# ADVENTURES IN AERODYNAMICS

*Streamlining for performance and efficiency is a 'breeze' when the ways of the wind and its effect on your car are understood* **PART II** by Jack Heltemes

*The Renault Shooting Star gas turbine. The French Eiffel Laboratories were responsible for the efficient body design enabling this little streamliner to run 192.5 mph at Bonneville. Note the large radius to cowl fairing and wheel covers.*

Above 50 mph more engine power is required by air resistance than all other losses combined. This resistance, called aerodynamic drag, acts as a poison to speed, power and fuel economy, but worst of all it increases as the square of the speed. Thus, air drag at 300 mph will be 36 times that at 50 mph and would require 216 times as much horsepower! Since the horsepower requirement soon gets to be ridiculous, the only alternative is to reduce air drag. To a vehicle moving through air it makes no difference whether you increase horsepower or reduce drag. Consequently, a vehicle may give equivalent top speeds with either a 40 cubic inch increase in engine displacement or 15% reduction in drag. In April HRM we learned what aerodynamic drag was, the cause and the different components. Now let's see what can be done to chop this giant down to size.

**DRAG CALCULATIONS**

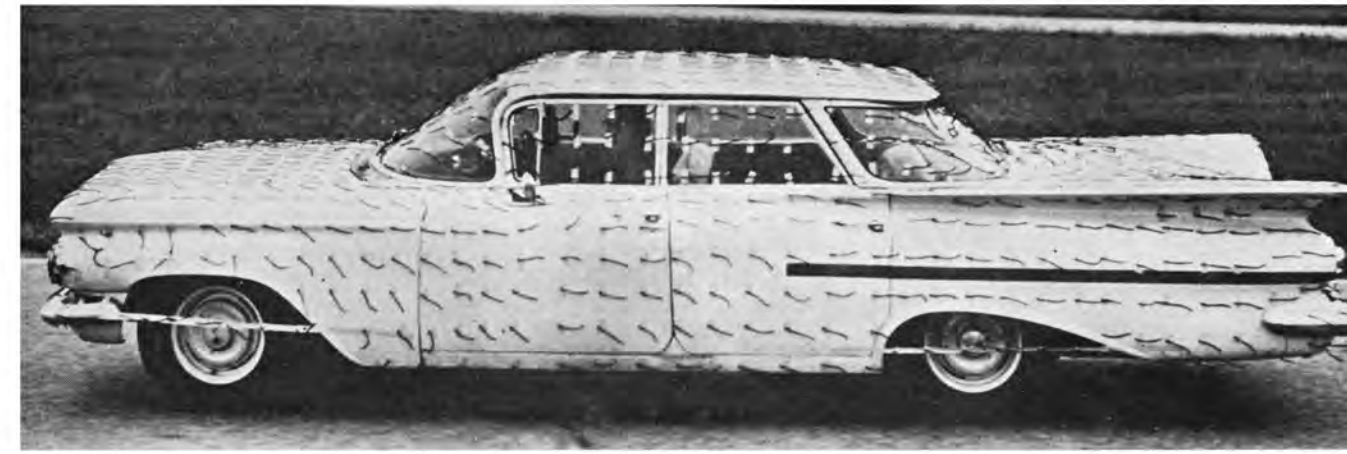
Aerodynamic drag is calculated with this equation:

$$D = C_d \times A \times F \times V^2$$

Where:

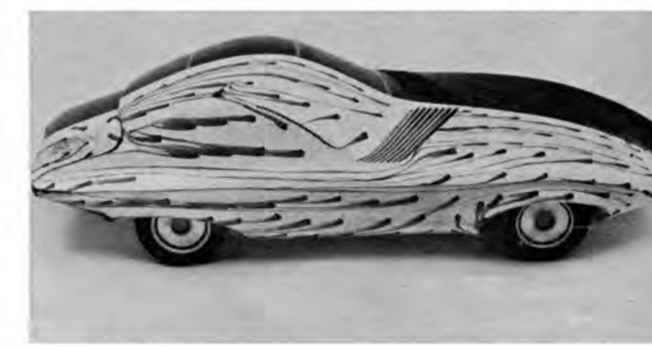
D = Total aerodynamic drag in pounds
F = Frontal area in sq. ft.
V = Vehicle speed in mph
$C_d$ = Drag coefficient (dimensionless)
A = Mass density of air in slugs $\frac{(\#\ sec^2)}{ft^4}$





*A 1959 Chevrolet performing a tuft study. The hood and top seem to have attached flow, but other areas show various degrees of turbulence and eddying. We see that the open wheel areas are also being checked with tufts attached to special bar.*

*The wind can be used to do many things, as demonstrated by this airfoil on front of the 170-mph Adams-McEwen drag machine. Angle of wing puts pressure on front end at speed.*



*Potential automotive designers at Art Center school in Los Angeles perform air flow studies by spotting scaled models with liquid dye and subjecting them to strong blast of air.*

and drag may be converted into equivalent or required rear wheel horsepower by the relationship: Required horsepower =

$$\frac{\text{Drag} \times \text{Velocity}}{375}$$

To become familiar with all aspects of these formulas and to show how they can be used, let's work a few examples:

1. The 1960 Chevrolet has a $C_d$ of about .48, the frontal area is 24.5 ft² and if a normal air density is assumed, the drag at 100 mph would be:

$$D = .48 \times 24.5 \times .0025 \times (100)^2 = 294\#$$

and the required horsepower =

$$\frac{294 \times 100}{375} = 78.5$$

2. The frontal area of the XKE Jaguar is 16.47 ft² and the drag has been reported as 184# at 100 mph—Let's calculate the drag coefficient and required horsepower.

Upon rearranging

$$C_d = \frac{\text{Drag}}{F \times A \times V^2} =$$

$$\frac{184}{(16.47)\,(.0025)\,(100)^2} = .44$$

And the required horsepower =

$$\frac{(184)\,(100)}{375} \text{ or } 49 \text{ HP}$$

3. For our third example let's show how easy it is for the convertible owners to save on horsepower. By putting up the top on an open convertible, the $C_d$ is reduced from .85 to .55 (approximately). Assuming a 1960 Ford with its frontal area of 24.9 ft², normal air condition, and a speed of 100 mph, the savings in horsepower would be:

Top down =

$$\text{Drag} = (.85)\,(24.9)\,(.0025)\,(100)^2 = 530\#$$

Top up =

$$\text{Drag} = (.55)\,(24.9)\,(.0025)\,(100)^2 = 342\#$$

saving from putting top up = (530# − 342#) = 188#

Saving in horsepower =

$$\frac{(188)\,(100)}{375} = 50.1 \text{ HP}$$

In other words that open air feeling costs cool horsepower.

**AERODYNAMIC REFINEMENTS**

Analyzing the formula for aerodynamic drag shows the vehicle's speed is the only absolute variable. Once that is specified there are three courses of attack to reduce air drag, i.e. minimize or lower the drag coefficient, frontal area, and the mass density of the air. Since these three variables are linear with drag, a reduction in any one will reduce drag proportionately. For example, reducing the drag coefficient by 10% lowers air drag 10%. And the reductions are additive, therefore, if the $C_d$ could be lowered 20%, the frontal area reduced 10%, and the mass density 5%, the resulting drag would be only 65% of the previous value. Every little bit helps, a small percentage here and there may produce that extra margin. So fasten your seat belts and away we go to attack the problems of drag coefficient, frontal area and even air conditions.

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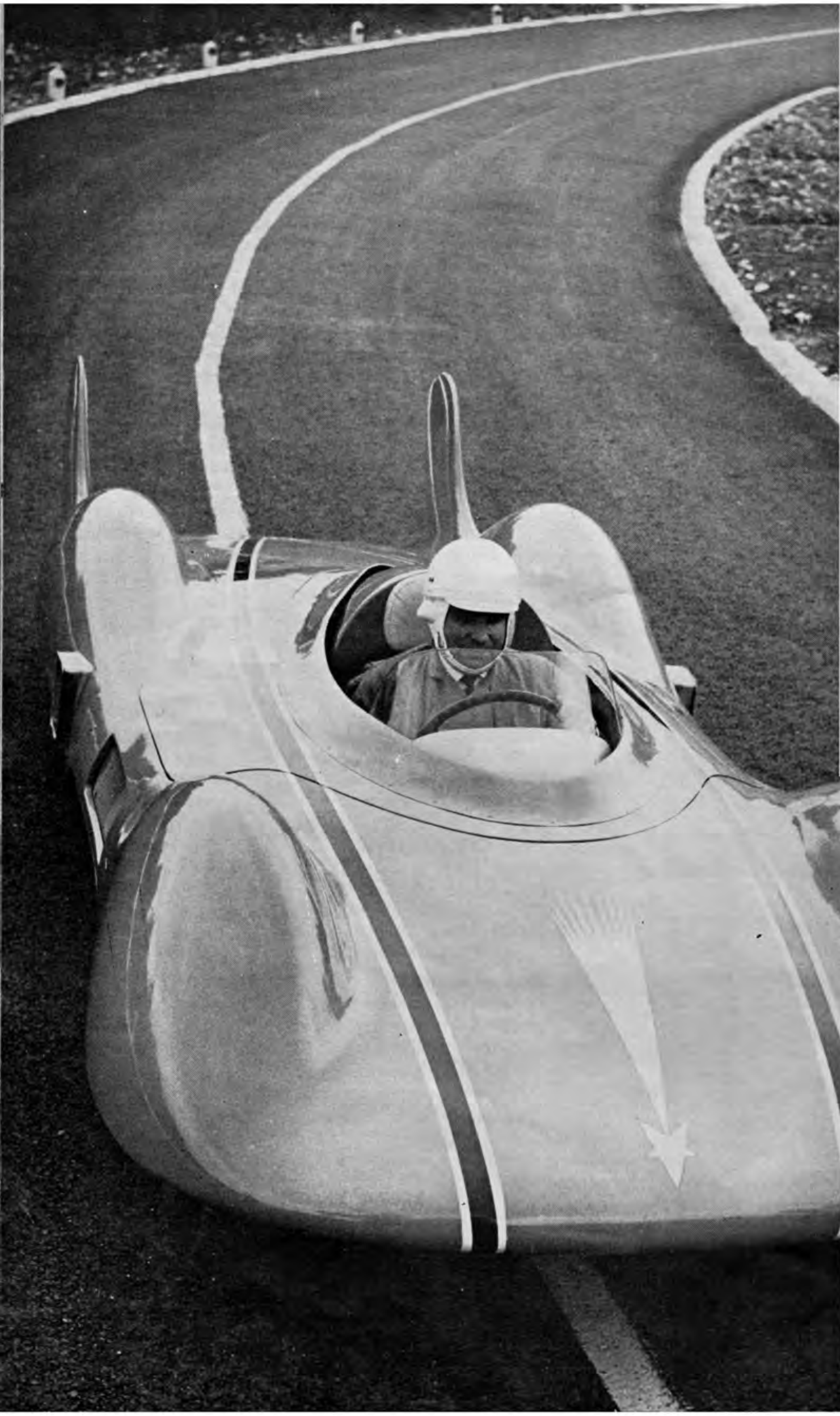

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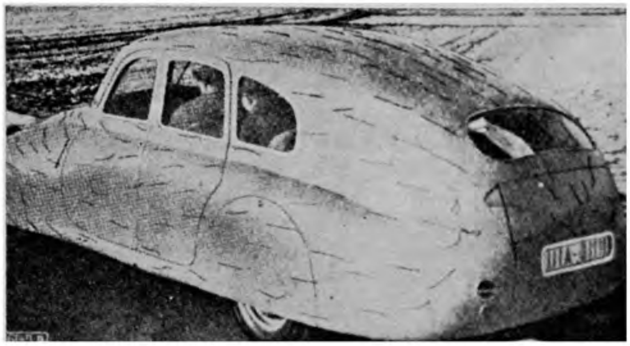
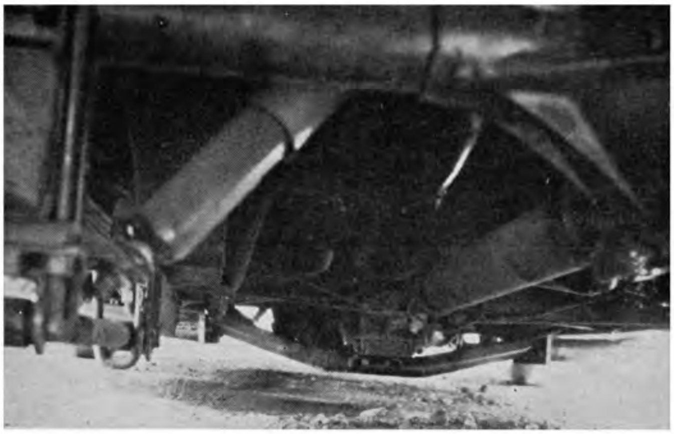
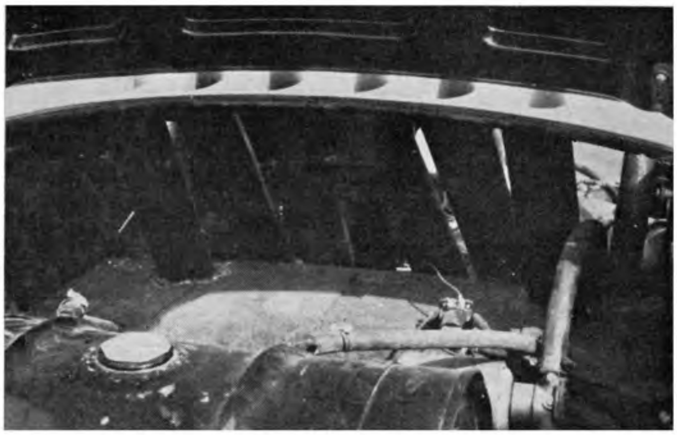
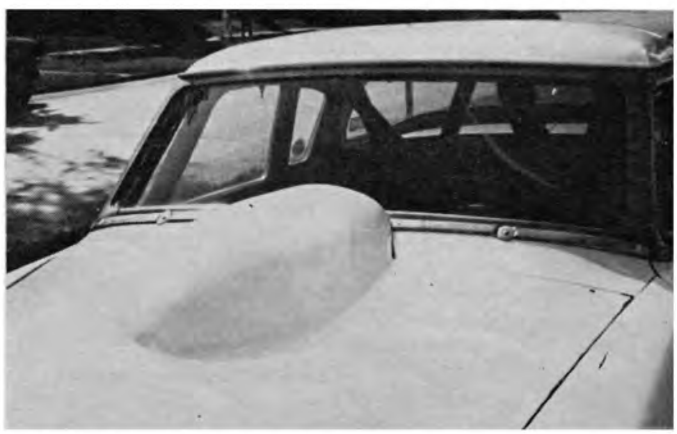


Two 1/25 scale '53 Studebakers used in wind tunnel experiments at Davidson Laboratory of Stevens Institute of Technology. Note body extension and fins used to reduce air drag. Also shown is Dr. Kamm's K-5 model undergoing tuft studies. Attached flow is visible on top and sides. This model has neutral lift, excellent performance and fuel economy. The $C_d$ is about .25.







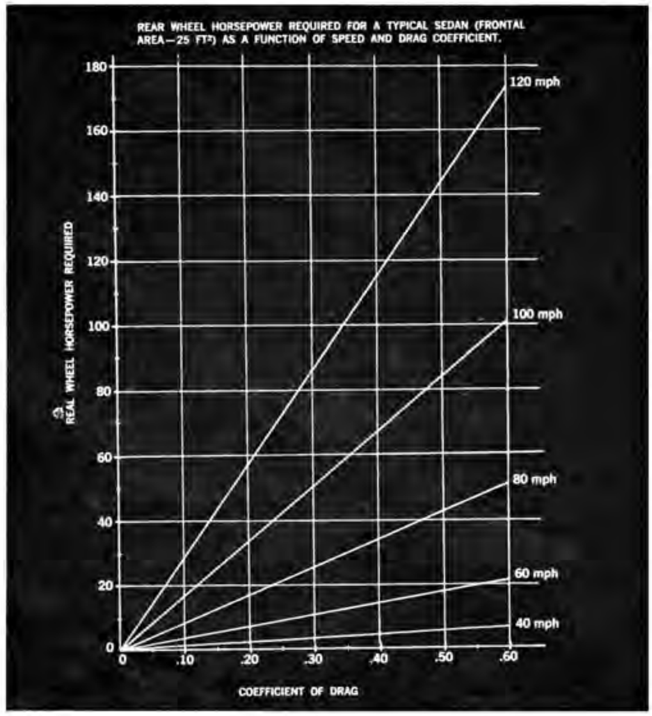



Photos above show technique used by John Simonson on his 188-mph Stude. Air is scooped from high pressure area under car, discharged at negative pressure point behind the rear window to reduce drag and lift. Center photos show ducting: engine compartment air is exhausted to the negative pressure areas behind the doors, where pressure differential is beneficial; underbody air is ducted up behind seat. Bottom photos show fender vents for trapped air, hood streamlining for blower.

## TABLE ONE

**MASS DENSITY OF AIR $\left(\frac{\# - sec^2}{ft^4}\right)$ AS A FUNCTION OF TEMPERATURE AND ALTITUDE**

| Temerature in °F | Altitude in feet above sea level: Sea Level | 1,000 | 2,000 | 5,000 |
|---|---|---|---|---|
| 0° | .0026824 | .00258 | .00248 | .00222 |
| 20° | .0025706 | .00247 | .00238 | .00212 |
| 40° | .0024678 | .00237 | .00229 | .00204 |
| 60° | .0023728 | .00228 | .00220 | .00196 |
| 80° | .0022850 | .00220 | .00212 | .00189 |
| 100° | .0022030 | .00212 | .00204 | .00182 |
| 120° | .0021274 | .00205 | .00197 | .00176 |




## ADVENTURES IN AERODYNAMICS continued

**DRAG COEFFICIENT**

The drag coefficient represents the aerodynamic efficiency of a vehicle (car, truck, airplane, etc.) as it moves through the air. Referred to as the $C_d$, this dimensionless number will usually be a constant in the vehicle's speed range and generally will vary from .4 to .6 for American sedans now on the market. As was discussed last article, components and magnitudes of aerodynamic drag are form drag (57%), skin friction drag (9%), induced drag (7%), internal flow drag (12%), and drag from projections and accessories (15%). Any reduction in the magnitude of any of these five components will manifest itself in a lowered $C_d$. The more aerodynamic the shape, the lower the drag coefficient.

Since a reduction in any of the five components of air drag will reduce the $C_d$, let's analyze each component separately and see where horsepower can be saved.

1. Form Drag – This largest drag force is due to the shape or sheet metal form of the body. It can truly be said, "In drag, the shape's the thing." The shape determines the air flow pattern around the body, thus setting the pressure conditions and related flow separation. Any modifications in shape that reduce flow separation will lower drag and the drag coefficient.

First of all there are the gains to be achieved by choosing the "right car." It is no secret that $C_d$'s vary from make to make, year to year, and even model to model of the same make. Unfortunately complete aerodynamic information is not given out with each new model, but more material is getting into technical literature. Also some of the automotive tests now contain drag data although the value given is the total drag which includes rolling resistance. An example of the differences between models is borne out by the 1961 Vauxhall sedan and station wagon. The sedan's $C_d$ is about .47, but the station wagon has an admirable $C_d$ of .36. This also points out an example in the never ending controversy of which roof slope (fast or notch back) has the lower drag. The only difference between the 1959 Chevrolet BelAir 4-door sedan and the Impala 4-door hardtop is the shape of the roof. However, the fast back style of the sedan gave a $C_d$ of .44, while the $C_d$ of the hardtop (notch back) was 10% higher at .48. Another example is again the Corvair coupe and sedan. The $C_d$ of the coupe is about 5% lower than that of the sedan – the equivalent of some built-in horsepower. This is one reason why the 2-door hardtops with their smooth tapering roofs are so popular in stock car racing.

Since form drag is due to the shape of a body, one general rule should be kept in mind. The design of the rear half of the car, i.e. the tail, is more important than the front end design. Perhaps you have seen the experiment showing this fact. Two cone drinking cups closed at the open end are mounted on each end of a rod allowed to pivot in the middle. The rod is placed in an air stream from a fan with the tapered tail of one cup facing the impinging air, and the other cup has the flat perpendicular face toward the air. With the rod free to pivot, the side that has the cup with the flat face toward the wind will swing forward, showing it has the least resistance. The closed cones represent a body with a horrible front design but with an outstanding rear one. In an automobile there is much to gain in proper front and rear shape, but pay particular attention to how air leaves your car. You want it to be smooth and undisturbed.

Wind tunnel studies have shown that there is an optimum roof slope for minimum drag. Although this angle may depend somewhat on the other body shapes, these tests have shown that sufficient deviation from the optimum may increase vehicle drag as much as 10% and perhaps more. Dr. W. I. Kamm, a leading figure on automotive aerodynamics, maintains that the roof slope should never exceed 10°. If the downward slope is greater than this, the air flow will not follow the body contours smoothly, resulting in flow separation and pressure drag. The best aerodynamic shape allows the roof to gently taper to a sharp edge. This, however, generally requires the body to be exceedingly long, especially when viewed from traffic and parking considerations. A practical solution to this problem of length is to extend the roof as far as possible with less than a 10° slope, then cut off the body in a pleasant shape. Dr. Kamm found even though the relative blunt end does give some pressure drag, this technique lowers both drag and lift by minimizing flow separation. Since a body should taper in both the horizontal and vertical planes, the rear area will be considerably smaller than the maximum cross section of the body. Extensive wind

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tunnel research has been done in perfecting this method with some of it leading to the radical rear engine Ferraries and Porsches' Kamm roof design. Dr. Kamm's car utilizing this refinement had a $C_d$ of .23 and hit 113 mph from only 85 hp.

A well designed front end has a minimum area blended smoothly into the body. Headlights should not interrupt this curvature and thus should be covered or faired over to allow a minimum of restriction. The lower portion should allow the air to bend and flow easily under the car.

Proper windshield design is essential for minimum drag. If the body shape permits the air to flow along the lateral sides rather than along the top, lift and the induced drag due to the lift will be reduced. A well rounded windshield enables the air flow to bend smoothly around the corner posts, something not permitted by the flat windshield. In this regard the wrap-around windshield that appeared in 1954 seems to fit the bill, but it must be blended into the body lines. Sharp points are to be avoided; a general rule used in airplane practice is a fairing radius approximately 25% of the enclosed height. It is always a good idea to give all fairings a large radius to help minimize turbulence as the air flow changes direction. An example is the 1960 DeSoto, where a 15% reduction in the $C_d$ occurred by redesigning the shape around the headlights and at the top of the windshield.

Windshield slope is important but is dependent on other body shapes. As mentioned last month, Porsche sport car racing models have used a windshield slope of 24° as a result of wind tunnel studies. Ford engineers offer further proof of the importance of windshield slope. In a series of tests with a 1960 Ford Anglia, they installed a false windshield of approximately 30° slope and found it reduced drag 16%. This modification alone was enough to raise the top speed from 72 to 76 mph. In a series of wind tunnel tests at Chrysler Corp., they found by increasing the windshield rake by 7°, the pressures acting on the top cowl surface were reduced 9 to 15%. This may not permit the ventilation engineer to get by without a fan but it does what we want— it lowers drag.

One of the simplest, but not always the easiest methods to cut form drag is to "bellypan." Today the stylists design generally for appearance and are not concerned with the pipes, bars,

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# ADVENTURES IN AERODYNAMICS
continued

brakes, axles, mufflers, etc., that can't be seen. Still the rough undersides are hit by the air stream. In tests conducted by the University of Wichita in conjunction with the Nash Motor Company, a smooth underbody was found to reduce drag by 6.3%, over the entire speed range. This compares closely with a reduction of 5.8% measured in tests at the University of Michigan. There is evidence that the savings may be even greater, since one model study showed a smooth underside of a bus lowered the $C_d$ from .40 to .27. With care and patience in bellypan design, drag may be reduced by as much as 20% depending on the vehicle characteristics. The $C_d$ of a typical sedan has to be lowered by only .03 to mean a savings of 40 hp at 200 mph. The advantage from a smooth bottom will vary with models and types, but all cars with low $C_d$'s will be underpanned.

The wheel openings are also a source of form drag. This source of drag is comparatively small, usually less than 4%. However, by covering either the front or rear wheels the $C_d$ can be reduced approximately .02. This saving may not be worth the effort trying to cover the front wheels, but it's one of the small things that can be done.

Besides giving a cool breeze, open windows will also give some additional drag. In one test, opening the front windows increased the $C_d$ by .03 to .04. Any time a window is open, a convertible top lowered, a ventilator or sliding roof is opened, air is disturbed and drag results. It should be noted, however, that these small sources of drag (open windows, wheel openings) become more important as streamlining is improved and are negligible in cars with a very high drag coefficient.

2. Skin Friction Drag – This is the resistance presented from the sheer force between the body surface and th air traveling on it. There isn't a whole lot that can be done to reduce this drag force besides reducing the surface area and maintaining the smoothest finish possible. The surface may not be a 20-coat lacquer job but it should be painted, waxed and washed. By just waxing the surface of the C118 (DC-6) airplane the Air Force was able to save an hour's time, or 370 gals of gasoline, between Honolulu and Japan – so shine it up for *go* as well as *show.*

3. Induced Drag – The resultant of the lift forces is inclined backward and, therefore, has an appreciable rearward component termed induced drag. If there is no lift there will be no induced drag.

Lift occurs because of the unequal flow of air under and over the body. The air appears to split about bumper height, allowing about 15% to flow underneath. The resulting pressure differential acting on the upper and lower surfaces exerts a net upward force termed "lift" which, like drag, increases as the square of the speed.

The danger of lift is very real since it affects the load distribution and braking efficiency, changes the directional characteristics of the car, and reduces road adhesion. Some general methods of lift reduction include either raising the body or replacing the usual flat under-surface by a curved bellypan swept up at the ends and sides. The windshield and body design should urge the air to flow along the sides of the body rather than over the top. As mentioned earlier, a gentle roof slope with a rectangular shaped tail-end design produces a low value of lift.

4. Drag from Accessories and Projections – One method of reducing this drag is simply to remove all the objects on the outside of the body for competition. This includes bug deflectors, radio aerials, rear-view mirrors, license plates, windshield wipers, door handles, bumpers, spotlights, rain gutters, spinner hub caps, attached headlights, etc. Accessories such as outside sun visors and luggage racks cost a high price in drag. For instance, at 90 mph, outside sun visors will add 30 pounds of drag and steal over 7 hp.

The drag from a small part is of itself small because the frontal area is small. However, the $C_d$ may be high and the projection may cause interference or disturbance of flow over the surface behind it. The drag from each source is perhaps small, but the total is appreciable (about 15% of the total air drag) and worth attention. Generally remove what you can and then use fairing and large radius fillets to integrate the rest into the body. It's surprising what masking tape and cardboard can do for a high speed run, if applied to areas of high restriction.

5. Drag from Internal Flow Resistance — Here, in my estimation, is the place for development work. Generally once the air flows through the radiator core it has to find its own escape through the open bottom. The resulting

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## ADVENTURES IN AERODYNAMICS continued

restrictive flow condition usually produces about 12% of the total air drag. This, however, can be minimized in two ways. First, keep the radiator openings as small as possible, allowing only enough air to enter to prevent overheating. Part of the grille may be blocked off with masking tape and cardboard. The second method is by the use of large and properly designed ducts, permitting the air to enter and leave undisturbed. The extensive use of ducting offers intriguing possibilities. By mapping the surface pressures, air ducts or exhaust outlets may be located in the high negative areas and knowledge of the high pressure areas can help you establish air inlets at the points of greatest effectiveness. In the future, ducting may make possible the use of boundary layer control to improve flow conditions. This would especially be applicable at the rear of a body to help maintain attached flow.

John Simonson, veteran race car builder and driver from Grand Forks, North Dakota, has spent considerable time and money developing aerodynamic refinements in his record-holding 1953 Studebaker. Each side of the engine compartment has large (approximately 16 x 12-inch) air scoops channeling the air into 8-inch round ducts that exhaust behind the doors. Since this is a point of negative pressure, the pressure differential gives a gentle push in producing an easy exit.

Another interesting and effective use of ducting are the six 4-inch tubes scooping air from the high pressure area under the car and discharging it into the negative pressure area immediately behind the rear windows. Besides reducing drag, this also minimizes the lift forces since lift is produced by the high positive pressures under a car and the generally negative pressure acting on the top surface. Another use of ducting is found behind the rear wheels, furnishing a straight path from the wheel well to the rear of the car.

Basically the body of this coupe has not been changed, but the fact that it is a 188-mph record holder testifies for the benefit of aerodynamic refinements. With a full bellypan, additional refinements, and planned slightly higher horsepower, this stock bodied car should soon hit 200 mph.

### FRONTAL AREA

Since air drag is linearly dependent on the frontal area, a reduction of the frontal area will decrease air drag by the same percentage. An example is the reduced drag of today's cars over those 12 years ago, due almost entirely to the 8% reduction in frontal area.

The frontal area is, of course, the maximum projected cross-sectional area. It may be found by using a head-on photograph and a planimeter, an engineering tool able to trace the perimeter of any irregular shape and give the enclosed area. However, a good approximation of the frontal area may be found by multiplying the over-all height and width by the factor .80. Usually used in square feet, the frontal area will range from the 13.77 square feet of Mickey Thompson's Challenger I to about 74 square feet for a truck-trailer combination. The standard methods for reducing frontal area such as chopping, channeling, sectioning, and lowering have been around for a long time. Lowering the body as a whole does decrease drag slightly, but will increase lift and thus is not very effective or desirable.

Some designs have an extremely good $C_d$ but failed due to a large frontal area. For example, the $C_d$ of the Corvair Greenbrier has been reported as .37, but with its frontal area of 26.85 $ft^2$ it still has about 15% more drag than the Corvair coupe with a higher $C_d$.

Accessories may also increase frontal area. The installation of a top luggage rack 42 inches wide and 15 inches high increases frontal area enough to drop gas consumption by 3 mpg at 60 mph. So to make it go, make it slim and low.

#### AIR DENSITY

The last factor in the drag equation is the mass density of the air, given in the units of slugs, $(\# - sec^2/ft^4)$. Table one presents the mass density of air for temperature from 0° F to 100° F and altitudes from sea level to 5,000 ft above sea level. Here again, as in the case of the drag coefficient and frontal area, drag varies linearly with mass density of the air.

For a moment let's forget that engine horsepower varies inversely with air density. Then it follows that you should be able to go faster on a hot day than on a cold or rainy day, and go faster at high altitudes than at low altitudes because there's less aerodynamic drag. Table one is presented primarily to make you aware of the air density factor, and to point out how drag will vary with atmospheric conditions.

#### A FINAL NOTE

Unfortunately the only way to design body shapes efficiently and safely is by use of a scale model and a wind tunnel. Certain necessary information such as side forces, moments, and pressure distributions cannot be obtained by running a full scale car. And at the speeds American auto enthusiasts are obtaining it is almost foolish not to get complete tunnel data. Directional stability and lift should be known on safety grounds alone, and in the design stage where corrections can be easily and quickly determined. Of course, model studies offer a golden opportunity to obtain minimum drag as shown by the VW bus which lowered its $C_d$ from .75 to .43, over a 40% reduction in drag, as a result of model studies.

There are several methods for obtaining data in the field if you're one of us who can't afford the $20,000, or so, for a wind tunnel. Drag values may be obtained by deceleration runs, using a Tapley meter or one of several analytical methods. However these methods have the disadvantage of giving the total drag, not a separate aerodynamic component. Given enough time and patience, the effect on drag of any modification can be determined, and by trial and error approach an efficient design can be evolved.

A method allowing an insight into the flow conditions around the body involves the attachment of yarn tufts to the surface. If the tufts lie flat and to the rear, smooth attached flow in that area may be assumed. When, however, the tufts are disturbed or fluxuating badly, eddying and separated flow are indicated. Usually motion pictures will be taken of the tufts' behavior to give a qualitive analysis if pressure data is not available.

Correct aerodynamics in high speed cars is not only desirable, but absolutely necessary. This does not only imply a low value of drag, it goes much further. Drivers have lost their lives and many cars have been destroyed by aerodynamic instability or critical values of lift. An aerodynamic design will not only set the records, but assure that the car will go where you point it.

### YOUTH SAFETY RUN

The Los Angeles Police Advisory Council for Car Clubs has just announced the dates for the Annual Youth Safety Run. Scheduled for June 25, 26, 27, the three day test is to originate and terminate in West Covina, California, with the mid-way point being beautiful Yosemite Park high in the Sierra mountains. The PACCC economy run, designed exclusively for feather-footed car clubs in the Los Angeles County area, is being presented this year in cooperation with the West Covina Chamber of Commerce and West Covina Police Chief Alan Sill. L.A. region car club members consider the annual run a high point in the year's activity and focus great importance upon being selected for participation.