are shown in figure 12. Table II lists the tire type, the inflation pressure, the type of test, and the figure in which the test results are shown. Each figure contains the actual test points as taken from the strip-chart recorder and the best second-order fit to the test points as determined by the least-squares method.

Rolling Resistance as a Function of Time

Figure 13 shows the rolling resistance values as a function of time for both sets of tires as obtained by using the method outlined in the section DATA REDUCTION. Table III lists the tire type, the inflation pressure, the type of tests, and the figure in which the data appear.

DISCUSSION OF RESULTS

Many factors that are not encountered in laboratory tests affect the results of tests conducted on a test track. In fact, carefully conducted laboratory tests usually avoid factors such as ambient temperature changes, radiation heat input to the tires from the Sun, and test track temperature. These factors become very important when evaluating low-rolling-resistance tires designed for electric vehicles.

Ambient conditions have a large influence on contained-air temperature and therefore on tire pressure, which in turn affects the rolling resistance (ref. 4).

In figure 14 is shown an example of the effect of radiation from the Sun on contained-air temperature. These data were taken on the Viva tires with 276-kPa (40-psi) pressure on a day that was described as partly sunny. The track surface temperature went from 27° C (80° F) at the beginning of the test to 30° C (86° F) at the end of the test. The vehicle was being driven over a Schedule D driving cycle. The time to negotiate one lap is shown on the curve as 15 minutes. Note that the period of the temperature undulations was also 15 minutes. Each time the vehicle came around the track so that the Sun shined on the tire the contained-air temperature increased, and as the tire was shaded by the vehicle, the tire cooled. The same effect was noted on all the data taken during sunny days.

In contrast, one test was run late in the evening after the track and air temperatures had dropped. The temperature trace for this run is shown as the lower trace in figure 15. Also in the same figure, the upper trace is of the temperature taken under identical circumstances earlier the same

day while the Sun was still high. A couple of observations can be made from this figure. The Sun effects are apparent in the upper trace, where the temperature undulations have the same period as the time to traverse one lap. This effect is not seen in the lower trace. The lower trace shows very little temperature increase at higher speeds. The entire temperature spread is only 3° C (5° F). Apparently the convection cooling effect of the higher speed compensates for increased losses. The upper trace shows that the tire actually cools down at the beginning of each constant-speed run and heats up at the end of the run while the vehicle is stopped. This is also probably due to convection cooling of the tires when the vehicle is moving and heating from the Sun when the vehicle is standing.

CONCLUDING REMARKS

Track tests were conducted on two sets of low-rolling-resistance tires to provide means for accurately programming the Road Load Simulator. One set of tires was specially made of low-rolling-resistance material for use on electric vehicles. The other was a set of standard commercial automotive tires. The rolling resistances of both sets of tires were indeed much lower than those of other radial tires. The Viva tires, which were manufactured approximately 3 years after the special electric vehicle tires, had even lower rolling resistance than the special tires. This illustrates the continuing improvement in automotive tire materials and construction methods in an effort to reduce fuel consumption (private communication from G. E. Pollard, Goodyear Tire and Rubber Co., Akron, Ohio). Other observations were made as follows:

1. The average change in rolling resistance when starting the test with tires at ambient temperature was 5 percent at equilibrium. The tests were conducted in the summer with a lowest ambient temperature of about 15° C (59° F). Tests conducted in the laboratory of the Firestone Tire and Rubber Company suggest that the change in rolling resistance is much larger at lower ambient temperatures.

2. For the constant-speed tests the average time for the rolling resistance to reach an equilibrium condition after starting the test with the tires at ambient temperature was 23 minutes and was not affected by the vehicle speed. For all SAE J227a driving cycle tests the average time to reach equilibrium was 32 minutes.

3. With low-rolling-resistance tires there is very little heating of the tires from velocity-dependent losses. The heating that does occur is apparently compensated for by increased convection cooling of the tires.

4. The predominant heating source for these low-resistance tires was radiation heating from the Sun. Tests run at dusk showed less than 3° C (5° F) change in tire temperature at speeds up to 88 km/hr (55 mph).

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8. Electric Vehicle Test Procedure. SAE J227a, Feb. 1976, SAE.

TABLE I. - RANGE OF TEST CONDITIONS FOR DRIVING TESTS

[Tire types, Viva and special electric vehicle tires.]

Tire pressure, kPa (psi)	207 and 276 (30 and 40)
Ambient temperature, °C (°F)	15 to 32 (59 to 89)
Vehicle speed, km/hr (mph)	24, 56, 72, 88 (15, 35, 45, 55)
Driving cycles, SAE J227a Schedules	B, C, D

TABLE II. - INDEX OF FIGURES FOR TIRE-CONTAINED-AIR TEMPERATURE AS A FUNCTION OF TIME

Tire type	Tire pressure		Test speed or driving cycle		Figure
	kPa	psi	km/hr	mph	
EV ^a	276	40	24	15	12(a)
	276	40	56	35	12(b)
	276	40	72	45	12(c)
	276	40	88	55	12(d)
	207	30	24	15	12(e)
	207	30	56	35	12(f)
	207	30	72	45	12(g)
	207	30	88	55	12(h)
Viva	276	40	24	15	12(i)
	276	40	56	35	12(j)
	276	40	72	45	12(k)
	276	40	88	55	12(l)
	207	30	24	15	12(m)
	207	30	56	35	12(n)
	207	30	Schedule D	Schedule D	12(p)
	276	40	Schedule D	Schedule D	12(q)
EV	276	40	Schedule D	Schedule D	12(r)
Viva	207	30	Schedule C	Schedule C	12(s)
Viva	276	40	Schedule C	Schedule C	12(t)
EV	207	30	Schedule C	Schedule C	12(u)
EV	276	40	Schedule C	Schedule C	12(v)
Viva	207	30	Schedule B	Schedule B	12(w)
EV	207	30	Schedule B	Schedule B	12(x)
EV	276	40	Schedule B	Schedule B	12(y)

^aSpecial electric vehicle tires.

TABLE III. - INDEX OF FIGURES FOR ROLLING RESISTANCE
AS A FUNCTION OF TIME

Tire type	Tire pressure		Test speed or driving cycle		Figure
	kPa	psi	km/hr	mph	
EV ^a	276	40	24	15	13(a)
	276	40	56	35	13(b)
	276	40	72	45	13(c)
	276	40	88	55	13(d)
	207	30	24	15	13(e)
	207	30	56	35	13(f)
	207	30	72	45	13(g)
	207	30	88	55	13(h)
Viva	276	40	24	15	13(i)
	276	40	56	35	13(j)
	276	40	72	45	13(k)
	276	40	88	55	13(l)
	207	30	24	15	13(m)
	207	30	56	35	13(n)
	207	30	Schedule D	Schedule D	13(p)
	276	40	Schedule D	Schedule D	13(q)
EV	276	40	Schedule D	Schedule D	13(r)
Viva	207	30	Schedule C	Schedule C	13(s)
Viva	276	40	Schedule C	Schedule C	13(t)
EV	207	30	Schedule C	Schedule C	13(u)
EV	276	40	Schedule C	Schedule C	13(v)
Viva	207	30	Schedule B	Schedule B	13(w)
EV	207	30	Schedule B	Schedule B	13(x)
EV	276	40	Schedule B	Schedule B	13(y)

^aSpecial electric vehicle tires.

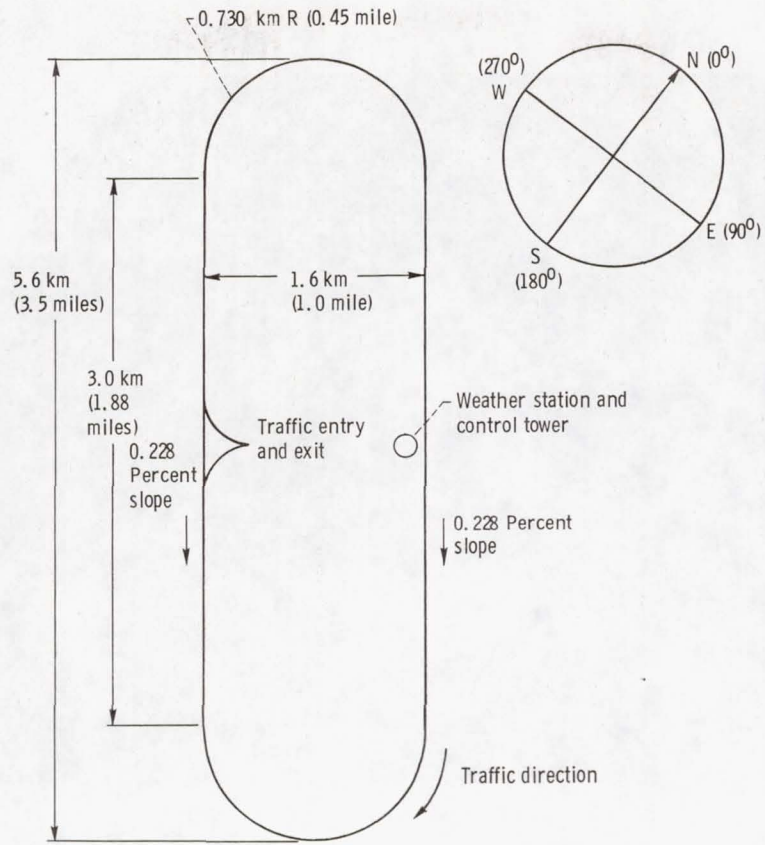


Figure 1. - Characteristics of Transportation Research Center test track, East Liberty, Ohio.

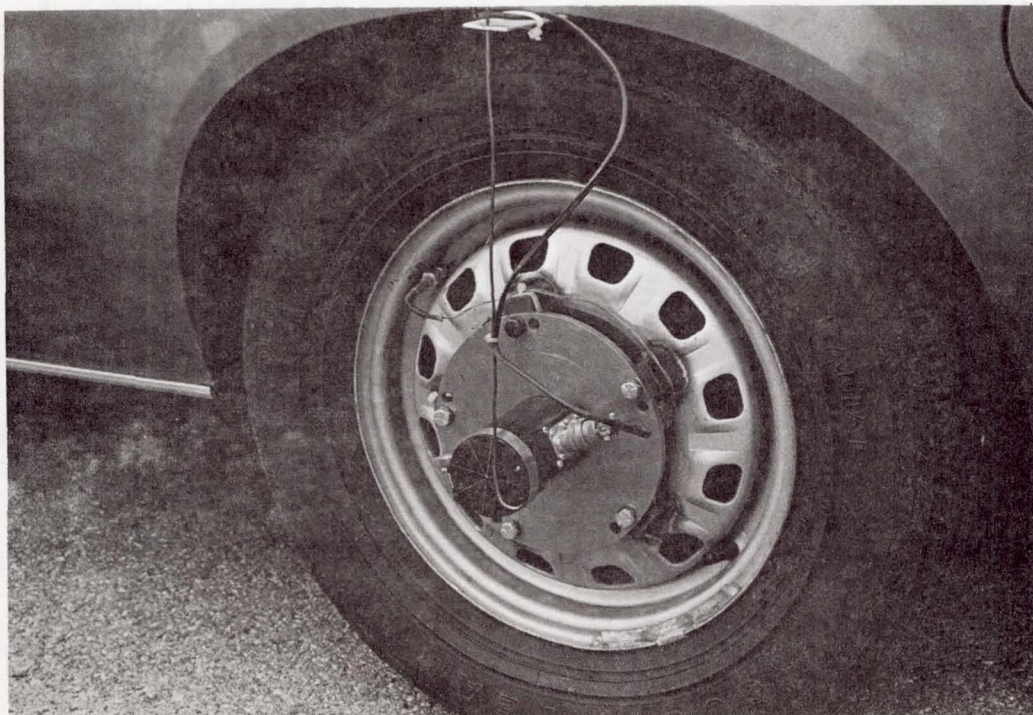


Figure 2. - Slip-ring unit mounted on rear wheel of Chevette. Thermocouple passthrough in upper left of wheel.

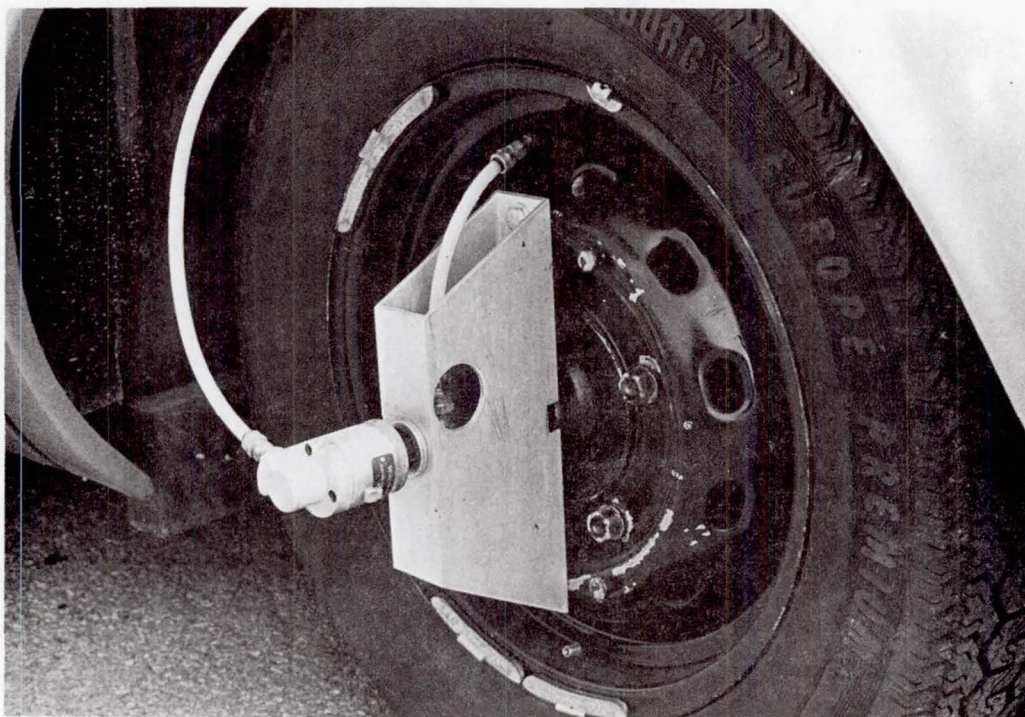


Figure 3. - Rotating union used to measure pressure in tire.

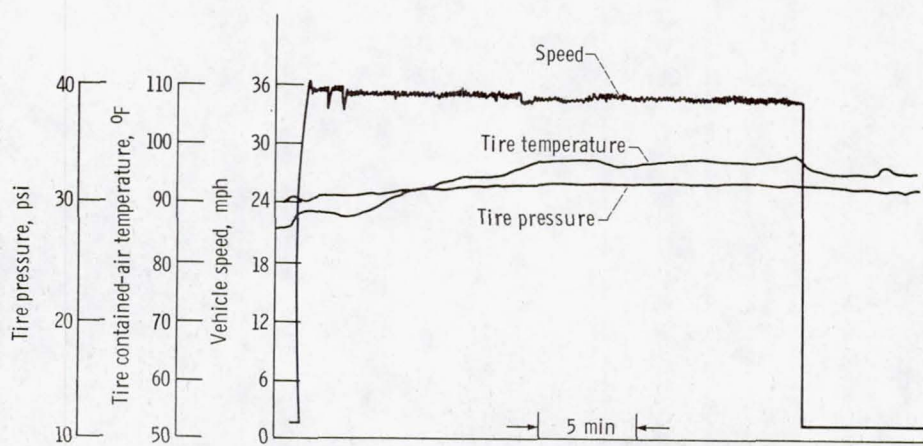


Figure 4. - Sample test record taken during 56-km/h (35-mph) constant-speed tests. (Temperature trace was copied from another record.)

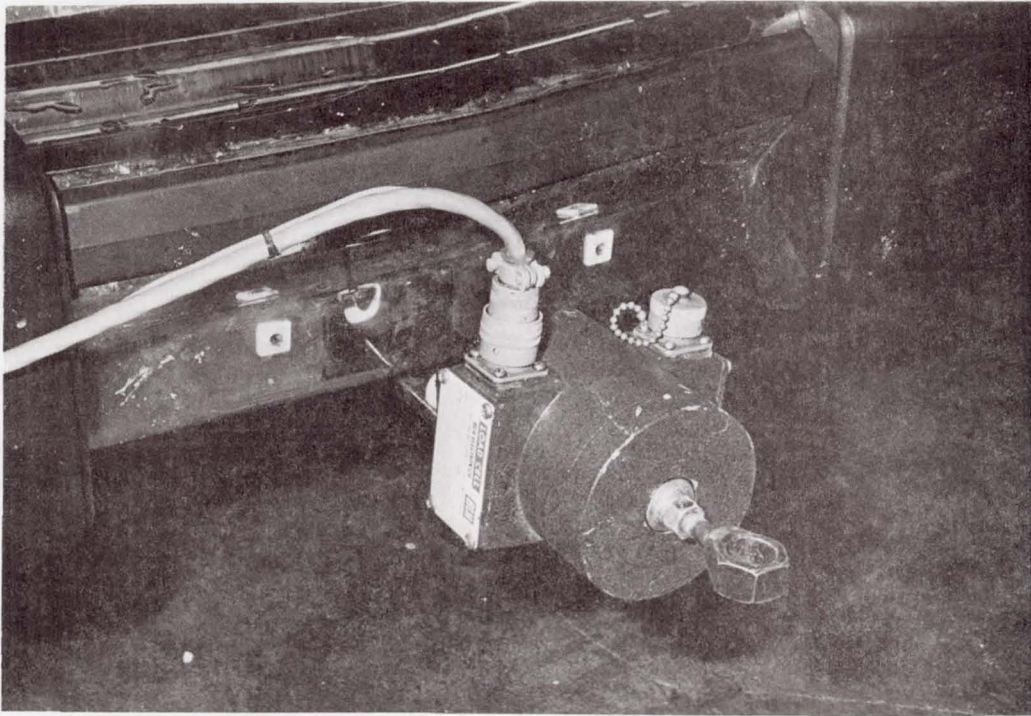


Figure 5. - Load cell installed on front bumper of Chevette.

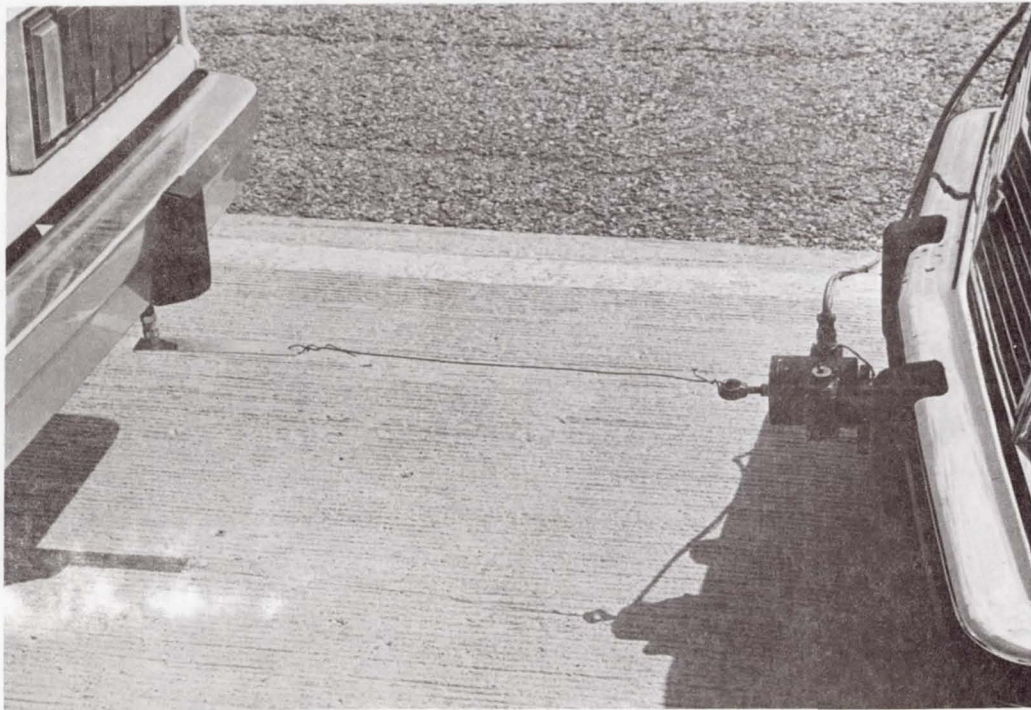


Figure 6. - Small-diameter wire connecting load cell to towing vehicle.

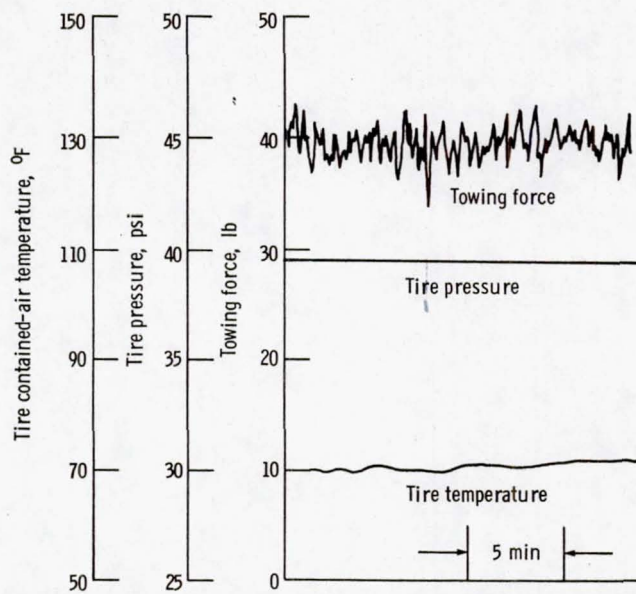


Figure 7. - Sample record from towing test. (Temperature trace was copied from another record.)



Figure 8. - Tire contained-air temperature as a function of time for constant-speed test. Speed, 56 km/hr (35 mph).

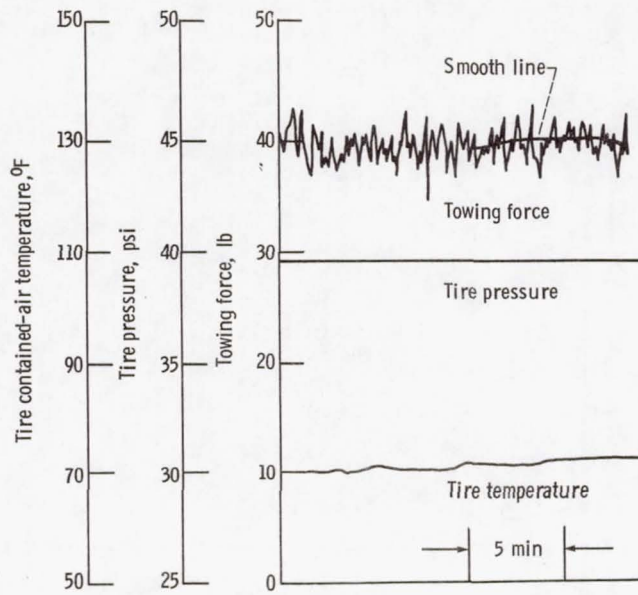


Figure 9. - Sample record from towing test with smooth line through force data. (Temperature trace was copied from another record.)

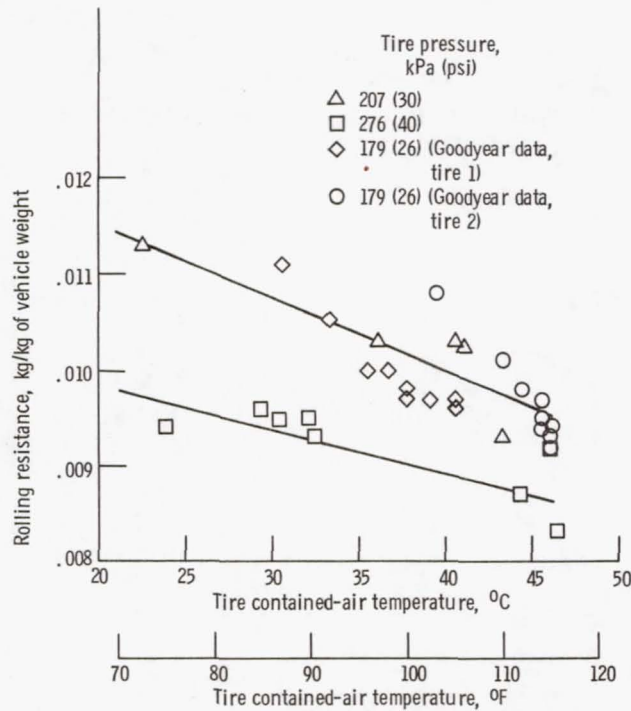


Figure 10. - Rolling resistance as a function of contained-air temperature for special electric vehicle tires.

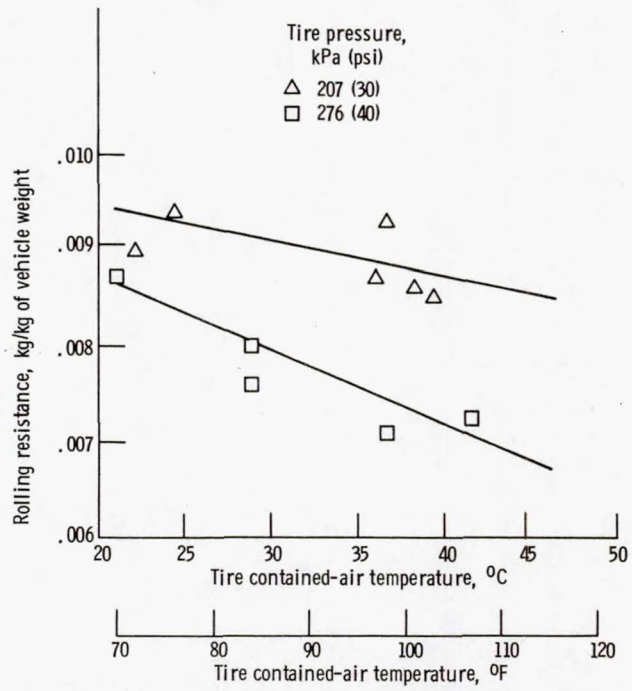
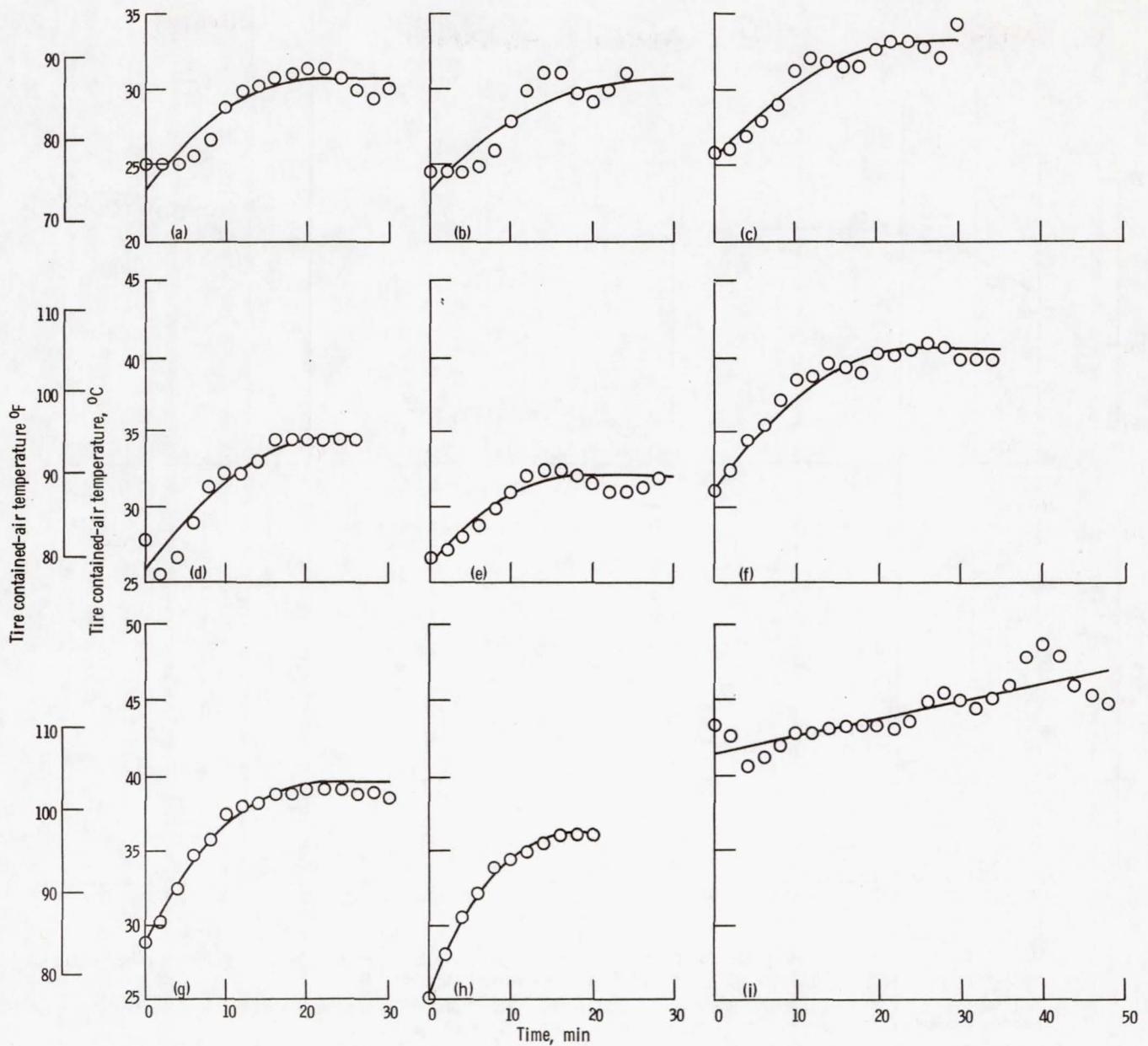
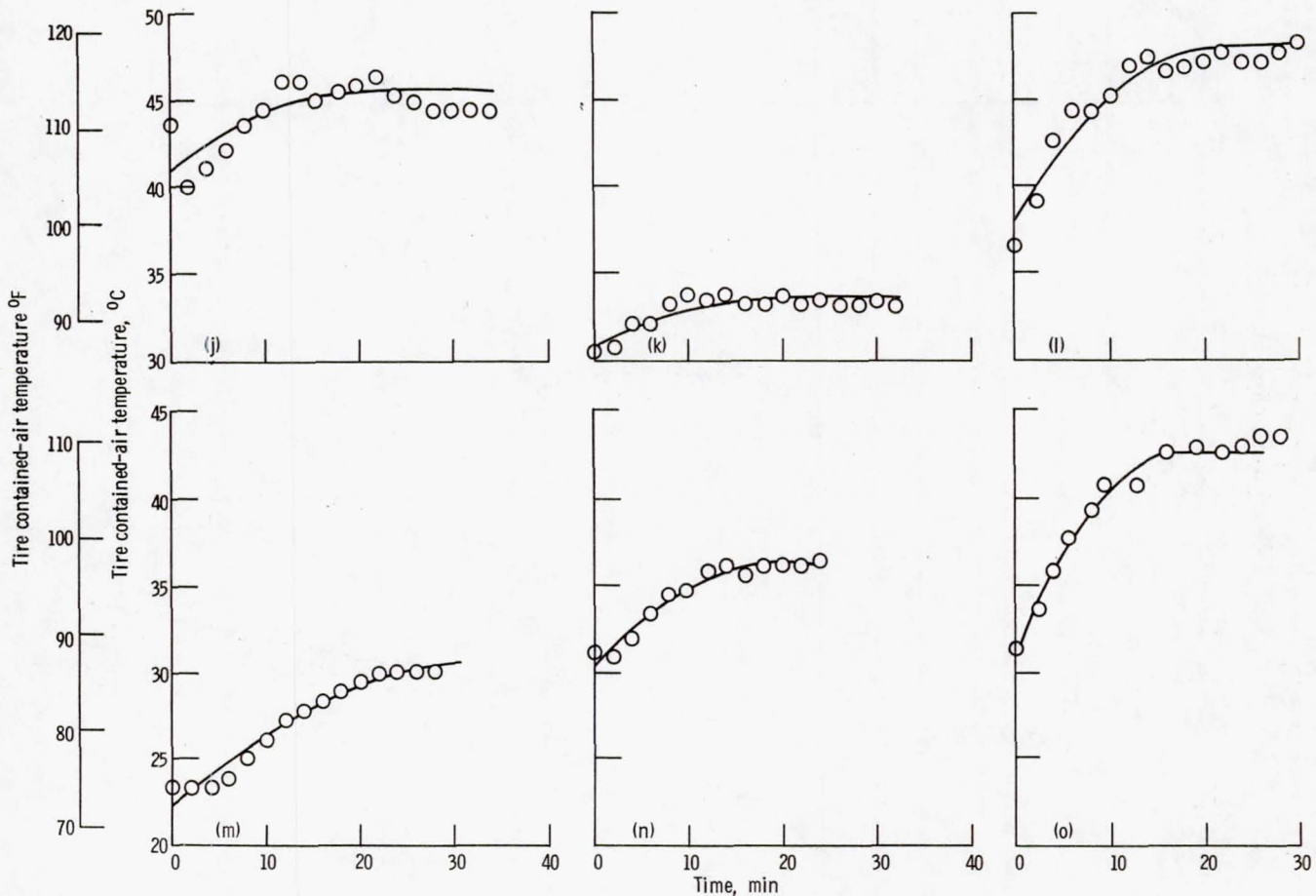


Figure 11. - Rolling resistance as a function of contained-air temperature for Goodyear Viva tires.



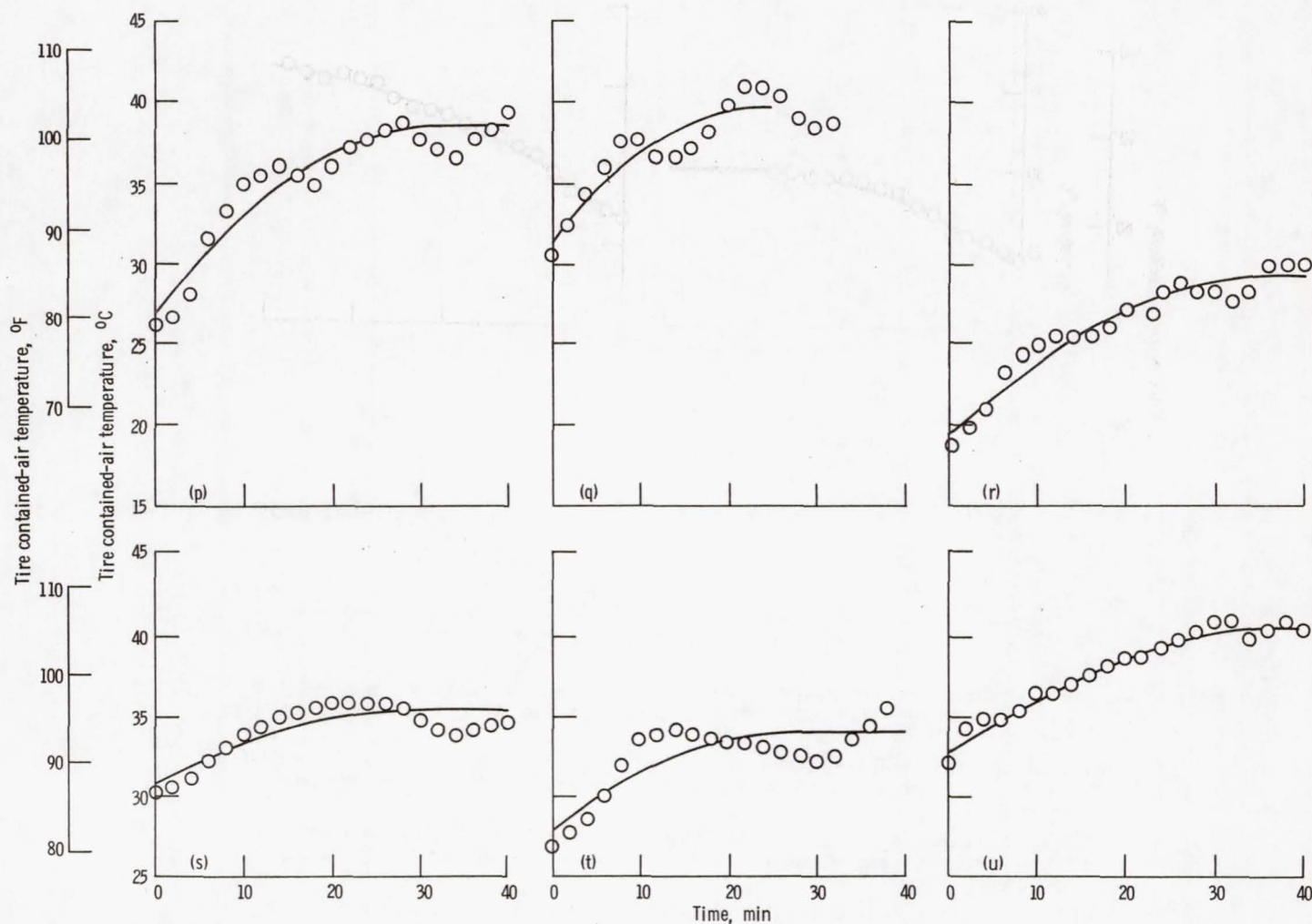
- (a) Run, 28; tire type, EV; tire pressure, 276 kPa (40 psi); date, 5-21-81; time, 10:20 a. m.; wind speed, 3 to 6 km/hr (2 to 4 mph); vehicle speed, 24 km/hr (15 mph); ambient temperature, 18° C (65° F); track temperature, 21° C (70° F).
- (b) Run, 20; tire type, EV; tire pressure, 276 kPa (40 psi); date, 5-19-81; time, 3:30 p. m.; wind speed, 8 to 24 km/hr (5 to 15 mph); vehicle speed, 56 km/hr (35 mph); ambient temperature, 15° C (59° F); track temperature, 22° C (72° F).
- (c) Run, 26; tire type, EV; tire pressure, 276 kPa (40 psi); date, 5-20-81; time, 5:55 p. m.; wind speed, 8 to 11 km/hr (5 to 7 mph); vehicle speed, 72 km/hr (45 mph); ambient temperature, 19° C (66° F); track temperature, 29° C (85° F).
- (d) Run, 23; tire type, EV; tire pressure, 276 kPa (40 psi); date, 5-20-81; time, 12:30 p. m.; wind speed, 6 to 14 km/hr (4 to 9 mph); vehicle speed, 88 km/hr (55 mph); ambient temperature, 17° C (62° F); track temperature, 34° C (93° F).
- (e) Run, 38; tire type, EV; tire pressure, 207 kPa (30 psi); date, 6-1-81; time, 12:55 p. m.; wind speed, 8 to 16 km/hr (5 to 10 mph); vehicle speed, 24 km/hr (15 mph); ambient temperature, 17° C (63° F); track temperature, 33° C (91° F).
- (f) Run, 44A; tire type, EV; tire pressure, 207 kPa (30 psi); date, 6-2-81; time, 6:09 p. m.; wind speed, 8 to 14 km/hr (5 to 9 mph); vehicle speed, 56 km/hr (35 mph); ambient temperature, 26° C (78° F); track temperature, 32° C (89° F).
- (g) Run, 45; tire type, EV; tire pressure, 207 kPa (30 psi); date, 6-2-81; time, 7:34 p. m.; wind speed, 10 to 14 km/hr (6 to 9 mph); vehicle speed, 72 km/hr (45 mph); ambient temperature, 25° C (77° F); track temperature, 31° C (88° F).
- (h) Run, 46; tire type, EV; tire pressure, 207 kPa (30 psi); date, 6-2-81; time, 6:2-81; wind speed, 0 km/hr (0 mph); vehicle speed, 88 km/hr (55 mph); ambient temperature, 21° C (70° F); track temperature, 28° C (83° F).
- (i) Run, 61; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-15-81; time, 4:24 p. m.; wind speed, 10 to 37 km/hr (6 to 23 mph); vehicle speed, 24 km/hr (15 mph); ambient temperature, 32° C (89° F); track temperature, 41° C (105° F).

Figure 12. - Contained-air temperature as a function of time.



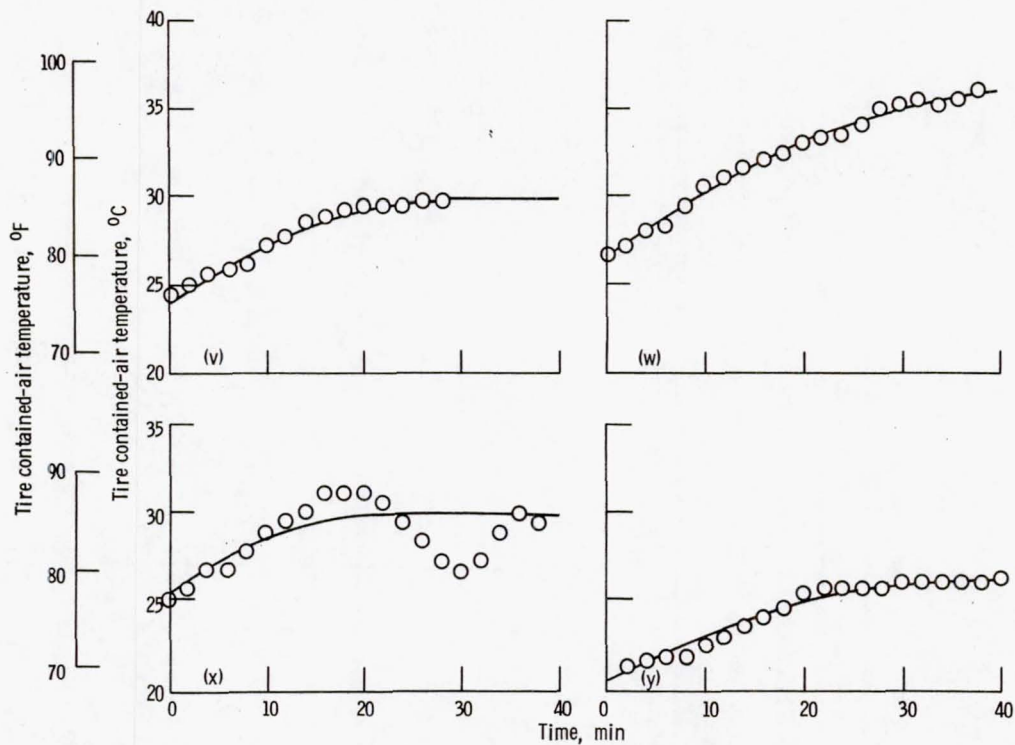
- (j) Run, 60; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-15-81; time, 1:55 p. m.; wind speed, 16 to 24 km/hr (10 to 15 mph); vehicle speed, 56 km/hr (35 mph); ambient temperature, 31° C (88° F); track temperature, 42° C (108° F).
- (k) Run, 64; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-17-81; time, 5:07 p. m.; wind speed, 2 to 5 km/hr (1 to 3 mph); vehicle speed, 72 km/hr (45 mph); ambient temperature, 22° C (71° F); track temperature, 31° C (87° F).
- (l) Run, 59; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-15-81; time, 12:05 p. m.; wind speed, 16 to 24 km/hr (10 to 15 mph); vehicle speed, 88 km/hr (55 mph); ambient temperature, 29° C (85° F); track temperature, 38° C (101° F).
- (m) Run, 50; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-15-81; time, 9:17 a. m.; wind speed, 8 to 14 km/hr (5 to 9 mph); vehicle speed, 24 km/hr (15 mph); ambient temperature, 23° C (73° F); track temperature, 28° C (82° F).
- (n) Run, 49; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-4-81; time, 6:55 p. m.; wind speed, 11 to 18 km/hr (7 to 11 mph); vehicle speed, 56 km/hr (35 mph); ambient temperature, 24° C (76° F); track temperature, 33° C (92° F).
- (o) Run, 54; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-8-81; time, 2:34 p. m.; wind speed, 26 to 39 km/hr (16 to 24 mph); vehicle speed, 72 km/hr (45 mph); ambient temperature, 28° C (83° F); track temperature, 39° C (102° F).

Figure 12. - Continued.



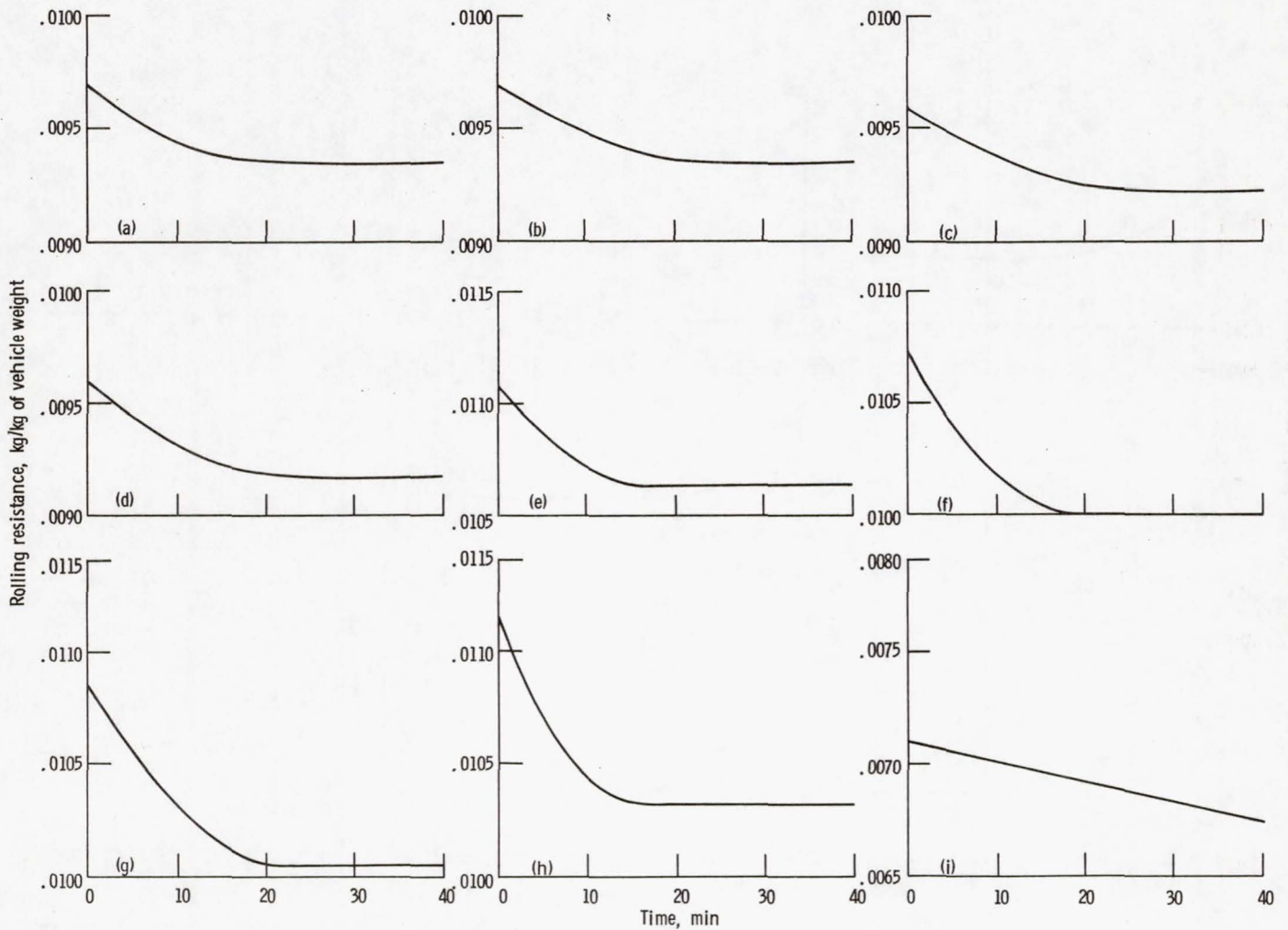
- (p) Run, 52; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-8-81; time, 10:47 a. m.; wind speed, 16 to 24 km/hr (10 to 15 mph); driving cycle, Schedule D; ambient temperature, 24^o C (76^o F); track temperature, 30^o C (86^o F).
- (q) Run, 58; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-15-81; time, 9:30 a. m.; wind speed, 11 to 23 km/hr (7 to 14 mph); driving cycle, Schedule D; ambient temperature, 27^o C (80^o F); track temperature, 28^o C (83^o F).
- (r) Run, 22; tire type, EV; tire pressure, 276 kPa (40 psi); date, 5-20-81; time, 10:40 p. m.; wind speed, 5 to 11 km/hr (3 to 7 mph); driving cycle, Schedule D; ambient temperature, 15^o C (59^o F); track temperature, 24^o C (75^o F).
- (s) Run, 51; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-5-81; time, 12:45 p. m.; wind speed, 10 to 16 km/hr (6 to 10 mph); driving cycle, Schedule C; ambient temperature, 27^o C (80^o F); track temperature, 39^o C (102^o F).
- (t) Run, 67; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-19-81; time, 9:41 a. m.; wind speed, 8 to 14 km/hr (5 to 9 mph); driving cycle, Schedule C; ambient temperature, 24^o C (75^o F); track temperature, 32^o C (90^o F).
- (u) Run, 36; tire type, EV; tire pressure, 207 kPa (30 psi); date, 5-29-81; wind speed, 6 to 16 km/hr (4 to 10 mph); driving cycle, Schedule C; ambient temperature, 25^o C (77^o F); track temperature, 34^o C (94^o F).

Figure 12. - Continued.



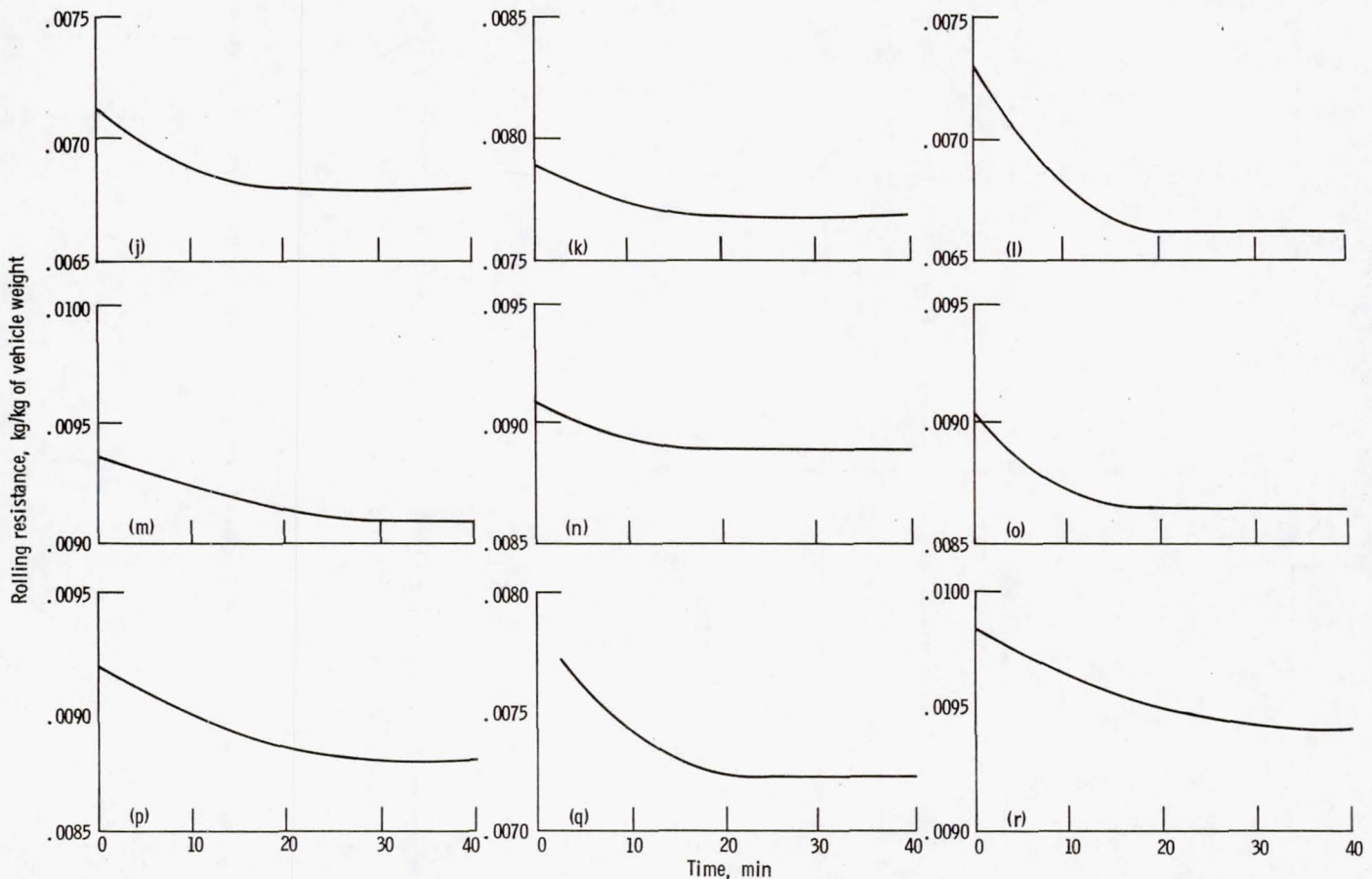
- (v) Run, 41; tire type, EV; tire pressure, 276 kPa (40 psi); date, 6-2-81; time, 10:35 a. m.; wind speed, 10 to 16 km/hr (6 to 10 mph); driving cycle, Schedule C; ambient temperature, 18° C (64° F); track temperature, 26° C (78° F).
- (w) Run, 47; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-3-81; time, 4:22 p. m.; wind speed, 13 to 19 km/hr (8 to 12 mph); driving cycle, Schedule B; ambient temperature, 26° C (78° F); track temperature, 31° C (88° F).
- (x) Run, 37; tire type, EV; tire pressure, 207 kPa (30 psi); date, 6-1-81; time, 10:28 a. m.; wind speed, 8 to 16 km/hr (5 to 10 mph); driving cycle, Schedule B; ambient temperature, 15° C (59° F); track temperature, 26° C (79° F).
- (y) Run, 40; tire type, EV; tire pressure, 276 kPa (40 psi); date, 6-2-81; time, 8:57 a. m.; wind speed, 8 to 13 km/hr (5 to 8 mph); driving cycle, Schedule B; ambient temperature, 17° C (63° F); track temperature, 21° C (69° F).

Figure 12. - Concluded.



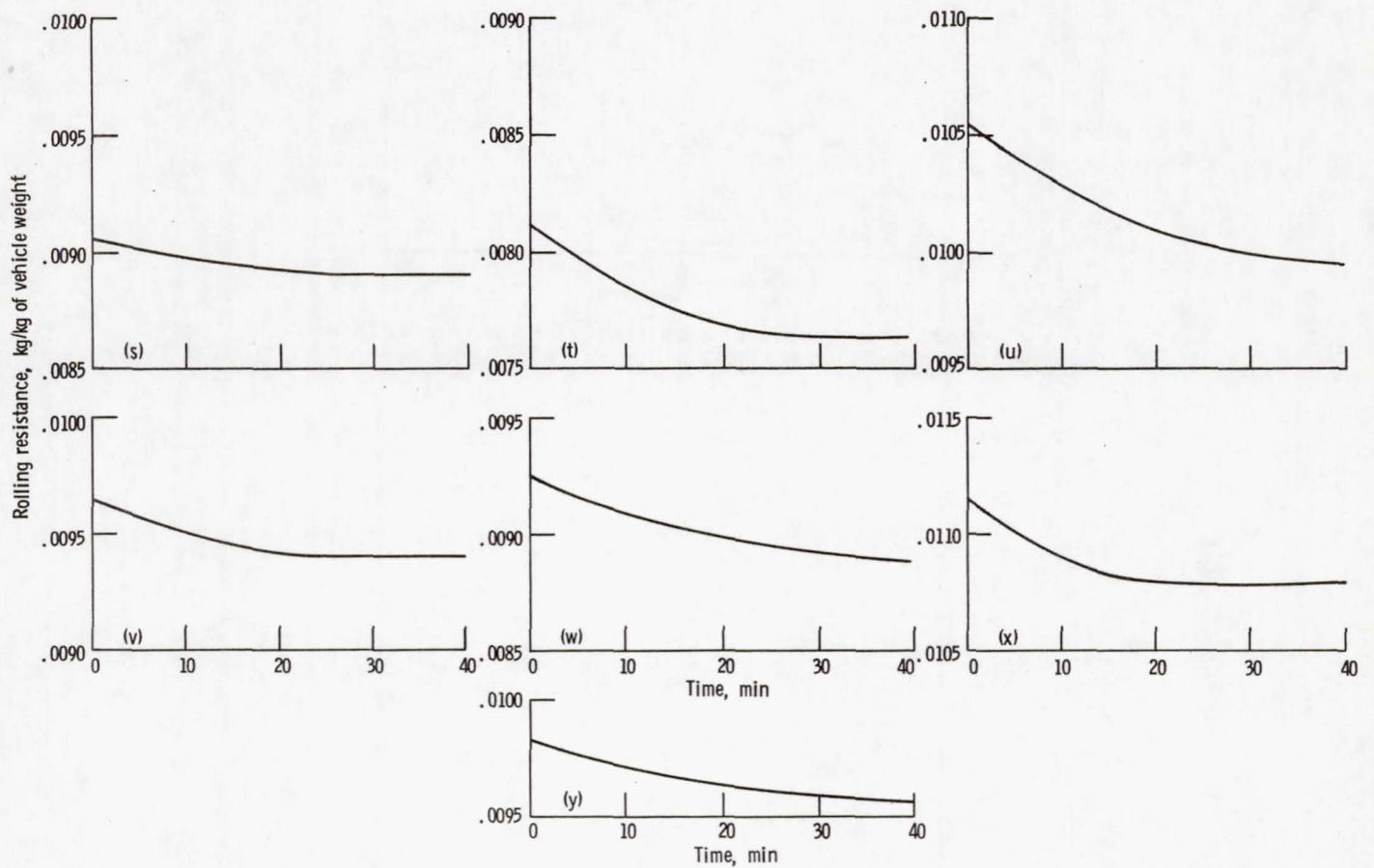
- (a) Run, 28; tire type, EV; tire pressure, 276 kPa (40 psi); date, 5-21-81; time, 10:20 a. m.; wind speed, 3 to 6 km/hr (2 to 4 mph); vehicle speed, 24 km/hr (15 mph); ambient temperature, 18° C (65° F); track temperature, 21° C (70° F).
- (b) Run, 20; tire type, EV; tire pressure, 276 kPa (40 psi); date, 5-19-81; time, 3:30 p. m.; wind speed, 8 to 24 km/hr (5 to 15 mph); vehicle speed, 56 km/hr (35 mph); ambient temperature, 15° C (59° F); track temperature, 22° C (72° F).
- (c) Run, 26; tire type, EV; tire pressure, 276 kPa (40 psi); date, 5-20-81; time, 5:55 p. m.; wind speed, 8 to 11 km/hr (5 to 7 mph); vehicle speed, 72 km/hr (45 mph); ambient temperature, 19° C (66° F); track temperature, 29° C (85° F).
- (d) Run, 23; tire type, EV; tire pressure, 276 kPa (40 psi); date, 5-20-81; time, 12:30 p. m.; wind speed, 6 to 14 km/hr (4 to 9 mph); vehicle speed, 88 km/hr (55 mph); ambient temperature, 17° C (62° F); track temperature, 34° C (93° F).
- (e) Run, 38; tire type, EV; tire pressure, 207 kPa (30 psi); date, 6-1-81; time, 12:55 p. m.; wind speed, 8 to 16 km/hr (5 to 10 mph); vehicle speed, 24 km/hr (15 mph); ambient temperature, 17° C (63° F); track temperature, 33° C (91° F).
- (f) Run, 44A; tire type, EV; tire pressure, 207 kPa (30 psi); date, 6-2-81; time, 6:09 p. m.; wind speed, 8 to 14 km/hr (5 to 9 mph); vehicle speed, 56 km/hr (35 mph); ambient temperature, 26° C (78° F); track temperature, 32° C (89° F).
- (g) Run, 45; tire type, EV; tire pressure, 207 kPa (30 psi); date, 6-2-81; time, 7:34 p. m.; wind speed, 10 to 14 km/hr (6 to 9 mph); vehicle speed, 72 km/hr (45 mph); ambient temperature, 25° C (77° F); track temperature, 31° C (88° F).
- (h) Run, 46; tire type, EV; tire pressure, 207 kPa (30 psi); date, 6-2-81; wind speed, 0 km/hr (0 mph); vehicle speed, 88 km/hr (55 mph); ambient temperature, 21° C (70° F); track temperature, 28° C (83° F).
- (i) Run, 61; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-15-81; time, 4:24 p. m.; wind speed, 10 to 37 km/hr (6 to 23 mph); vehicle speed, 24 km/hr (15 mph); ambient temperature, 32° C (89° F); track temperature, 41° C (105° F).

Figure 13. - Tire rolling resistance as a function of time.



- (j) Run, 60; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-15-81; time, 1:55 p. m.; wind speed, 16 to 24 km/hr (10 to 15 mph); vehicle speed, 56 km/hr (35 mph); ambient temperature, 31^o C (88^o F); track temperature, 42^o C (108^o F).
- (k) Run, 64; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-17-81; time, 5:07 p. m.; wind speed, 2 to 5 km/hr (1 to 3 mph); vehicle speed, 72 km/hr (45 mph); ambient temperature, 22^o C (71^o F); track temperature, 31^o C (87^o F).
- (l) Run, 59; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-15-81; time, 12:05 p. m.; wind speed, 16 to 24 km/hr (10 to 15 mph); vehicle speed, 88 km/hr (55 mph); ambient temperature, 29^o C (85^o F); track temperature, 38^o C (101^o F).
- (m) Run, 50; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-5-81; time, 9:17 a. m.; wind speed, 8 to 14 km/hr (5 to 9 mph); vehicle speed, 24 km/hr (15 mph); ambient temperature, 23^o C (73^o F); track temperature, 28^o C (82^o F).
- (n) Run, 49; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-4-81; time, 6:55 p. m.; wind speed, 1 to 18 km/hr (7 to 11 mph); vehicle speed, 56 km/hr (35 mph); ambient temperature, 24^o C (76^o F); track temperature, 33^o C (92^o F).
- (o) Run, 54; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-8-81; time, 2:34 p. m.; wind speed, 26 to 39 km/hr (16 to 24 mph); vehicle speed, 72 km/hr (45 mph); ambient temperature, 28^o C (83^o F); track temperature, 39^o C (103^o F).
- (p) Run, 52; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-8-81; time, 10:47 p. m.; wind speed, 16 to 24 km/hr (10 to 15 mph); driving cycle, Schedule D; ambient temperature, 24^o C (76^o F); track temperature, 30^o C (86^o F).
- (q) Run, 58; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-15-81; time, 9:30 a. m.; wind speed, 11 to 23 km/hr (7 to 14 mph); driving cycle, Schedule D; ambient temperature, 27^o C (80^o F); track temperature, 28^o C (83^o F).
- (r) Run, 22; tire type, EV; tire pressure, 276 kPa (40 psi); date, 5-20-81; time, 10:40 p. m.; wind speed, 5 to 11 km/hr (3 to 7 mph); driving cycle, Schedule D; ambient temperature, 15^o C (59^o F); track temperature, 24^o C (75^o F).

Figure 13. - Continued.



- (s) Run, 51; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-5-81; time, 12:45 p. m.; wind speed, 10 to 16 km/hr (6 to 10 mph); driving cycle, Schedule C; ambient temperature, 27° C (80° F); track temperature, 39° C (102° F).
- (t) Run, 67; tire type, Viva; tire pressure, 276 kPa (40 psi); date, 6-19-81; time, 9:41 a. m.; wind speed, 8 to 14 km/hr (5 to 9 mph); driving cycle, Schedule C; ambient temperature, 24° C (75° F); track temperature, 32° C (90° F).
- (u) Run, 36; tire type, EV; tire pressure, 207 kPa (30 psi); date, 5-29-81; wind speed, 6 to 16 km/hr (4 to 10 mph); driving cycle, Schedule C; ambient temperature, 25° C (77° F); track temperature, 34° C (94° F).
- (v) Run, 41; tire type, EV; tire pressure, 276 kPa (40 psi); date, 6-2-81; time, 10:35 a. m.; wind speed, 10 to 16 km/hr (6 to 10 mph); driving cycle, Schedule C; ambient temperature, 18° C (64° F); track temperature, 26° C (78° F).
- (w) Run, 47; tire type, Viva; tire pressure, 207 kPa (30 psi); date, 6-3-81; time, 4:22 p. m.; wind speed, 13 to 19 km/hr (8 to 12 mph); driving cycle, Schedule B; ambient temperature, 26° C (78° F); track temperature, 31° C (88° F).
- (x) Run, 37; tire type, EV; tire pressure, 207 kPa (30 psi); date, 6-1-81; time, 10:28 a. m.; wind speed, 8 to 16 km/hr (5 to 10 mph); driving cycle, Schedule B; ambient temperature, 15° C (59° F); track temperature, 26° C (79° F).
- (y) Run, 40; tire type, EV; tire pressure, 276 kPa (40 psi); date, 6-2-81; time, 8:57 a. m.; wind speed, 8 to 13 km/hr (5 to 8 mph); driving cycle, Schedule B; ambient temperature, 17° C (63° F); track temperature, 21° C (69° F).

Figure 13. - Concluded.

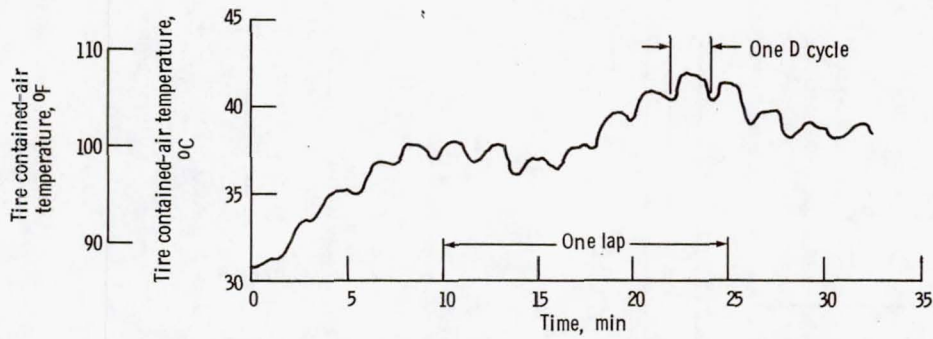


Figure 14. - Contained-air temperature as a function of time for SAE J227a Schedule D driving cycle test, showing effect of Sun radiation.

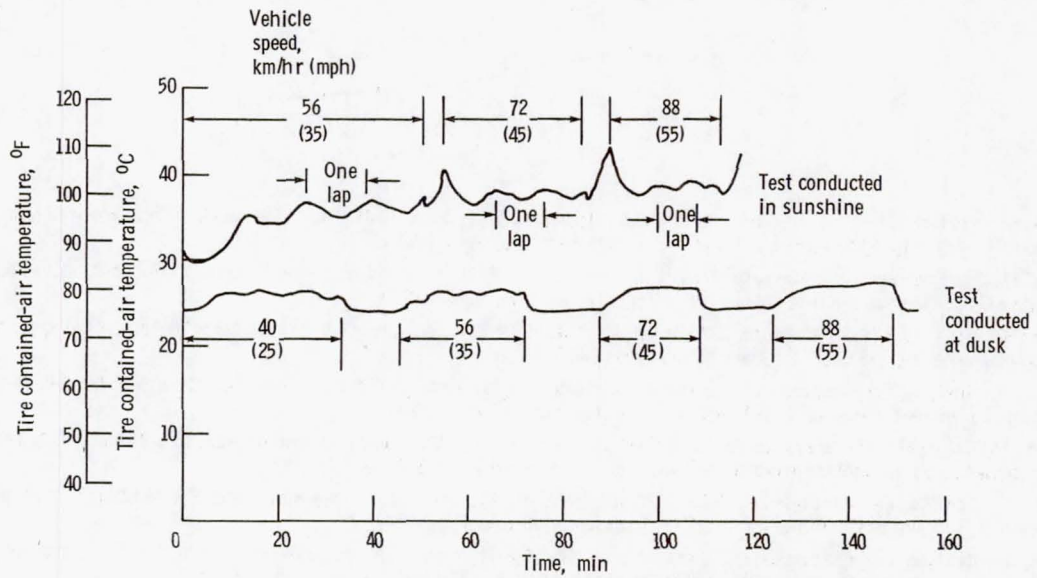


Figure 15. - Comparison of contained-air temperature during tests conducted in sunshine and at dusk.

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16. Abstract Special low-rolling-resistance tires were made for DOE's ETV-1 electric vehicle. Tests were conducted on these tires and on a set of standard commercial automotive tires to determine the rolling resistance as a function of time during both constant-speed tires and SAE J227a driving cycle tests. The tests were conducted on a test track at ambient temperatures that ranged from 15 ⁰ to 32 ⁰ C (59 ⁰ to 89 ⁰ F) and with tire pressures of 207 to 276 kPa (30 to 40 psi). At a contained-air temperature of 38 ⁰ C (100 ⁰ F) and a pressure of 207 kPa (30 psi) the rolling resistances of the electric vehicle tires and the standard commercial tires, respectively, were 0.0102 and 0.0088 kilogram per kilogram of vehicle weight. At a contained-air temperature of 38 ⁰ C (100 ⁰ F) and a pressure of 276 kPa (40 psi) the rolling resistances were 0.009 and 0.0074 kilogram per kilogram of vehicle weight, respectively.			
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