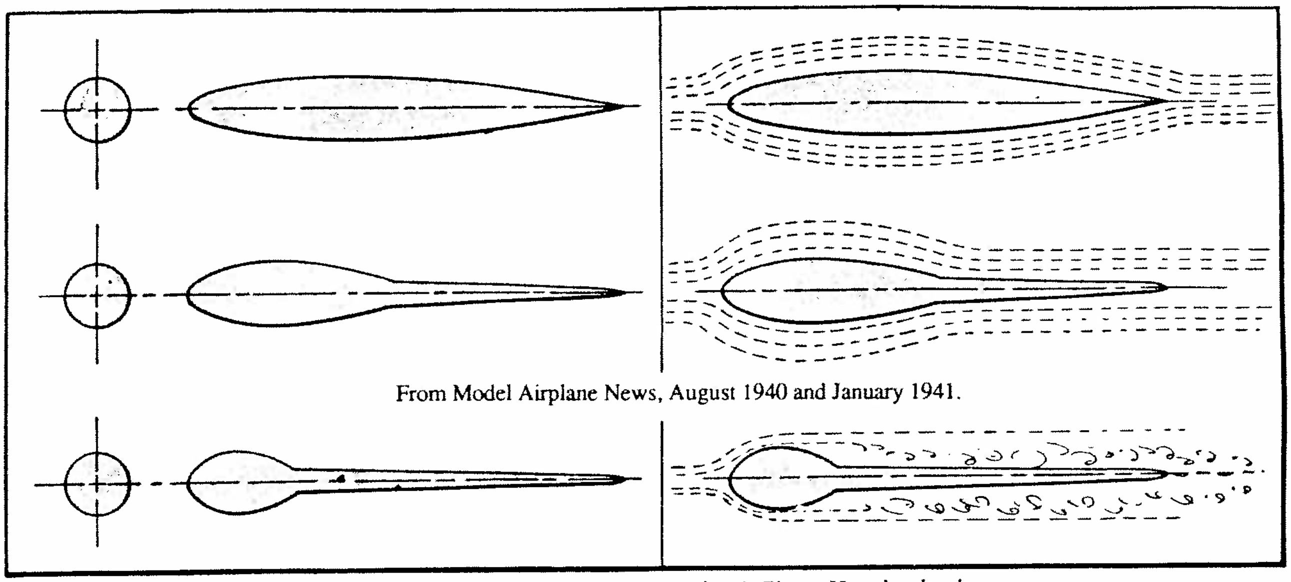

Fig. 1. Which of these fuselages gives the least drag? Fig. 2. Here is what happens

CUTTING DOWN THE DRAG

HERE at last is what gas model designers have always wished for! A complete series of tests on gas model fuselages made in a real wind tunnel, at speeds equivalent to those of actual gas model flight.

All model builders know, when designing their planes, that lift is something to be desired and drag something to be avoided. In fact, with a little more precise aeronautical knowledge, the performance of a plane can be accurately predicted if its characteristics of lift and drag are known. Unfortunately, because of the natural perversity of airplanes which is so well known to all aeromodelers, lift can be obtained only in limited amounts and by the use of special apparatus, such as wings, whereas drag is available in abundance and appears whenever any object starts to move.

Though every builder has his own ideas regarding gas model design, the fact remains that the lifting apparatus and ability of all types is more or less the same. In other words, wings are standard equipment. The great differences among models come in the quality of the streamlining which is built into other parts of the plane, especially the fuselage and its accessories. The reduction of drag is what is most needed to make a model superior to its competitors, yet it is the phase of model design which is least understood.

Thus we find some builders who advocate streamlined, monocoque fuselages, while others stick to the square box-car types and point to the fact that contest records show many victories for so-called "unstreamlined" planes. The fact is that pleasing lines and smooth appearance is not at all a measure of the amount of drag which a body will have, and that many factors other than gracefulness of lines determine the air resistance of a complicated object like a fuselage equipped with landing gear, motor, wing mount and other fittings.

In order to obtain accurate, quantitative information on the design of gas model fuselages, the following series of wind tunnel tests were made. The equipment

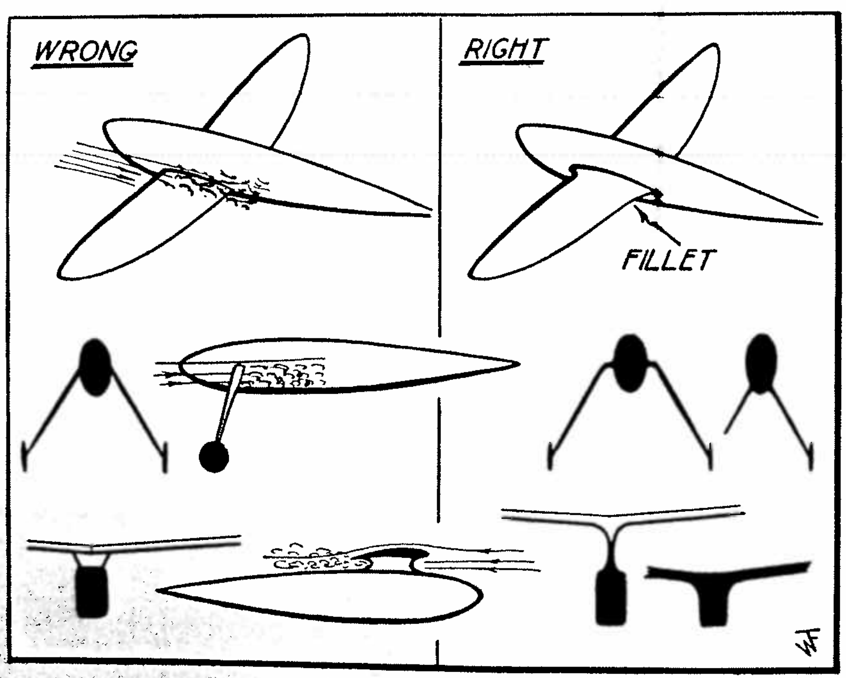

Fig. 4. Causes of interference drag

Coefficients For Diameters Of Least Drag Circular Fuselages

Station	Fuselage No. 4	Fuselage No. 7
00	00.00	00.00
5%	00.0475	00.075
10%	00.066	00.098
20%	00.092	00.113
30%	00.108	00.103
40%	00.113	00.075
50%	00.103	00.052
60%	00.090	00.039
70%	00.071	00.0325
80%	00.049	00.025
90%	00.025	00.018
100%	00.00	00.00

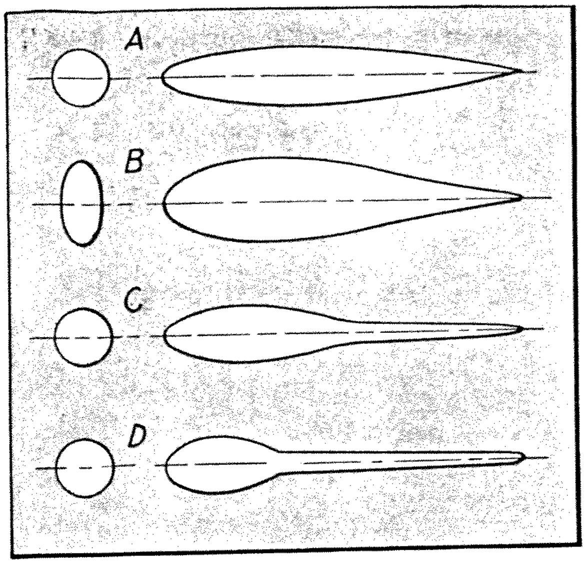

Fig. 3. Some fuselage designs

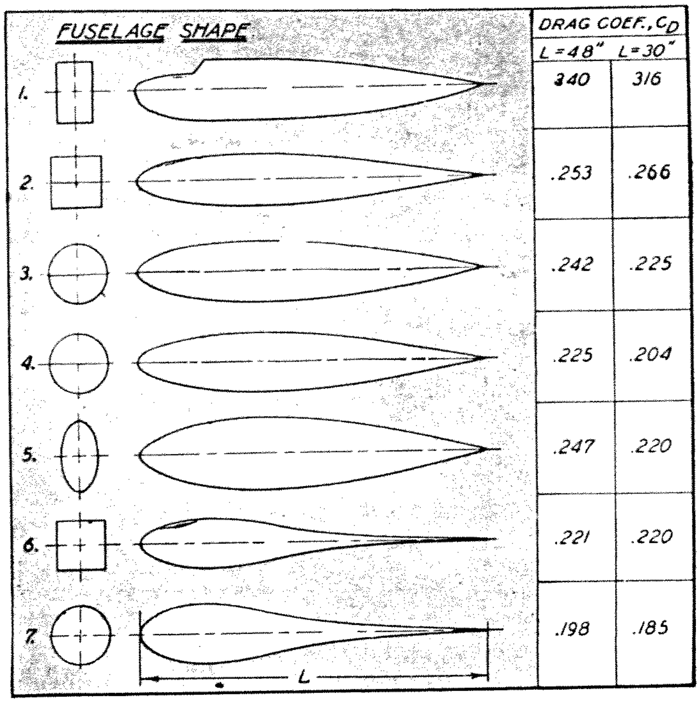

Fig. 5. Drag coefficients of fuselages

Results of Tests on Various Fuselage Shapes Run in the Mass. Institute of Technology Wind Tunnel at Speeds Attained by the Average Gas Model

By HEWITT PHILLIPS and BILL TYLER

used was the four foot tunnel of the Massachusetts Institute of Technology aeronautical laboratory. This wind tunnel was the first one to be built at M.I.T. During the early 1920's it was the best tunnel in this country, but it has long since been superseded for the testing of full sized airplanes by larger and faster wind tunnels. However, for the testing of gas models it is ideal; it gives accurate measurements at speeds ranging from 15 to 40 m.p.h. The balances used for measuring the forces on the models are extremely sensitive, allowing the detection of differences in drag and lift of as little as one-ten-thousandth of a pound.

The models used for the tests were of typical model airplane construction, accurately built and conforming to the N.A.A. rule which states that the cross sectional area shall equal $L^2/100$. All the models in a given series were of the same length and cross sectional area.

A discussion of some of the things we may expect to find from our test results will make them more useful in practical designs. In the first place, we need a clear concept of the causes of drag. Perhaps the simplest notion of this subject would be to consider air resistance as caused by the friction of the air rubbing over the surface of a body, exactly as a solid body experiences friction when it is moved about on a surface.

This explanation is indeed partly correct, but a much clearer idea of what is occurring is obtained if we recognize the fact that, because air is not solid but instead free to move, it will be pulled along with an object whenever it exerts a friction force on it. For example, it is a familiar fact that a bucket pulled behind a motorboat will experience a large amount of resistance. This is because it is dragging along a large amount of water when it moves. In exactly the same way, the drag on a body moving through the air is caused by the air which is dragged along with the body when it moves. Whenever anyone speaks of drag, what is really meant is that air is being "dragged along." A good streamline shape is one which will move through the air without trying to pull much of the atmosphere along with it.

A clear understanding of the causes of drag will now be obtained if we determine the ways in which air may be dragged along by a body. Non-lifting objects like fuselages can do this in only two ways. The first is the formation of turbulence and eddies behind the body. This process is familiar to everyone who has observed the eddies formed behind his hand as he moved it through water. A careful observation of these eddies will show that they are moving along with the object that is causing them. In other words, fluid is dragged along whenever eddies are formed, hence the drag on a body which causes a lot of turbulence is sure to be high. The drag of a flat plate moving broadside through the air is almost entirely caused by this eddy formation giving the familiar high drag of such an object.

It is an experimental fact, however, that many smoothly curved objects, of the well-known dirigible-shaped streamline form, move through the air without causing any eddies at all. Yet these bodies still experience a certain amount of drag. The reason for this, the second of the two mentioned above, is the "skin friction" of the air passing close to the body. This effect results from the viscosity of the air. A fuselage moving through the air drags along a certain amount of the gas, just as a spoon moving through cold molasses pulls along some of the liquid. The only difference between the two cases is that air is very much less viscous than molasses. Nevertheless, on smooth streamline bodies which cause no eddy formation, all of the drag comes from this latter cause.

Since this skin-friction part of the drag is caused by air sticking to the surface of a body, it would certainly be expected that this drag could be reduced by keeping the surface area as small as possible. The re-

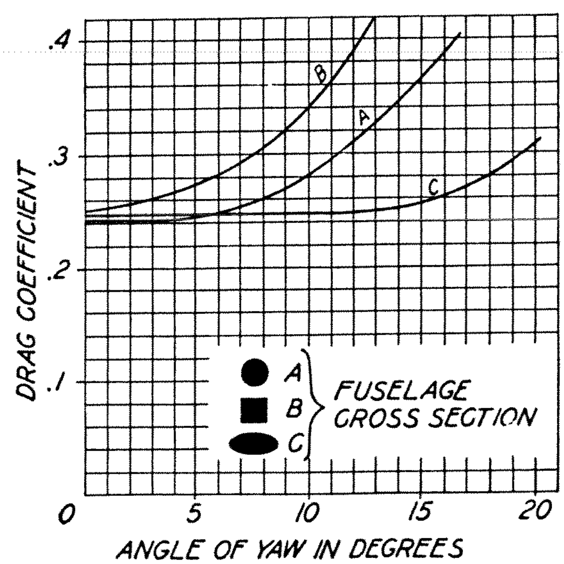

Fig. 6. Increase of drag with angle of yaw for fuselages of various cross sections

sults of these and many other tests made on streamline bodies show that this conclusion is indeed correct.

In fact, it may be stated as a general rule, that *for bodies over which the air flows smoothly and without eddies, the drag is directly proportional to the surface area.* This rule immediately has an important application to the problem of fuselage drag. Consider the fuselage design shown in fig. (3). Each of these types has the same maximum cross sectional area and therefore complies with the contest regulations. The first one, marked (a), is the familiar dirigible-shaped streamline form. Type (b) is similar except that it has an elliptical cross section. Many model builders consider both of these types to be excellently streamlined but a little consideration will show that, in the light of the above rule, type (b) should have at least 20% more drag than type (a), because its surface area is about 20% greater. However, there is no need to stop with type (a). By simply shortening the "streamlined" portion of the body and adding a tail boom, the surface area may be reduced still further. Such a design, shown as type (c), would be expected to have even less drag than the commonly used type (a).

This process of shortening the fat part of the fuselage and lengthening the tail boom can not be continued indefinitely, however, for when a certain point has been reached the airflow will no longer be of smooth, eddy free type which we have been discussing but will instead break away as shown in fig. (2), with a resulting tremendous increase in drag. To find just how much may be gained by using the pod-type fuselage with a tail boom was one of the chief objects of this series of tests.

Unfortunately, on an actual fuselage it is usually impossible to obtain the ultimate in streamlining because such protuberances as cylinder heads, landing gear struts, etc., always cause a certain amount of turbulent flow. Such sources of drag can of course be minimized by proper cowling and fairing of the parts.

However there are less obvious sources of turbulent flow which must be avoided if low drag is to be attained. In the first place, not all apparently streamlined forms actually give a smooth flow. Many fuselages have been tested which give high drag in spite of having a round cross section and smooth lines. For this reason the form of a fuselage should never be drawn by eye, but instead should be obtained from a set of ordinates giving the shape of a fuselage which has actually been wind tunnel-tested and proven to have low drag. Even if such a form is used, large drag may be caused by eddies formed by the so-called "interference" of other parts of the airplane. Such eddies form at the junction of the wing and fuselage on a low-wing monoplane, or where improperly designed struts enter the fuselage. Several cases to be avoided, together with their cures, are illustrated in fig. (4),

The test results are presented in the accompanying table. The values given are the drag coefficients obtained at two different Reynolds numbers. The left-hand column, which corresponds to the flight conditions encountered by a large gas model, is at the Reynolds number of a 48″ fuselage flying at 20 m.p.h. The right-hand column corresponds more closely to the smaller gas jobs, and was taken for a 30″ fuselage travelling at 19 m.p.h. There is no great difference between the two sets of values.

If the actual drag is desired for any particular model, it may be obtained from the formula:

$$D = (.000132) C_d A V^2$$

where D is the drag in ounces, A the maximum fuselage cross sectional area in square inches, and V the speed in feet per second. C_d is the drag coefficient given in the table.

The comparative values of C_d for various fuselages, rather than the actual drag, is what interests us most here. Fuselage No. 1, the typical box-car type with a windshield, is seen to give 70% more drag than the best form tested. As may surprise many builders, the square fuselages are only slightly poorer than those of round cross section. Thus type No. 2, has a drag coefficient only slightly larger than the round section of type No. 3. There is really no reason why a square, cross sectioned fuselage should give much more drag than a round one, because the surface area of the square cross sectioned type is only slightly larger than that of the round fuselage. This reasoning holds only when the fuselages are headed directly into the wind. As will be explained below, a square fuselage may be worse than a round one if it is yawed a few degrees.

Type No. 4 is the best dirigible shape tested. Its ordinates are given for use in model design. As might be expected from the discussion above, it is better than type No. 5, the best form with elliptical cross section tested.

Best of all, however, is No. 7 the pod-type fuselage with its reduced surface area. It is notably better than any of the other "streamlined" shapes. Even the pod-type fuselage No. 6, with a square cross section, is better than a dirigible shape with a round cross section. Because of the ease of construction of this type of fuselage, it should find wide application in the design of gas models for contest work. Because this type appears so superior to all the rest, some builders may be prompted to ask why it is not often used for real airplane fuselages or dirigibles. The answer to this question is that in real airplanes the problem is to enclose a given *volume* with the least possible drag, rather than to fair a given *cross section area.* The best streamline shape for enclosing a given volume is one with a length about eight times its maximum diameter, whereas the best shape to enclose a given cross section area is only three times as long as its diameter. On man-carrying soaring gliders, where the problem actually is to build a fairing enclosing the cross section area of the pilot, pod-type fuselages are coming more and more into use.

The curves of fig. No. 6 show the increase in drag caused by yawing fuselages with different shapes of cross section. Since ordinarily models are never yawed as much as five degrees while flying, these curves are mainly of scientific rather than practical interest.

The results presented with this article show the ideal minimum of drag which can be attained. The very important problem of how to avoid drag caused by the various accessories such as landing gears, cylinder heads, etc., will be taken up in the second article on the subject. Until then, happy landings!

PART 2

BY FAR the most important source of drag on any type of aircraft, whether it be a midget gas model or a passenger-carrying transport, is the unavoidable group of items which project into the airstream and break up the underlying "clean" lines of the streamlined surfaces. This group includes structural details like rivet heads, wing spars which cause a bump in the covering and many other small disturbing objects which, fortunately, can be much more easily avoided by the model builder than by the real plane designer. Then there are the necessary accessories which every model embodies. These include the cylinder head or cowling, the landing gear, and on some models dummy windshields, wing struts, exposed timers and so forth. Finally there is the propeller, which, though a very useful piece of equipment while the model is climbing, is a most unwelcome source of drag during the glide.

Though it is obvious that these objects all increase the drag of a model, it is nevertheless impossible to determine just how much they will spoil its performance, except by actual test in a wind tunnel. We can estimate fairly well how a square fuselage will compare with one of round cross-section from the standpoint of drag, but there is no theory which will throw any light on the subject of the drag of a cylinder head or the effect of a cowling. This article, for the first time, presents the result of actual wind tunnel experiments on this problem. The tests were made in the four-foot tunnel of the Massachusetts Institute of Technology aeronautical laboratory. They were carried out on full scale gas models and at wind speeds corresponding to those of actual gas model flight. The great precision of the balances with which this tunnel is equipped insures the accuracy of the results.

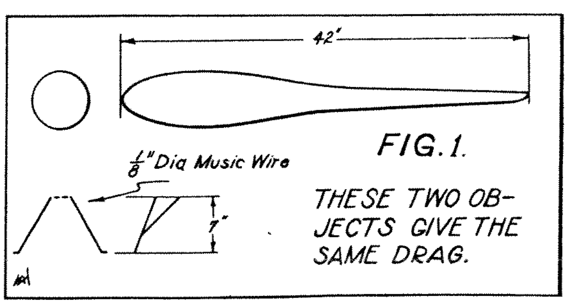

FIG. 1.
THESE TWO OBJECTS GIVE THE SAME DRAG.

As was pointed out in the first article in this series, what we really mean when we speak of the drag of an object is that air is being "dragged along" with the body when it moves. This concept is particularly useful in understanding the results of this series of tests, for one can readily see how protuberances such as a cylinder head or landing gear strut can "hang on" to some air and pull it along in their wakes. Only by this mechanism can we imagine the explanation of the remarkable situation shown in figure (1); a seemingly insignificant group of landing gear struts giving more drag than a full-sized fuselage. And if this situation still appears amazing, let us warn you that it is but the first surprise of a number which will appear in the following paragraphs.

The drag of an apparently small object may be much greater than expected for two reasons. The first is that a round or otherwise unstreamlined strut can generate a wake much wider than the strut itself. This situation, which is illustrated in figure (2), occurs especially when the strut is small; or, more precisely, as the aerodynamic experts would say, when it is operating at low Reynolds numbers. This is the case when we are considering, for example, a landing gear strut of 1/8" diameter music wire and the drag of such an item would be expected to be very large.

The second reason is that an obstacle to the flow near the nose of a streamlined fuselage may cause turbulence in the air all along the side of the fuselage from the nose to the tail. The result of this disturbed airflow in the layer of air near the fuselage replacing the smooth streamlines which would otherwise occur is a large increase in the fuselage drag. A typical example of this unfortunate occurrence is the use of an elastic band wrapped around the fuselage to hold the wings in place. Though the drag of the elastic by itself might be negligible, when it is placed next to the fuselage surface an appreciable increase of drag results, as will be seen in the test data which follows. A model designer is not much concerned with riveted construction, but the large increase in drag which is known to be caused by the rivet heads on an all-metal airplane is likewise attributable to this cause. For this reason, the most modern airplanes employ flush-riveted or spot-welded construction.

Little more can be said regarding drag in general terms; therefore, let us proceed to examine the test results. These are presented in the table of figure (3). In this list the resistance of the combination tested is given as a drag coefficient based on the maximum cross-sectional area of the fuselage. In order to obtain the actual drag in any given case, one may use the formula:

$$D = (.000132)\ C_d\ A\ V^2$$

where D is the drag in ounces, A the maximum fuselage cross section area in square inches, V the speed of flight in feet per second, and C_d the drag coefficient given in the table.

What we are most interested in, however, is a comparison of the various values. As a standard of comparison, we will take the drag of a well streamlined fuselage form of round cross-section. This particular shape, pictured in the table, is the one which was found to have the lowest drag of the various forms which were tested. Its drag coefficient is .198. Contrasted to this low value is that for a square fuselage with a windshield, which is all of 72% greater. Tests show that nearly all of this gain is attributable to the windshield, which causes a disturbance in the airflow. Obviously models intended for contest work should not make such a large sacrifice in efficiency for the sake of appearance.

Now going back to the round fuselage, we add a cylinder head entirely exposed above the former lines of the fuselage. The result is a 20% increase in drag. This is not too alarming, but it certainly indicates the desirability of a cowling to improve the streamlining. No doubt a motor completely exposed from the firewall forward, as is the practice on many models which are otherwise streamlined, would cause a much worse increase in drag. Not only does the flat firewall give a large amount of resistance, but the airflow is made turbulent over the entire fuselage by the rough projecting parts.

In order to determine the improvement possible by using a cowling, a hood was made which fitted over the cylinder head. This fairing had openings at the front and rear which were adequate for cooling the motor. The test showed a reduction in drag coefficient from .237 to .225. No doubt if the fuselage were designed to fair in smoothly with the cowling, instead of adding the cowling later as an afterthought, still greater improvement could be obtained. Moreover, it is well known from tests on full-sized airplanes that the resistance of a fuselage equipped with a cowled motor always increases as more air is allowed to flow through the cowling.

Now for contest work, where only a twenty-second motor run is required: It should be possible to completely enclose the motor, thereby eliminating drag from the cooling air. If this was done, the cylinder could be so smoothly faired that the fuselage should give no more drag than the basic streamline form. Experiments have shown that a miniature gas motor will run for about a minute without overheating even when completely enclosed. If longer warming up runs than this are desired, the gas model builder could probably use his ingenuity to design a cowling which could be removed for testing the motor and slipped on for official flights.

Next we will turn to the subject which was mentioned previously; namely, the effect of holding wings on with an elastic band wrapped around the fuselage. For this test, a slightly poorer fuselage of round cross-section was used, which had a drag coefficient of .242. An ordinary elastic band, of approximately 1/16" square cross section, was slipped over the fuselage. When it was placed about 25% of the distance back from the nose, the drag coefficient jumped to .261, an increase of 8%, and when it was moved to a point 3" back from the nose, the value increased further to .269. This bears out the supposition that the more fuselage area is exposed to turbulent air, the greater will be the drag. While these increases in drag perhaps do not seem alarming, it must be remembered that many builders have labored for hours doping, polishing and rubbing down their fuselages to a mirror-like finish in order to get a gain in efficiency of the same order of magnitude. Obviously it is foolish to spend time polishing the surface of a fuselage if the airflow is to be broken up by an elastic band which holds the wings on. Some other method of wing attachment should be used on highly streamlined ships.

One of the most unavoidable sources of drag on a gas model is the landing gear. Though some builders endeavor to streamline their landing gear struts, the great majority of gas models have landing gears made from round music wire, about 1/8" in diameter, with no additional fairing. This practice is prevalent even when the rest of the model is built with greatest of attention to finish and lines. We expect, therefore, that the next test will come as a shock to the majority of gasoleers. The landing gear tried was of very simple design, as shown in the diagram. It was attached to the fuselage which was first mentioned in this article. As a result, the drag coefficient jumped from .198 to .458, in increase of over 230%! All this was with fairly thin wheels. In fact, further tests showed that airwheels gave only slightly more drag than thin ones, and that by far the greater part of the landing gear drag came from the struts, rather than the wheels.

The reason for this situation was mentioned before, and its cure is not hard to find. The struts should be enclosed in a streamlined fairing. A study of the tests reported in the first article of this series reveals that the drag reduction to be expected from this procedure is about three times as great as that which would result from using a round fuselage in place of one with a square cross section. Again we are forcibly reminded that streamlining is not a matter of looks but rather of careful attention to the details of areodynamics.

Although a large improvement may be made by better streamlining of conventional landing gears, the possibility of eliminating landing gear drag by completely retracting the landing gear must not be overlooked. Even if a perfectly streamlined landing gear, such as is typified by the design used on the Stinson "Reliant" or on Col. Roscoe Turner's "Meteor" racer, gives only one-quarter the drag of the typical unfaired gear, it still has about half the resistance of our well-shaped fuselage form. Perhaps the greatest improvement in the efficiency of full-sized planes in recent years has come about through landing gear retraction, and a similar improvement is possible on gas models. Of course, the advantages of a retracting gear are offset by its increased weight and by the danger of breaking the propeller each time the model lands. The ideal mechanism would seem to be one which could be locked in place for test flights but allowed to retract on official flights at contests.

Finally we must consider the drag of a stopped propeller, because this piece of equipment pulls the gas model along for only twenty seconds of each flight and tries to hold it back all the time it is riding the thermals. On outdoor rubber-powered models, of course, the propeller is so big that the plane will not glide at all if it is held fixed. Therefore free-wheeling or folding propellers are absolutely necessary. On gas models the propeller is much smaller and no one has ever worried much about its effect on drag. Our test result shows, however, that the propeller is by far the largest drag contributor which we have studied. It gives three times as much drag as the fuselage! Thus our combination of the streamlined fuselage and propeller has a drag coefficient of .755, compared to .198 for the fuselage alone. In this test, the propeller diameter was one-third of the fuselage length, which conforms to standard gas model practice, at least for the smaller models.

Here we have a really serious situation. There are several steps which could be taken to improve it somewhat. On a model which is expected to spend most of its flight gliding, the propeller blades should be made as narrow as possible, even at the sacrifice of a certain amount of efficiency in the climb. This is especially true of the portion of the blades near the hub, for only the tips are really effective in giving thrust. Also, a spinner over the hub should help the fuselage streamlining. However, it is obvious that the only way to really overcome this tremendous source of drag is to use a propeller with folding or feathering blades. Free-wheeling is not recommended, for a propeller whose blade angle is as low as is ordinarily used for gas models gives more drag when free-wheeling than when locked.

The problem of designing a propeller hub with provision for folding blades should be an interesting challenge to the model builder's ingenuity, for here is a chance to really make something better than the competitors possess. The hinges at the hub of the blade would have to be very strong, because a half-ounce propeller blade revolving at 6000 R.P.M. experiences a centrifugal force of about 128 pounds. Some difficulty might be experienced in spinning the propeller to start the motor, but no doubt this could be overcome by using some auxiliary starting device. Incidentally, it might be pointed out that a propeller with folding blades would have the practical advantage of avoiding breakage in landing.

In conclusion, let us put the landing gear, motor and propeller on our fuselage all at once. The drag coefficient reaches the tremendous value of 1.034. When these items are used on the square fuselage with the windshield, the drag coefficient is 1.261. This is six and one-half times as great as the drag of the ideal fuselage form! Incidentally, it was noted that the drag of the cylinder head could be eliminated by stopping the propeller in a vertical position, so that it shielded the cylinder.

The result of these tests is a proof of the fact that streamlining really does pay. It shows more than this, however: It shows that for streamlining to be worthwhile, it is necessary to do a really thorough job. Practically nothing is gained by making a beautifully smooth monocoque fuselage unless the motor is cowled, the landing gear faired and all unnecessary projecting parts studiously avoided. It is these small things which give the major portion of the fuselage resistance. Hope these suggestions help!