eliminate this duplication, a deduction has been made in combining road costs and vehicle costs This deduction is shown in column (13), and amounts to about 14/23 of the total motor vehicle tax contributions

The costs of transportation in column (14) vary in nearly the reverse order from the road costs in column (10) That is, although the road costs for the modern types are much higher than those for the lower types, the cost of transportation for these modern types is less than for the old types This is further evidence that the old types should be replaced by modern types In fact, the road costs for these old types could be doubled in order to provide a modern pavement, and still the resulting cost of transportation would be lower than at present due to the saving effected in vehicle operating cost

In conclusion, the purpose of this study was to illustrate the application of an economic analysis to a system of connected highways, and to point out the value and use of the information obtained from such a study In this paper the results are presented graphically in a flow sheet of road costs and contributions This chart shows at a glance the economic relationship between all parts of the highway system studied It points out those roads which appear to have more than their share of development and those which have less It suggests the need of further study to determine the justification for the road costs on those roads which are high in cost and to determine the advisability of improving those roads which are low in cost It serves as a basis for planning highway improvement and studying the effects of such improvement on the system as a whole With certain modifications it can be used to estimate the amount of motor vehicle revenue required for the system, and the proper distribution of expenditures of this revenue among the different highways in the system

The next step in an analysis of this kind would be to prepare a flow sheet of transportation costs, including both road costs and vehicle operating costs This will require the development of a simple method for measuring vehicle operating costs over a considerable mileage of pavements of different type and condition

AIR RESISTANCE OF MOTOR VEHICLES

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SYNOPSIS

Tests were made on 54 automobiles in the wind tunnel at Kansas State College in 1932 and 1933 Check tests were made on two cars by coasting down hills

The 54 cars represent 14 makes, 7 yearly models, and 4 body types A succession of yearly models of the same make were secured whenever possible Duplicate wind tunnel tests were made on three cars at a later date and under different atmospheric conditions The greatest individual difference in the duplicate tests was 4 per cent

The authors conclude that

1 A wind tunnel capable of testing full-size automobiles offers a practical

means of determining the wind resistance of automobiles There is no scale effect for such tests Rolling resistance is not a factor Comparison with the coasting tests indicates that the much dreaded ground effect in wind tunnel tests is probably small

2 Coasting tests carefully made on smooth pavements afford a practical method of determining the wind resistance

3 In the wind resistance formula $P = K'AV^n$ these tests indicate that the exponent is close to 2, the average being 2 02 for the fifty-four cars tested

4 Of the cars tested, the later models show in general a definite improvement in aerodynamic characteristics

5 The passenger load in a car decreases the wind resistance below wind tunnel values in direct proportion to the decrease in projected area

The Committee under the auspices of which this report is being submitted was organized about fifteen years ago under the leadership of Dean T R Agg Dean Agg, then Professor of Highway Engineering at the Iowa State College, presented the problems of the Committee to a group of institutions of which one happened to be the Kansas State College We were asked if we would be interested in working on any of the problems Some perversity of fate suggested to us this one of, "Air Resistance of Automobiles," which we have been unable either to drop or to completely solve up to the present time

At the time the work was started under the direction of Dean Agg, comparatively little work had been done on the problem Since that time, however, a number of experimenters have worked with it Some of the work has been reported, but we have an idea that a large amount of work has been done by privately controlled laboratories and has not been reported It is, therefore, quite likely that a considerable amount of work has been done with which the writers are not familiar

During the earlier years of our work, very material assistance was given to us by the Bureau of Public Roads It was at that time that the wind tunnel for testing full sized cars was built, and in which an attempt was made to determine the air resistance of 22 motor vehicles of various types, mostly open cars manufactured between 1917 and 1925 (1) [1]

About four years ago it became evident that the wind tunnel, which was built mostly of timber and without protection, would, within the next few years deteriorate to such an extent as to make it unsafe for high air speeds This, together with the further consideration that considerable interest was then being shown in the aerodynamic characteristics of automobiles, inspired us to undertake the series of tests which are reported herein In this later series of tests, wind tunnel determinations of the wind resistance of 54 automobiles were made with an independent check by coasting The results of the investigation are presented as evidence—not as proof We protect ourselves because many of the variable factors which must be dealt with can be only approximately evaluated, and it is extremely difficult for any one working this field to be absolutely sure of results The 54 cars represent 14 makes, 7 yearly models, and 4 body types

At about the time this work was started manufacturers were just beginning to become conscious of the extremely unfavorable shapes of American automo-

[1] Numbers in parentheses refer to list of references at end

TABLE I

DATA AND TEST RESULTS

Make of Car	Year	Body Type	Fig No	Projected Area sq ft	Total Resistance at 50 mi per hr lbs	Unit Resistance at 50 mi per hr lb per sq ft of proj Area	H P Required to overcome Wind Resistance at 50 mi per hr	General Wind Resistance Formula $P = K^1AV^n$	Conventional Wind Resistance Formula $P = K AV^2$	Remarks (All cars carried rear spare unless otherwise noted)
Auburn	1931	Sedan	3	29 18	128 7	4 41	17 18	$0\ 00174AV^{2\ 00}$	$0\ 00174AV^{2\ 00}$	
Austin	1930	Coupe	4	17 35	73 5	4 24	9 82	$0\ 00169AV^{2\ 00}$	$0\ 00169AV^{2\ 00}$	
Buick	1929	Sedan	5	29 03	131 5	4 53	17 53	$0\ 00199AV^{1\ 98}$	$0\ 00185AV^{2\ 00}$	
Buick	1930	Sedan	6	27 96	124 8	4 46	16 64	$0\ 00190AV^{1\ 98}$	$0\ 00177AV^{2\ 00}$	Trunk, 2 fender wells
Buick	1931	Sedan	7	27 54	119 6	4 34	15 95	$0\ 00208AV^{1\ 95}$	$0\ 00174AV^{2\ 00}$	
Buick	1932	Sedan	8	28 26	119 0	4 21	15 86	$0\ 00203AV^{1\ 95}$	$0\ 00170AV^{2\ 00}$	2 tires in fender wells; 2 horns
Buick	1932	Coupe	9	27 94	113 1	4 05	15 09	$0\ 00113AV^{2\ 09}$	$0\ 00156AV^{2\ 00}$	
Chevrolet	1927	Coach	10	25 98	129 0	4 96	17 20	$0\ 00142AV^{2\ 03}$	$0\ 00189AV^{2\ 00}$	Without trunk, no spare
Chevrolet	1927	Coach	11	25 98	114 5	4 41	15 27	$0\ 00189AV^{1\ 98}$	$0\ 00176AV^{2\ 00}$	Trunk and rear spare
Chevrolet	1928	Coach	12	26 04	115 3	4 43	15 37	$0\ 00126AV^{2\ 09}$	$0\ 00174AV^{2\ 00}$	Rear rim, no tire
Chevrolet	1929	Coach	13	26 56	125 0	4 70	16 67	$0\ 00154AV^{2\ 05}$	$0\ 00184AV^{2\ 00}$	
Chevrolet	1930	Coach	14	26 56	121 6	4 58	16 22	$0\ 00175AV^{2\ 01}$	$0\ 00181AV^{2\ 00}$	
Chevrolet	1931	Sedan	15	26 36	130 4	4 96	17 40	$0\ 00259AV^{1\ 93}$	$0\ 00202AV^{2\ 00}$	
Chevrolet	1932	Coach	16	26 95	128 3	4 76	17 12	$0\ 00175AV^{2\ 02}$	$0\ 00188AV^{2\ 00}$	
Chevrolet	1932	Coupe	17	26 01	107 1	4 12	14 28	$0\ 00131AV^{2\ 06}$	$0\ 00162AV^{2\ 00}$	
Chevrolet	1931	Cabriolet	18	27 00	106 8	3 96	14 25	$0\ 00148AV^{2\ 02}$	$0\ 00159AV^{2\ 00}$	
Cord	1931	Sedan	19	29 00	143 6	4 95	19 16	$0\ 00180AV^{1\ 99}$	$0\ 00174AV^{2\ 00}$	2 tires in fender wells
Dodge	1927	Sedan	20	26 83	126 0	4 70	16 82	$0\ 00206AV^{1\ 98}$	$0\ 00192AV^{2\ 00}$	
Dodge	1928	Sedan	21	26 30	121 0	4 60	16 14	$0\ 00192AV^{1\ 99}$	$0\ 00185AV^{2\ 00}$	
Dodge	1929	Sedan	22	26 08	123 6	4 74	16 50	$0\ 00141AV^{2\ 08}$	$0\ 00187AV^{2\ 00}$	
Dodge	1930	Sedan	23	28 74	131 0	4 56	17 48	$0\ 000832AV^{2\ 20}$	$0\ 00169AV^{2\ 00}$	
Dodge	1931	Sedan	24	27 04	122 0	4 52	16 27	$0\ 00122AV^{2\ 10}$	$0\ 00173AV^{2\ 00}$	
Dodge	1932	Sedan	25	27 53	115 1	4 18	15 36	$0\ 00150AV^{2\ 03}$	$0\ 00167AV^{2\ 00}$	2 tires in fender wells
Ford	1925	Coach	26	27 29	133 1	4 88	17 77	$0\ 00175AV^{2\ 02*}$	$0\ 00193AV^{2\ 00}$	
Ford	1927	Sedan	27	27 38	128 0	4 68	17 07	$0\ 00192AV^{1\ 99}$	$0\ 00185AV^{2\ 00}$	
Ford	1929	Coach	28	25 97	111 6	4 30	14 89	$0\ 000789AV^{2\ 20}$	$0\ 00196AV^{2\ 00}$	
Ford	1930	Sedan	29	27 31	125 3	4 59	16 71	$0\ 00165AV^{2\ 03}$	$0\ 00183AV^{2\ 00}$	Std tires, wind wing

Ford	1930	Sedan	30	27 54	117 8	4 28	15 72	0 00167$AV^{2\ 01}$	0 00173$AV^{2\ 00}$	Aır balloons, wınd wıngs
Ford	1931	Sedan	31	26 74	116 1	4 34	15 49	0 00285$AV^{1\ 87}$	0 00180$AV^{2\ 00}$	Trunk, 2 tıres ın wells
Ford V8	1932	Sedan	32	25 94	105 0	4 05	14 01	0 00198$AV^{1\ 98}$	0 00185$AV^{2\ 00}$	
Ford V8	1932	Coupe	33	24 91	102 8	4 13	13 72	0 00165$AV^{2\ 00}$	0 00165$AV^{2\ 00}$	
Graham-Paıge	1928	Sedan	34	26 38	123 2	4 68	16 42	0 00231$AV^{1\ 95}$	0 00194$AV^{2\ 00}$	
Graham-Paıge	1929	Sedan	35	27 84	128 1	4 59	17 08	0 00208$AV^{1\ 97}$	0 00187$AV^{2\ 00}$	
Graham-Paıge	1930	Sedan	36	28 40	132 0	4 64	17 60	0 00144$AV^{2\ 06}$	0 00179$AV^{2\ 00}$	Trunk, 2 tıres ın wells
Graham-Paıge	1931	Sedan	37	28 25	128 5	4 55	17 13	0 00171$AV^{2\ 02}$	0 00183$AV^{2\ 00}$	Spot lıght
Graham-Blue Streak	1932	Sedan	38	29 03	120 5	4 15	16 07	0 00135$AV^{2\ 05}$	0 00161$AV^{2\ 00}$	2 tıres ın fender wells
Hudson	1928	Coach	39	26 63	126 8	4 76	16 90	0 00153$AV^{2\ 06}$	0 00190$AV^{2\ 00}$	Trunk, tıre on rear
Hudson	1929	Sedan	40	28 51	128 5	4 51	17 12	0 00180$AV^{2\ 00}$	0 00180$AV^{2\ 00}$	1 tıre ın fender well
Hudson	1930	Sedan	41	27 61	138 2	5 00	18 41	0 00140$AV^{2\ 09}$	0 00193$AV^{2\ 00}$	Trunk, 2 tıres ın wells
Hudson	1931	Sedan	42	27 92	137 9	4 94	18 38	0 00117$AV^{2\ 13}$	0 00186$AV^{2\ 00}$	Trunk, 2 tıres ın wells
Hudson	1932	Sedan	43	28 73	121 8	4 24	16 23	0 00236$AV^{1\ 92}$	0 00177$AV^{2\ 00}$	
Plymouth	1929	Sedan	44	26 25	115 0	4 38	15 35	0 00203$AV^{1\ 96}$	0 00176$AV^{2\ 00}$	
Plymouth	1930	Sedan	45	27 01	121 3	4 49	16 18	0 00192$AV^{1\ 98}$	0 00178$AV^{2\ 00}$	
Plymouth	1931	Sedan	46	26 70	120 5	4 51	16 06	0 00174$AV^{2\ 01}$	0 00180$AV^{2\ 00}$	
Plymouth	1932	Sedan	47	26 51	105 6	3 98	14 08	0 00148$AV^{2\ 02}$	0 00159$AV^{2\ 00}$	
Plymouth	1932	Coupe	48	24 97	115 8	4 63	15 44	0 000981$AV^{2\ 16}$	0 00173$AV^{2\ 00}$	
Pontıac	1928	Coach	49	26 08	110 4	4 23	14 72	0 00156$AV^{2\ 02}$	0 00168$AV^{2\ 00}$	
Pontıac	1929	Coach	50	27 30	125 6	4 60	16 75	0 00160$AV^{2\ 04}$	0 00185$AV^{2\ 00}$	
Pontıac	1930	Sedan	51	27 60	125 9	4 56	16 80	0 00102$AV^{2\ 15}$	0 00174$AV^{2\ 00}$	
Pontıac	1931	Coach	52	27 64	123 4	4 47	16 45	0 00195$AV^{1\ 98}$	0 00181$AV^{2\ 00}$	
Pontıac	1932	Coach	53	27 87	123 7	4 44	16 51	0 00127$AV^{2\ 09}$	0 00175$AV^{2\ 00}$	
Pontıac	1932	Coupe	54	26 56	117 5	4 43	15 68	0 00136$AV^{2\ 07}$	0 00174$AV^{2\ 00}$	2 horns ın front
Studebaker	1931	Sedan	56	28 41	125 0	4 39	16 66	0 00177$AV^{2\ 00}$	0 00177$AV^{2\ 00}$	2 tıres ın fender wells
Wıllıs-Overland	1932	Sedan	57	27 93	141 1	5 05	18 82	0 00199$AV^{2\ 00}$	0 00199$AV^{2\ 00}$	2 horns
Wıllıs-Overland	1933	Sedan	58	27 84	124 2	4 46	16 57	0 00158$AV^{2\ 03}$	0 00176$AV^{2\ 00}$	2 horns
Reo	1932	Sedan	55	29 14	122 4	4 20	16 32	0 00167$AV^{2\ 00}$	0 00167$AV^{2\ 00}$	2 horns

biles, and the move toward an improvement was starting It was with the hope of establishing a quantitative measure of the accomplishments during the first few years that the tests we are now describing were undertaken A succession of yearly models of the same make was, therefore, secured whenever possible In some cases, individual cars were tested because they possessed some unusual feature The Cord has the front drive, and the Austin is the smallest American car

As a general check of procedure and equipment, duplicate wind tunnel tests were made on three cars at a later date and under different atmospheric conditions The greatest individual difference between the two tests of the same car was 4 per cent

Table I gives a description of the cars tested together with the results of the wind tunnel test on each car The range in data of manufacture was from 1925 models to 1933 models In making the tests the windows and wind-shields were closed, and unless otherwise noted, a spare tire was attached at the rear of the car

The cars used for these tests were privately owned and in all cases were in actual service by the owner from whom they were borrowed for the purpose of running the tests

THE WIND TUNNEL

The old wind tunnel with a few modifications, was used The only important change made was the substitution of a Liberty engine for the two 55 h p electric motors to drive the fan With the motors, we were able to obtain air speeds of 38 to 40 miles per hour in the measuring section With the Liberty engine, air speeds of 48 and 50 miles per hour were obtained

The 1932 wind tunnel tests were all made with the cars in a standard position on the tunnel platform Each car to be tested was placed in the tunnel with the rear glass of the sedans and coaches and the rear axle of coupes in line with index marks on the tunnel walls

It was observed that the position of the car in the tunnel affected the resistance Consequently, a calibration test was run on the tunnel following the other tests Three cars, a 1935 Ford sedan, a 1929 Buick sedan, and a 1928 Dodge sedan were placed in a number of positions and complete test runs made The cars were placed 9 in and 18 in back of standard, in standard position, and at 12, 24, 36, 48, and 60 in ahead of standard position A study of the data indicated that the cars should have been 36 in ahead of standard position A calibration curve was drawn from the data and the results presented here have been corrected as indicated by the calibration curve

After the instruments and the tunnel itself had been calibrated, the work involved in running a test on one car was not great It required the services of three men for about two hours Of course, the work had to be limited to periods during which the natural winds were low, generally not over two miles per hour In general, the operation of the plant was entirely satisfactory

PROCEDURE

In the tunnel tests, the car was backed into the tunnel and locked in position on the swinging platform In this position the air flowed past the car from front to rear, simulating the flow past a car moving through still air

The platform, 7 ft 6 in by 13 ft 5 in , in the enlarged portion of the tunnel, is supported beneath the floor on two beams which are suspended from the roof by four chains outside of the tunnel walls The platform may swing longitudinally in the tunnel, but its movement is resisted by a dynamometer spring in the instrument room The spring is attached to the front of the platform through a link motion, and the pull on the platform was measured by the deflection of the spring

The wind velocity was measured by a Pitot tube mounted on a movable stand in the center of the tunnel, 30 in ahead of the platform, 36 in from the floor, and connected to a bottle manometer in the instrument room The height of the liquid in the manometer was read on an inclined tube

All cars were tested in the same way The car was backed into the tunnel and locked in position on the platform The platform was then released and the Pitot tube set up With the zero of the instruments recorded, the engine was started and allowed to warm up Then beginning at 600 R P M the speed of the engine was increased by steps of about 200 R P M until 1450 was reached This was the maximum speed of the en- with the propeller which was used At each engine speed the instruments were allowed to reach equilibrium and simultaneous readings of the Ames dial and inclined tube were taken

After a run, the engine speed was reduced to the starting figure and a second similar run was made with another observer reading the instruments The data from both runs were used in the calculations

By means of a calibration table the dial reading was changed to pounds This quantity was then corrected for standard temperature and pressure to give total pull

The general air resistance formula $P = K'AV^n$ was used in reducing the data P in the formula is determined as previously described The first step in computing K′ was to plot the individual points, plotting the air resistance, or pull, as ordinates and velocities as abscissae The equation of the curve most nearly representing these data was determined by the method of averages (2)

In general, the exponent of V determined in this manner was very close to 2 The average value for all of the computed exponents of V is 2 02 Of the 54 curves which were computed, only six had exponents varying by more than 5 per cent from 2, that is, falling outside of the range 1 90 to 2 10

The computed curves were transformed into the conventional one $P = KAV^2$ by evaluating P at 35 miles per hour by use of the computed formula This value of P was then inserted in the formula $P = KAV^2$ to obtain K In all cases, the value of K for use in the conventional formula was obtained by this method

Table II shows the unit resistance, K, for the various cars tested as obtained from the conventional formula The cars in this table are arranged in seven groups The grouping depends on the date of manufacture and the general type and size of body Cars in group I range in year models from 1925 to 1927, while those in group VI and VII are 1932 except one 1933 model The K for the first group is 0 00190 and for the last group 0 00166 Group II contains car models running from 1928 to 1930 The average K for the group being 0 00183

In Figure 1, the 1928 and the 1929 Dodge sedans shown are from group II

TABLE II

Unit Resistances Class Groupings

		"K"
	Group I	
1925	Ford Coach	0 00193
1927	Ford Sedan	0 00185
1927	Chevrolet Coach	0 00189
1927	Dodge Sedan	0 00192
Average		0 00190
	Group II Short Bodied Models	
1928	Pontiac Coach	0 00168
1928	Chevrolet Coach	0 00173
1928	Dodge Sedan	0 00185
1929	Dodge Sedan	0 00187
1929	Ford Coach	0 00196
1929	Plymouth Sedan	0 00176
1928	Graham Paige Sedan	0 00194
1929	Graham Paige Sedan	0 00187
1930	Graham Paige Sedan	0 00179
Average		0 00183
	Group III Short Bodied Models	
1929	Chevrolet Coach	0 00184
1930	Chevrolet Coach	0 00181
1931	Chevrolet Sedan	0 00202
1929	Pontiac Coach	0 00185
1931	Pontiac Coach	0 00181
1930	Dodge Sedan	0 00169
1930	Plymouth Sedan	0 00179
1930	Ford Sedan	0 00183
1931	Ford Sedan	0 00179
Average		0 00183
	Group IV Long Bodied Cars	
1928	Hudson Coach	0 00190
1929	Hudson Sedan	0 00180
1930	Hudson Sedan	0 00193
1929	Buick Sedan	0 00185
1930	Buick Sedan	0 00177
1931	Buick Sedan	0 00174
1930	Pontiac Sedan	0 00174
1931	Dodge Sedan	0 00174
1931	Graham Paige Sedan	0 00183
1931	Studebaker Sedan	0 00177
Average		0 00181

TABLE II—*Concluded*

		"K"
	Group V Long Bodied Cars	
1931	Hudson Sedan	0 00186
1931	Auburn Sedan	0 00168
1931	Cord Sedan	0 00174
Average		0 00176
	Group VI New Cars	
1932	Ford Sedan	0 00185
1932	Pontiac Coach	0 00175
1932	Chevrolet Coach	0 00188
1932	Graham Paige Sedan	0 00161
1932	Reo Sedan	0 00167
1932	Plymouth Sedan	0 00159
1932	Dodge Sedan	0 00167
1932	Buick Sedan	0 00170
1932	Hudson Sedan	0 00173
1933	Willis-Overland Sedan	0 00176
Average		0 00172
	Group VII New Coupes	
1932	Pontiac	0 00174
1932	Plymouth	0 00173
1932	Chevrolet	0 00162
1932	Buick	0 00156
1932	Ford	0 00165
Average		0 00166

The figure also shows the curves representing the total air resistance of these models The plotted points indicated by circles are the corrected wind tunnel readings obtained as above described In Table II, the average value of K for the first group of cars, that is, the old ones is 14 per cent higher than the average value of K for group VII, the later cars The difference in date of manufacture being about five years In Figure 2 are shown two of the later cars tested together with the curves, as in the case of the preceding figure In some cases, the total resistance of the model shown has been further decreased by a decrease in the projected area of the bodies as may be

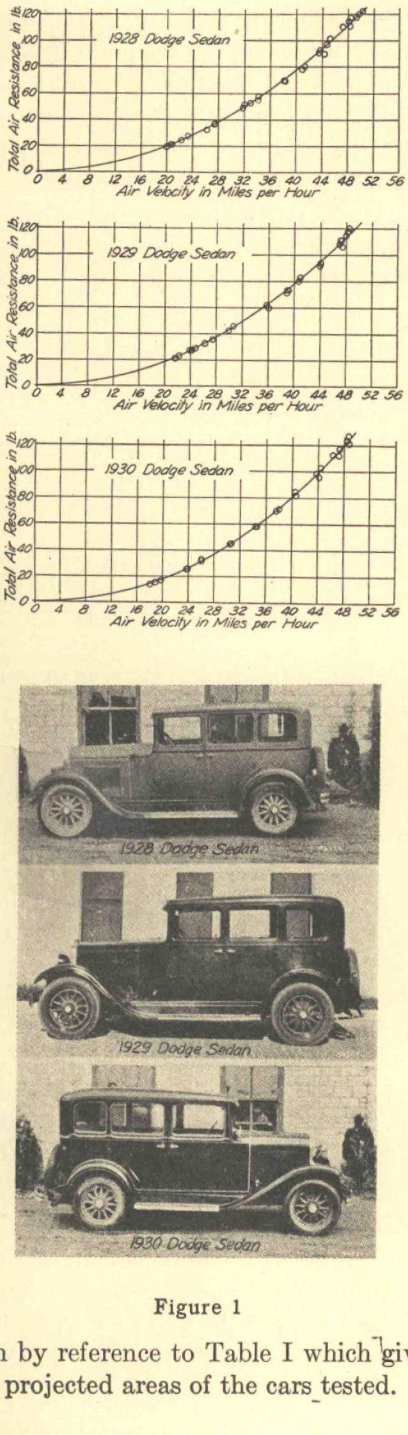

Figure 1

seen by reference to Table I which gives the projected areas of the cars tested.

It may be noted here that while the conventional formula $P = KAV^2$ may

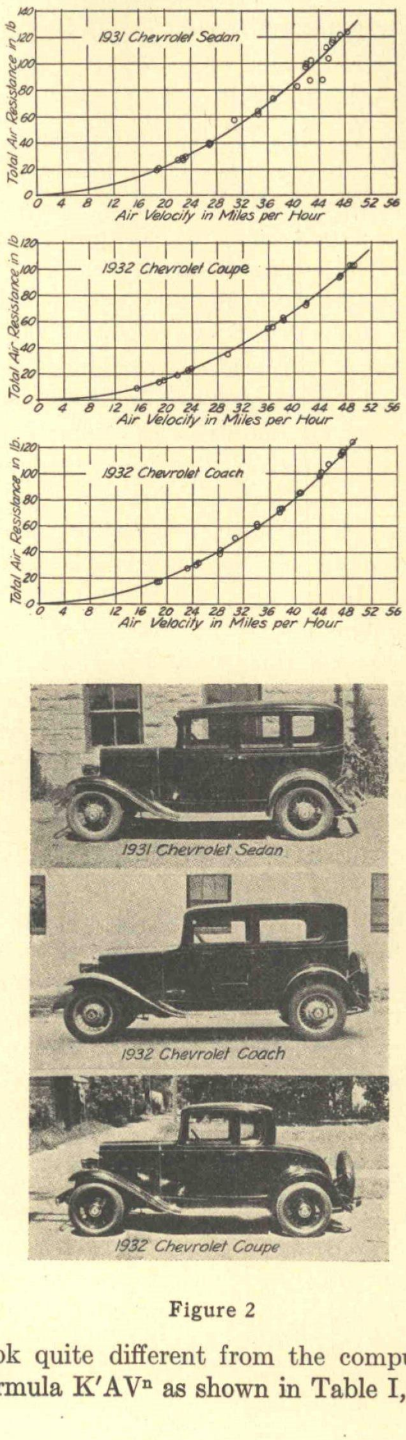

Figure 2

look quite different from the computed formula $K'AV^n$ as shown in Table I, the fact is that when evaluated at any given speed within the limits of the experiments, the two formulas will give results that are nearly the same

ROAD TESTS

Investigation of the air resistance of cars by the coasting method involves the determination of the rolling resistance This resistance may be assumed as constant over a range of speeds or it may be evaluated Its evaluation presents a difficult problem R G Paustian (3) of the Iowa Engineering Experiment Station solved the problem by installing a generator and motor in a Cadillac sedan in place of the transmission He measured the electrical energy required by the car under various conditions at rest on a dynamometer, and traveling along the road In this way he separated the rolling and air resistances E H Lockwood (4) also published results of rolling resistance tests made at Yale

It can readily be seen that a vehicle moving down a grade will be accelerated by a force equal to 20 T G , where T is the total weight of the vehicle in tons, and G is the rate of grade expressed in per cent

This acceleration will be opposed by forces which may be grouped under two heads first, the wind resistance, second, the rolling resistance The first may be represented by the expression KAV^2, the second, by the product TR, where T is, again, the weight of the vehicle in tons and R is the rolling resistance in pounds per ton at speed V

When the accelerating and retarding forces, above described, become equal the speed of the vehicle will remain constant and

$$20TG = KAV^2 + RT$$

or

$$KAV^2 = 20TG - RT$$

By comparing the two speeds at which a car will coast down two uniform slopes of different grades but of similar road surface, it is possible to derive the air resistance of the car Through a series of trials the speed is found at which the car should strike the uniform slope and down which it will coast, out of gear or declutched, with no change in velocity This speed is the one at which the accelerating force is equal to the sum of the force used to overcome rolling and wind resistances

If, now, coasting trails be made on grades G_1 and G_2 and the velocities V_1 and V_2 determined, two equations may be written as follows

$$(1) \quad KAV_2^2 = 20\,T_2\,G_2 - R_2\,T_2$$
$$(2) \quad KAV_1^2 = 20\,T_1\,G_1 - R_1\,T_1$$

By substituting rR_1 for R_2 in (1) we may derive the expression

$$KA = \frac{20\,T_1\,T_2\,(G_2 - rG_1)}{T_1\,V_2^2 - rT_2\,V_1^2}$$

In this equation values for R_1 and R_2 are not used directly but their ratio r is calculated from the results of dynamometer tests made by Paustian and Lockwood

The average rolling resistance in pounds per ton of car weight at velocities between 10 and 60 M P H for three cars (a Cadillac, a LaSalle, and a Chrysler) is a straight line approximately expressed by the equation $R = 0\ 16V + 23\ 70$

In using the above equation, the slopes of the two grades are measured, and the car weighed with equipment and passengers as present when the test is made V_1 and V_2, the floating speeds on the two grades are determined by coasting. With results on two hills with different grades, KA may be determined by the solution of the equations Of course, these coasting tests must be made at times when the natural winds are low as a small head or tail wind would invalidate the results Traffic, if the coasting is done on a public highway, will also constitute an obstacle In order to obtain favorable conditions, we found it necessary to do most of the work at night

When coasting tests are made with privately owned cars which are actually in service, it is, of course, necessary either to calibrate the speedometer which is on the car or to use some device for indicating the speed of coasting which may be readily attached to different cars Also, some method of ascertaining that the bearings are in good condition and well lubricated, that there is no brake drag, etc, is necessary We believe that failure to check up on these items is largely responsible for the considerable variation in the air resistance of the Austin as determined in the wind tunnel and by coasting

In order to check our work in the tunnel, coasting tests were run with two cars which had been used in the tunnel, the 1929 Buick sedan and the 1930 Austin Coupe Table III shows the data collected in the field on the coasting tests made on these two cars, and Table IV shows the computed values of KA When the average product KA for the Buick is divided by its projected area, we obtain a value of about 0 0018, when corrected for temperature as compared to a value of 0 00185 as determined in the wind tunnel In the case of the Austin, the value of K deduced from the average KA obtained from the coasting tests is 0 0018, as compared to 0 00169 as determined in the tunnel It will be noted that the coasting indicates lower resistance than the tunnel, in the case of the Buick and higher for the Austin, the differences being about 3 per cent in the case of the Buick and about 7 per cent in the case of Austin

TABLE III

COASTING TESTS

Hill No	Per Cent Grade "G"	Weight of Car and Passengers in Tons "T"	Coasting Speed M P H "V"	Car
1	2 75	2 155	31 4	1929 Buick
2	3 46	2 188	38 5	1929 Buick
3	3 81	2 155	41 6	1929 Buick
4	5 26	2 205	53 6	1929 Buick
5	1 94	0 805	7 1	1930 Austin
2	3 46	0 805	26 3	1930 Austin
4	5 26	0 810	38 6	1930 Austin

TABLE IV

COASTING TESTS

Hills No	Buick KA	Austin KA
1 and 2	0 0599	
1 and 3	0 0563	
1 and 4	0 0550	
2 and 3	0 0501	
2 and 4	0 0532	0 0340
2 and 5		0 0324
3 and 4	0 0541	
4 and 5		0 0332
Average	0 0547	0 0332

When corrected for temperature these values for KA will be somewhat lower

Additional coasting tests were recently run on a 1934 Studebaker five-passenger, four-door sedan with built-in trunk and spare tire, and a 1934 Airflow De Soto six-passenger, four-door sedan with spare tire Coasting tests were run on four grades varying from 1 67 per cent to 7 per cent The average value of KA corrected to 29-inch barometer and 70°F.

in the formula $P = KAV^2$ was 0 0337 for the Studebaker, and 0 0346 for the De Soto The areas of these cars were each 27 0 sq ft, making the value of K 0 00125 for the Studebaker, and 0 00128 for the De Soto

An inspection of Table II shows the best value of K previously obtained at Kansas State College was 0 00156 for the 1932 Buick Coupe The Studebaker and De Soto tests show a 22 per cent improvement over this value. This is rather remarkable in view of the fact that the value 0 00156 was on a two-passenger car, while the 0 00128 was for a six-passenger car.

SPECIAL TESTS

Special tests were run to determine the effect on the air resistance of a trunk at the rear of a car, the new type air-wheel tire and passenger load

Effect of Trunk A 1927 Chevrolet coach was tested with a trunk and spare tire at rear In Table I, column 6, the results of this test are shown The next line above, gives the results for the same car without spare tire or trunk The addition of the trunk decreased the total pull at 50 M P H by approximately 11 per cent, as indicated by these tests

Effect of Large Low-pressure Balloon Tires The effect on resistance of changing tires and wheels from standard size to oversize was investigated on a 1930 model A Ford sedan. The results indicated approximately a 5 per cent decrease in total resistance due to the oversized tires

Passenger Load All cars were tested with no load However, a test was made to determine the effect of load on wind resistance The areas of a car were determined with no load and with five passengers The load caused a settlement of about 2 in which decreased the projected area about 1 sq ft The car was then tested in the wind tunnel in the two different conditions The results indicate that a normal full load (five adults) decreases the wind resistance in direct proportion to the decrease in projected area caused by the load, about 4 per cent in this test

CONCLUSIONS

1 A wind tunnel capable of testing full size automobiles offers a practical means of determining the wind resistance of automobiles There is no scale effect for such tests Rolling resistance is not a factor Comparison with the coasting tests indicates that the much dreaded ground effect in wind tunnel tests is probably small

2 Coasting tests carefully made on smooth pavements afford a practical method of determining wind resistance

3 In the wind resistance formula $P = K'AV^n$ these tests indicate that the exponent is close to 2, the average being 2 02 for the fifty-four cars tested

4 Some of the more recent cars show definite, and considerable, improvement in aerodynamic characteristics

5. The passenger load in a car decreases the wind resistance below wind tunnel values in direct proportion to the decrease in projected area

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(4) E H Lockwood, "Air Resistance of Automobiles," Proceedings, Highway Research Board, Vol 8, page 142, 1928