REPORT OF PROJECT COMMITTEE ON TRACTIVE RESISTANCE AND ALLIED PROBLEMS

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AIR RESISTANCE OF MOTOR VEHICLES

BY W E LAY

SYNOPSIS

This report describes a new and direct method of measurement of the air resistance of a motor vehicle For these tests a full size body was built as a floating envelope about a car which supports it Tests were made on the road under actual operating conditions Initial results are given and compared with the results of wind tunnel test on the same body form

Last year we called your attention to our conception of the operation of the motor vehicle as at the bottom of an ocean of air It has helped us to visualize the disturbance of the air caused by the movement of a motor vehicle We said that it must open up a passage way for it to pass through, a passage way whose dimensions are determined by the shape and projected area of the vehicle The front of the streamlined vehicle must be so shaped that it will open up the passage way with the least disturbance of the surrounding air The rear must be shaped to lay the air back in place with a minimum of eddies and turbulence

We reported the results of a year's work with models in the wind tunnel Our procedure was based on experience of aeronautical engineers in tests of planes and airships We found however that the operation of a motor vehicle moving through the air was quite different in two respects It always operated within a few inches of the road and it usually moved into the air body at an angle We tried several methods of approximating the effect of the road in wind tunnel tests with quite inconsistent results

Again we are making a progress report. a report of results of full scale tests made at the University of Michigan under our direction by a group of graduate students, including Mr C D Holton and Mr R B Patterson

In making a survey of the practical methods of determining the air resistance of full size motor vehicles under actual operating conditions we considered the following possibilities—

(a) The towing method
(b) Deceleration on a level road
(c) Coasting down a uniform grade

It will be noted in all three of the above methods that the total resistance is first determined in still air Then by towing or test on a chassis dynamometer the rolling resistance is determined and subtracted from the total to give the air resistance

$$R_a = R - R_r$$

wherein. R = total resistance
R_r = rolling resistance
R_a = air resistance

The first method (a) consists of using one car to tow another at the end of a long cable On one end of the cable is attached a recording draw bar pull dynamometer which records the force transmitted through the cable from the towing to the towed car This method had been given a thorough trial in 1931 and discarded because of the terrific turbulence set up in the wake of the towing car

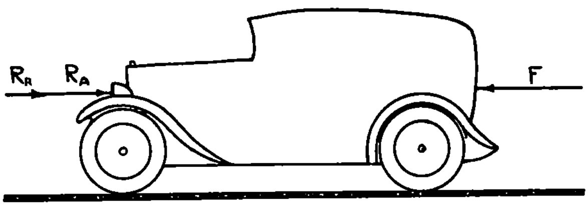

Figure 1. Diagram of Forces Acting on a Car When Coasting on a Level Road

Method (b) consists in driving the car up to its top speed and then letting it coast in neutral to a stop, noting the time required for each five mile decrease in car speed with some type of recording chronometer From these data the deceleration, or rate of speed change may be computed for each speed

If a car is decelerating or coasting at any speed on a level road its speed is decreasing, and its stored energy is decreasing, giving rise to a force that is applied to drive the car forward against the rolling and the air resistance

$$F = Ma = \frac{W}{g} a = R_r + R_a$$

$$K = \frac{\frac{W}{g} a - R_r}{AV^2}$$

where W = gross weight of the vehicle in pounds
g = the acceleration due to gravity in feet per second squared
a = the rate of deceleration for the vehicle in feet per second squared

R_r = the rolling resistance in pounds
A = the projected area of the vehicle in square feet
V = the vehicle speed in miles per hour

The above equation assumes, however, that all of the kinetic energy stored in the vehicle is that due to its linear motion There is stored additional energy in parts which have not only linear but also rotary motion so that the total energy is

$$\text{kinetic energy} = \frac{1}{2}\frac{W}{g}v^2 + \frac{1}{2}Iw^2$$

where v = vehicle velocity in feet per second
I = moment of inertia of the rotating parts
w = angular velocity of the rotating parts in radians per second

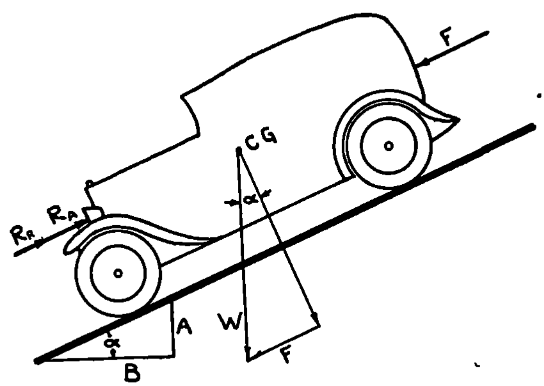

Figure 2. Digram of Forces Acting on a Car When Coasting Down a Grade at Constant Speed

It is therefore necessary to determine the moment of inertia of all rotating parts which include:

All wheels with their tires
Rear axle shaft with differential casing and gears
Propeller shaft with universal joints and pinion
Transmission main shaft with its gears

After the moment of inertia of all rotating parts has been determined is is more convenient to calculate an equivalent weight whose kinetic energy due to its linear speed is equal to the kinetic energy in all of the rotating parts when the car is moving at that speed

$$K = \frac{\frac{W + w}{g}a - R_r}{AV^2}$$

where w = the equivalent weight whose kinetic energy at any car speed is equal to the kinetic energy due to rotation of parts

The moment of inertia of the wheels and tires may be easily obtained but that of the other three items is determined with considerable difficulty

The coasting method "c" consists of driving a car over the brow of a hill of uniform grade and coasting down the grade at uniform speed The speed which will be maintained at a constant value by any car on a given grade is determined by trial Once that speed is determined we know that at that speed the component of the vehicle weight which tends to roll the vehicle down hill is equal to the rolling resistance plus the air resistance

$$F = R_r + R_a$$

$$F = W \sin \alpha$$

$$\tan \alpha = \frac{a}{b}$$

$\tan \alpha = \sin \alpha$ for grades less than 8 per cent without serious error

$$F = W\frac{a}{b}$$

$$\frac{a}{b} \times 100 = G$$

$$F = \frac{WG}{100} = R_r + R_a$$

$$K = \frac{\frac{WG}{100} - R_r}{AV^2}$$

where G = grade in per cent

= angle of grade in degrees

If a determination is to be made at any other speed a hill of a different uniform grade must be located and new tests made

Just as we had decided to adopt the deceleration method there came an inspiration, we would build a "floating envelope" We took a low priced car which had been loaned to us and removed the doors, hood, fenders and bumpers About the regular coupe body we built the "floating envelope" corresponding in shape to the rectangular box tested in the wind tunnel This envelope shown in Figures 3 and 4 was made of pressed wood panels fastened to a light wood frame well braced with wood braces and piano wire with airplane type turnbuckles The corners and edges are detachable so that sharp edges, and rounded edges of 6 and 9 inch radii may be investigated The edges are made of wire mesh fastened over a light frame work with airplane fabric stretched over the whole and doped so that it is as taut as a drum head All joints are covered with doped fabric On the front and rear bumper supports are mounted four ball bearing rollers shown in Figure 5 The frame work of the envelope is supported by steel tubing, which can move forward or backward on the grooved rollers. Thus the envelope is free to move forward or backward several inches on the ball bearing rollers. As the car inside the envelope is driven forward the air pressure tends to drive the envelope to the rear. This motion is restrained only by a piano wire connecting the envelope to a draw bar dynamometer

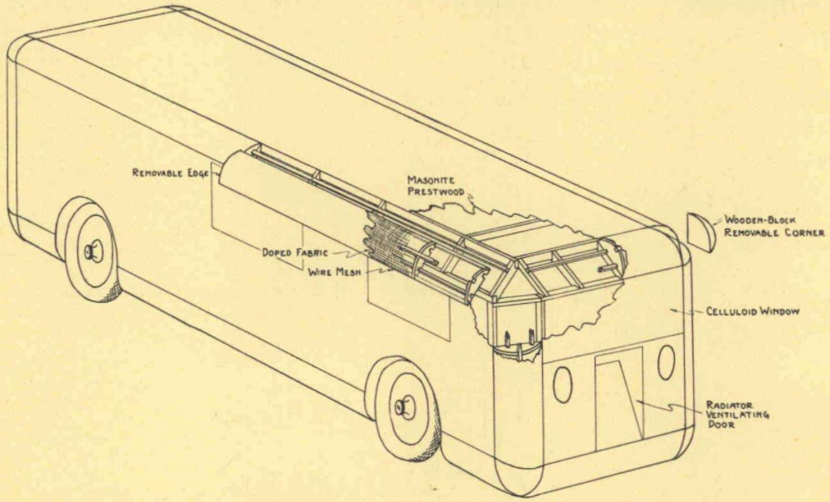

Figure 3. Sectional Diagram of the "Floating Envelope"

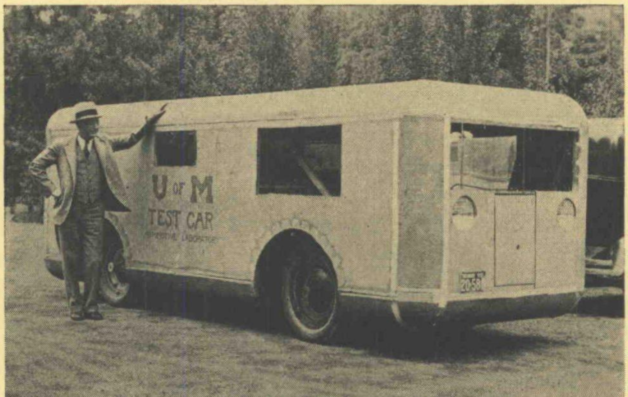

Figure 4. Car Equipped with a "Floating Envelope"

mounted in the rear of the car, as shown in Figure 6. This wire transmits from the car inside, to the envelope the force required to drive the envelope forward through the air. The forward end of the wire is attached by a link to a knife edge on the short arm of a bell crank which in turn pulls down on a Chatillon spring scale.

A four mile course of approximately level and smooth concrete road was located A mile of this road in the middle of the course was accurately measured Red lights were placed at each end of the measured mile and at one end of the course a miniature weather bureau station was set up to measure wind velocity and direction and the temperature, pressure, and humidity of the air The car was driven over the full length of the course on each high speed run On starting the run the

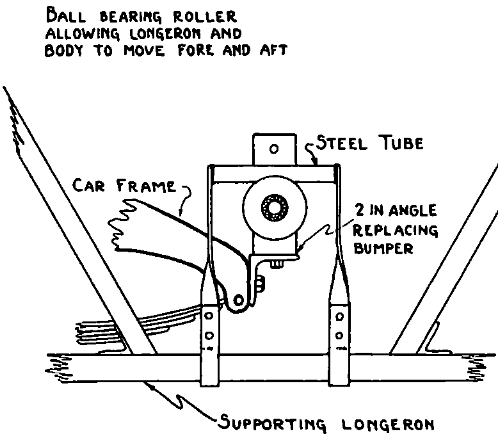

Figure 5. Ball Bearing Roller Allowing Longeron and Floating Body to Move Fore and Aft

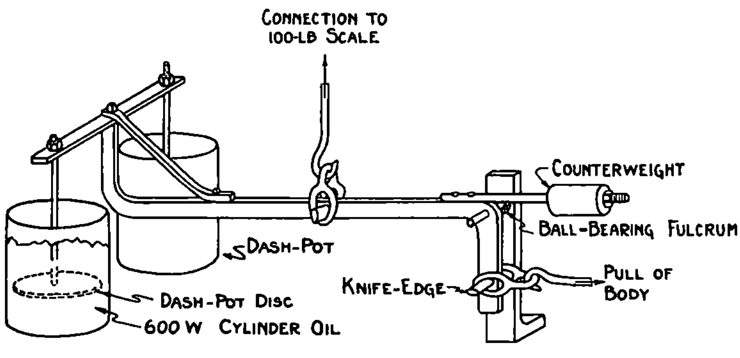

Figure 6. Dynamometer for Measuring Air Force on the "Floating Envelope"

throttle was adjusted at once to a point found by previous trial to give approximately the desired speed At the beginning of the test mile two stop watches were started and the observer began taking readings on the dynamometer as rapidly as possible At the end of the test mile both watches were stopped and the average speed over the course computed Immediately a test run was made in the opposite direction This was continued at different speeds until wind conditions made further test runs impossible

The dynamometer was calibrated before and after each set of runs to make certaın that no part of the apparatus had shıfted From the calıbratıon results the scale readıngs made on the test were converted to aır resıstance force ın pounds These results were then corrected to apply to standard aır condıtıons, 59°F temperature, 29 92 ınches

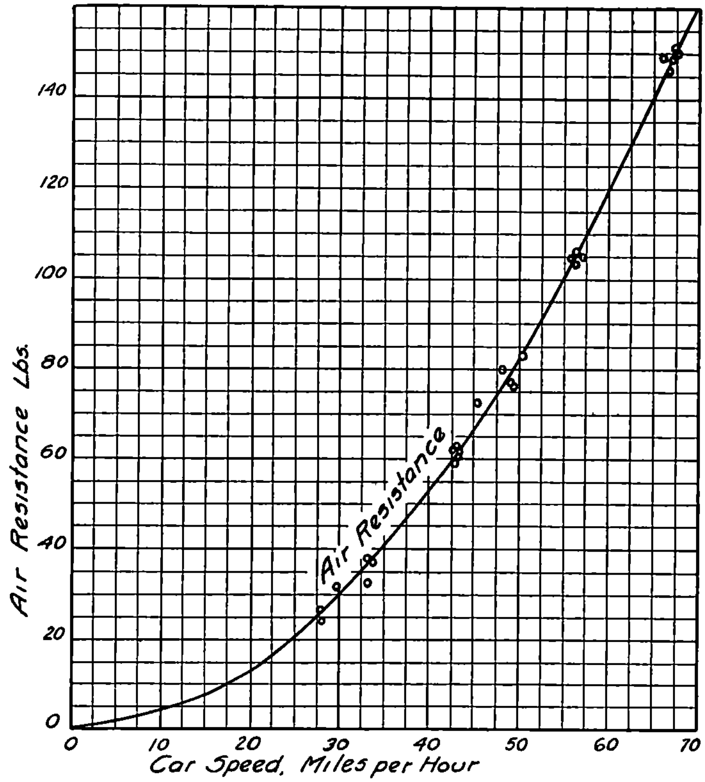

Figure 7 Drag Curve of the Floating Envelope

mercury pressure, and densıty of 076511 pounds per cubıc foot, assumıng that the aır resıstance varıes dırectly wıth the densıty of the aır

$$\text{Density of air} = \frac{080723}{1 + 002039(t - 32)} \times \frac{B - 378\,e}{29\ 92}$$

t = dry bulb temperature ın deg F

B = observed barometrıc pressure corrected to 32°F

e = water vapor pressure ın ınches of mercury as obtaıned by Carrıers equatıon

The values of the aır resıstance are then plotted on rectangular coordınates agaınst car speed as shown ın Fıgure 7 The average of a group of poınts ıs obtaıned by computıng the mean force for the mean speed assumıng the force to vary as the square of the speed When a smooth curve has been drawn, data read from the curve gıve us the data ın

Table I Through the kind cooperation of the staff of the General Motors Proving Ground, tests were made on the floating envelope by the deceleration method The value of "K" determined over a speed range of 15 to 55 miles per hour was 00103, in excellent agreement with the results of Table I

TABLE I

Speed M P H	Measured air resistance	"K" in $R_a = KAV^2$
	lbs	
30	30 0	001042
40	52 7	001029
50	81 7	001020
60	120 0	001041
70	162 0	001033
Average		001033
	By extrapolation	
10	3 25	00102
20	13 2	00103

TABLE II

Speed M P H	Measured air resistance	Exponent "n" in $R = KAV^n$	Coefficient "K" in $R_a = KAV^n$
	lbs		
10	3 25	1 98	001026
20	13 2	1 98	001046
30	30 0	1 98	001064
40	52 7	1 98	001060
50	81 7	1 98	001055
60	120 0	1 98	001081
70	162 0	1 98	001075

There is the possibility that the air resistance does not vary exactly as the square of the velocity but may be

$$R_a = KAV^n$$

By plotting the air resistance data of Table I on logarithmic coordinates, as shown in Figure 8, we find that all of the points lie on a straight line with a slope of 1 98 which determines the value n = 1 98 We can accurately extrapolate a straight line to obtain the resistance at lower speeds as given in Table I Knowing the value of the exponent we can determine the value of "K" for each speed and obtain the modified table (Table II) Such are the results so far, meagre indeed but indicative of a research problem fully worthy of our metal It is probably the first time that the air resistance of a motor vehicle has been determined directly, on the road, under actual operating conditions The work so far has been surrounded with many difficulties, only by tedious trial and error has the technique of test been developed

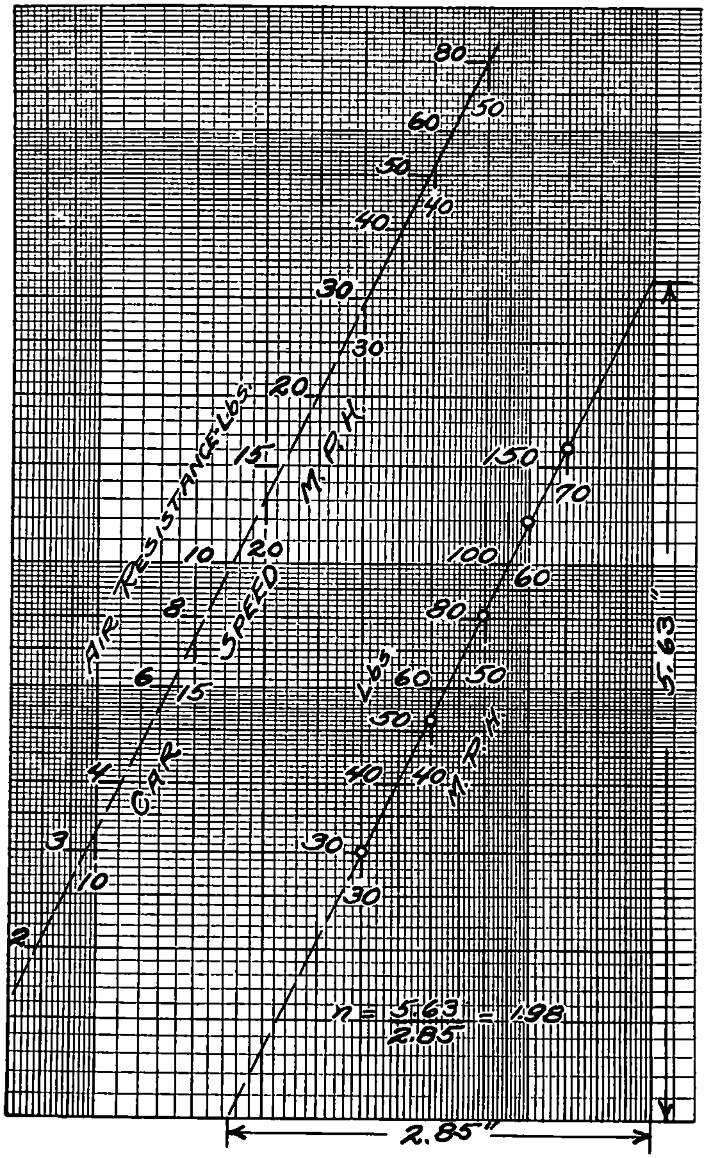

Figure 8 Drag Curve Plotted on Logarithmic Paper

Right: Plot of data to determine exponent n

Left· Extrapolation to determine drag at lower speeds.

The models tested in the wind tunnel had no radiator opening so the envelope body was built without one and the engine became hot and the coolıng system boıled A door was then arranged ın both front and rear to allow cırculatıon rıght up to the tıme the car moves on to the test mıle when both doors are closed and cold water ıs automatıcally pumped ınto the coolıng system from an extra supply tank carrıed on the car

The envelope ıs quıte lıght so was pushed and pulled by the turbulent eddıes at the rear so vıolently that the scale could not be read untıl the great dash pots shown ın Fıgure 6, were ınstalled

A very slıght wınd, ın fact any wınd that would run the Frıeze anemometer would cause the poınts to fall away off the curve So a call ıs put ın to the weather bureau every day to ask whether the wınd wıll be low the followıng nıght and then only the perıod from 3 A M to 7 A M ıs usually avaılable for accurate test results

In calıbratıng the dynamometer ıt was found that the rear axle torque reactıon and the wınd pressure both tılted the car backward changıng the level of the rollers The car sprıngs had so much frıctıon ın them that they would not return to a normal posıtıon after beıng compressed Fınally all calıbratıon was made wıth the engıne drıvıng the rear wheels on the drums of the chassıs dynamometer takıng great paıns to keep the weıght dıstrıbutıon ın the vehıcle exactly the same

Thus we find plenty of dıfficulty ın workıng out thıs new method, but we are goıng to complete the work on at least two models, the rectangular box and a practıcal streamlıned body lıke that shown here ın 1931 Wınd tunnel tests of exact replıcas made to one-eıghth scale wıll be made so that we wıll have correlated test data for a body of the truck or bus type and of an automobıle of very low aır resıstance

TRACTIVE RESISTANCE DETERMINATIONS WITH A GAS-ELECTRIC DRIVE AUTOMOBILE

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SYNOPSIS

Calıbratıon tests and road tests made wıth a car wıth a gas-electrıc drıve are descrıbed ın thıs paper Runs have been made on concrete, treated gravel, untreated gravel, and wet muddy roads Curves have been plotted to show gas consumptıon, power requırements and attractıve resıstance on these surfaces at speeds up to sıxty mıles per hour Durıng the course of these researches, several ınterestıng dıscoverıes have been made as to the effect of speed on tıre dıameters and the effect of tıre ınflatıon on power requırements

Thıs ıs a progress report on a project started by the Iowa Engıneerıng Experıment Statıon several years ago and descrıbed by the author at the 1931 meetıng of the Hıghway Research Board An opınıon that the set-up would provıde an accurate and dependable method of determınıng the