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No. 254

METHOD OF CORRECTING WIND TUNNEL DATA FOR OMITTED PARTS OF AIRPLANE MODELS

By R. H. Smith
Department of Construction and Repair
Washington Navy Yard

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METHOD OF CORRECTING WIND TUNNEL DATA FOR OMITTED PARTS OF AIRPLANE MODELS.

By R. H. Smith.

Models of airplanes are now widely used in wind tunnels to obtain results from which the performance and stability of the full scale airplanes are predicted. The wind tunnel model, however, does not have complete mechanical similarity to the full scale airplane. Part of the dissimilarity is due to the difference between the stationary model in the artificial wind stream of the tunnel and the moving airplane in still air, in that the former system can be brought into equilibrium by the application of forces and moments external to the model wind system while the latter system can not. As a consequence, the wind tunnel model may have any weight or centroid location consistent with the capacity of the wind tunnel balance to bring it into equilibrium at the desired attitudes to the wind. Therefore the only similarity required between the full scale airplane and the model is geometric similarity or similarity of external form.

Further, departures are made from exact geometric similitude in those models which are to be tested in atmospheric tunnels, for the purpose of obtaining empirically the equivalent of dynamic similitude and thus of escaping the experimental dif-

ficulties of scale effects. While it may be shown that exact dynamic similitude is obtained, and that the difficulties theoretically disappear, if the model Vl/ν is the same as that of the full scale airplane, making the prediction of full flight performance from tests on geometrically similar models scientifically exact, the practical difficulties of constructing such models and testing them at such high values of Vl/ν are great. Actually, predictions which are sufficiently precise for engineering purposes, can be made on tests run on models, geometrically similar to full scale, at values of Vl/ν much below the full flight value and almost within the upper limit of the larger and more powerful atmospheric tunnels now in use. However, for further reductions of the Vl/ν of the model test, prediction becomes increasingly bad due to scale effects until at the moderate speeds of the larger tunnels only stalling speeds and stability can be safely predicted from geometrically similar models. Rather than to strive toward the higher values of Vl/ν for the purpose of escaping scale effects, it is much more practical and economical for atmospheric tunnels to use a considerably lower value of Vl/ν and to depart from geometric similitude in such a way as to evade the scale effects of some parts and to cause the scale effects of others to be canceled by the aerodynamic effects of the departure. In this artificial way the equivalent of dynamical similitude is secured with the result that data, practically free of scale effects, are obtained

on simplified models tested at moderate air speeds and at atmospheric pressure. The successful and economical prediction of full scale airplane performance from atmospheric tunnel tests rests upon the fact that this can be done for a wide range of types and over a wide range of Vl ratios between model test and full flight.

Airplane models for tests in atmospheric wind tunnels are therefore made with two ends in view. The first is to provide a modified model whose wind tunnel forces and moments are practically free of scale effects; that is, whose forces can be converted to full scale according to the squares of the linear scale and air speed and moments according to the cube of the linear scale and the square of the air speed. The second end in view is, since exact geometric similitude is to be departed from, to provide a model as simple as possible for reasons of accuracy and economy in both testing and constructing. For these two reasons one omits from the model all minor parts of the full scale airplane, such as struts, wires, fittings, control horns and other parts, whose scale corrections are large. The resistance and moments of these omitted parts can be computed from tests made on them separately at approximately full flight Vl/ν and added, since the presence of such parts on the airplane adds only their own resistances as separately determined. On the other hand, one includes in the model all those parts of the full scale design where presence causes mutual interference between them-

selves and other parts of the model and therefore adds forces and moments which are different from those measured on the parts separately. Besides the principle parts of the airplane, the wings, body, tail group, and landing gear, such parts are engine cylinders, windshields or guns on fuselages, radiators between the wings and nacelles or cockpits on the wings.

By omitting the minor parts of the airplane in the wind tunnel model and adding to the forces and moments of the model those of these omitted parts measured full scale and properly reduced, the scale effects of such parts disappear from the model data. There remain, however, the scale corrections on the major parts of the airplane which are known to be large, particularly for the wings and fuselage. Except for compensating effects, these corrections would render prediction of full scale performance from model tests in atmospheric tunnels difficult. Fortunately, the aerodynamic effects of omitting the propeller and of making the model surface as smooth as possible, two further departures from geometric similitude between model and full scale that add considerably to the accuracy and economy of model tests, combine to cancel the scale effects of the major parts. Experiment on both full scale and model, thus simplified, has shown that the mutual effect of the propeller and fuselage, the effects of the slip stream, the difference in the surface roughness of the airplane and its model and the scale effects of the major parts consistently disappear from the performance by mutual nullification when the model and full flight performances are com-

pared. It is rarely that any individual item of performance, such as landing speed, maximum speed, climb or stability, is found to be effected by these corrections beyond the precision of the full flight tests.

In practice, therefore, airplane wind tunnel models for tests in atmospheric tunnels are composed of the mutually interfering parts except the propeller, in their correct relative positions but trussed together with substitute struts whose effects on the forces and moments of the rest of the model, called the "remnant" or "residual" model, can be determined and deducted. In practice such struts are made as simple as possible, usually they are of 3/32" diameter cylindrical brass wire, cross braced along the wind where necessary for rigidity, and located without reference to the design strut positions or attitudes. Their effect is determined from two tests, one made with the model fitted with duplicate or dummy struts, the other made without them. The dummies are spaced about ten diameters to one side of the permanent ones, at the same altitude to the wind and in model positions as nearly similar as possible. The difference in the forces and moments of the two tests is taken as the strut effect. The forces and moments of the single strut test minus the strut effect gives the forces and moments on the remnant model.

The forces and moments of the double-strut model, single-strut model and the residual model (Fig. 1) are given in Columns

1, 2 and 4, respectively, of Table I. Column 3 gives the strut effect.

Two ways are open for obtaining the forces and moments on the complete airplane at full scale from the forces and moments on its remnant model, and the forces and moments of the various omitted parts determined separately. The forces and moments on the remnant model may be sealed up to full scale Vl according to the square of the speed and the square or cube of the scale, respectively, and those of the omitted parts at that Vl added, or the forces and moments of the omitted parts may be scaled down according to the square of the speed and the square or cube of the scale, added to those of the remnant model and the sum of the forces and moments scaled up to full scale according to the same law. The former is better theory since it is more direct and avoids use of fictitious values for the forces and moments of the omitted parts, but the latter is better practice since it makes the model Vl the standard for both test and performance calculation, and thus avoids a second standard Vl at full scale from which to compute performance. The latter method, however, has the theoretical objection of using, at model Vl, values for the forces and moments of the omitted parts which do not obtain at that Vl. This method is the standard one at the Navy Aerodynamic Laboratory.

In the case of the airplane model (Fig. 1), the parts omitted in the wind tunnel model had a total resistance full scale

at 70 miles per hour of 44.6 pounds and together with their distribution in the vertical plane, the line of action 1.69 feet below the design centroid. The scale of the model is 1/16. Hence the omitted parts resistance reduced according to the square of the scale and speed to 1/16 full scale and to 40 miles per hour, the standard test speed is $(44.6)\left(\frac{1}{16}\right)^2\left(\frac{40}{70}\right)^2 = .058$ pounds. The line of action on the model is $\left(\frac{1}{16}\right)(1.69') = 1.27$ inches below the design centroid and 5.96 inches above the axis about which the pitching moments on the model were measured. The resistance of the omitted parts, therefore, exerts a positive pitching moment about this axis, which is $(5.96)(.058) = +.346$ pound-inch. These values for the omitted parts resistance and pitching moment are entered in column 5. Finally, column 6, under the heading "Complete full scale craft at model Vl" contains the forces and moments about the pitching moment axis of the remnant model plus those of the omitted parts, reduced. When these values of force and moment, the latter now referred to the design centroid, are scaled up to full flight Vl according to the square of the speed and the square or cube of the scale, the forces and moments of the airplane model (Fig. 1) are obtained.

In such engineering tests on airplane models, as this on model, Figure 1, no correction is made to the yawing moments for strut effect or for omitted parts. The assumption that the yawing moments, for small angles of yaw, are unaffected by any kind of pure resistance members, such as struts or truss wires which are placed symmetrically on either side of the model plane of

symmetry, has been considered as justified, particularly since the only yawing moment data that requires high accuracy is that near zero yaw. Similarly pure resistance parts, which exert only drag forces, can not enter the rolling moment whose axis is along the wind, and can enter rolling moments whose axes are pitched to the wind only to the order of the sine of the angle of pitch times the drag moment arising from the asymmetry of flow past these parts caused by the ailerons. This is a second order effect and therefore negligible. Both rolling and yawing moments, as measured on the model with round struts, are therefore considered valid as rolling and yawing moments on the full scale design when scaled up according to the square of the speed and the cube of the scale.

TABLE I.

Preliminary Tests on Airplane Model, Design No. 43, Figure 1.

Angle of attack	1 Remnant model + double struts			2 Remnant model + single struts			3 Strut effect (faired)		
	L*	D**	M***	L	D	M	L	D	M
-10°	-.983	.466	+2.241	-.969	.385	+1.610	+.012	.081	+.632
- 8	-.419	.380	+2.313	-.431	.294	+1.732	+.012	.079	+.600
- 7	-.155	.366	+2.488	-.167	.280	+1.864	+.012	.079	+.590
- 6	+.137	.348	+2.569	+.125	.263	+1.958	+.010	.078	+.581
- 5	+.407	.344	+2.682	+.377	.257	+2.065	+.008	.077	+.574
- 4	+.668	.338	+2.730	+.647	.255	+2.137	+.005	.077	+.565
- 3	+.913	.332	+2.675	+.913	.256	+2.114	0	.076	+.558
- 2	+1.180	.333	+2.608	+1.193	.265	+2.092	-.008	.075	+.551
- 1	+1.425	.339	+2.471	+1.442	.271	+1.955	-.015	.075	+.547
0	+1.666	.348	+2.305	+1.714	.283	+1.804	-.022	.074	+.542
2	+2.201	.397	+1.902	+2.243	.321	+1.380	-.036	.072	+.537
4	+2.704	.444	+1.304	+2.769	.373	+1.712	-.051	.071	+.533
6	+3.221	.505	+ .351	+3.260	.430	- .183	-.065	.070	+.531
8	+3.682	.593	- .715	+3.860	.524	-1.242	-.078	.068	+.529
10	+4.163	.697	-1.823	+4.239	.633	-2.486	-.093	.067	+.527
12	+4.619	.827	-3.175	+4.701	.774	-3.730	-.107	.065	+.526
14	+5.014	.982	-4.415	+5.152	.916	-4.974	-.121	.064	+.525
16	+5.349	1.124	-5.834	+5.506	1.081	-6.340	-.136	.063	+.525
18	+5.620	1.289	-7.239	+5.760	1.247	-7.778	-.152	.061	+.525
20	+4.841	1.814	-4.533	+4.976	1.767	-5.294	-.164	.060	+.525
22	+4.726	2.004	-4.906	-4.940	1.976	-5.666	-.178	.059	+.525
24	+4.755	2.194	-5.037	+5.020	2.211	-6.038	-.193	.058	+.525

* Lift in pounds.
** Drag in pounds.
*** Pitching moment in pound-inches about test axis.

TABLE I (Cont.)

Preliminary Tests on Airplane Model, Design No. 43, Figure 1.

Angle of attack	4 Remnant model			5 Omitted parts at model Vl			6 Complete full-scale craft at model Vl		
	L*	D**	M***	L	D	M	L	D	M
-10°	-.981	.304	.988	0	.058	+.346	-.981	.362	+1.334
- 8	-.443	.215	+1.132	0	.058	+.346	-.443	.273	+1.478
- 7	-.179	.201	+1.274	0	.058	+.346	-.179	.259	+1.620
- 6	+.115	.185	+1.377	0	.058	+.346	+.115	.243	+1.723
- 5	+.369	.180	+1.491	0	.058	+.346	+.369	.238	+1.837
- 4	+.642	.178	+1.572	0	.058	+.346	+.642	.236	+1.918
- 3	+.913	.180	+1.556	0	.058	+.346	+.913	.238	+1.902
- 2	+1.201	.190	+1.541	0	.058	+.346	+1.201	.248	+1.887
- 1	+1.457	.196	+1.408	0	.058	+.346	+1.457	.254	+1.754
0	+1.736	.209	+1.262	0	.058	+.346	+1.736	.367	+1.608
2	+2.279	.249	+ .843	0	.058	+.346	+2.279	.307	+1.189
4	+2.820	.302	+ .179	0	.058	+.346	+2.820	.360	+ .525
6	+3.325	.360	- .714	0	.058	+.346	+3.325	.418	- .368
8	+3.938	.456	-1.771	0	.058	+.346	+3.938	.514	-1.425
10	+4.332	.566	-3.013	0	.058	+.346	+4.332	.624	-2.667
12	+4.808	.709	-4.256	0	.058	+.346	+4.808	.767	-3.910
14	+5.273	.852	-5.499	0	.058	+.346	+5.273	.910	-5.153
16	+5.644	1.018	-6.865	0	.058	+.346	+5.644	1.076	-6.519
18	+5.912	1.186	-8.303	0	.058	+.346	+5.912	1.244	-7.957
20	+5.140	1.707	-5.819	0	.058	+.346	+5.140	1.765	-5.473
22	+5.118	1.917	-6.191	0	.058	+.346	+5.118	1.975	-5.845
24	+5.213	2.153	-6.563	0	.058	+.346	+5.213	2.211	-6.217

* Lift in pounds.
** Drag in pounds.
*** Pitching moment in pound-inches about test axis.

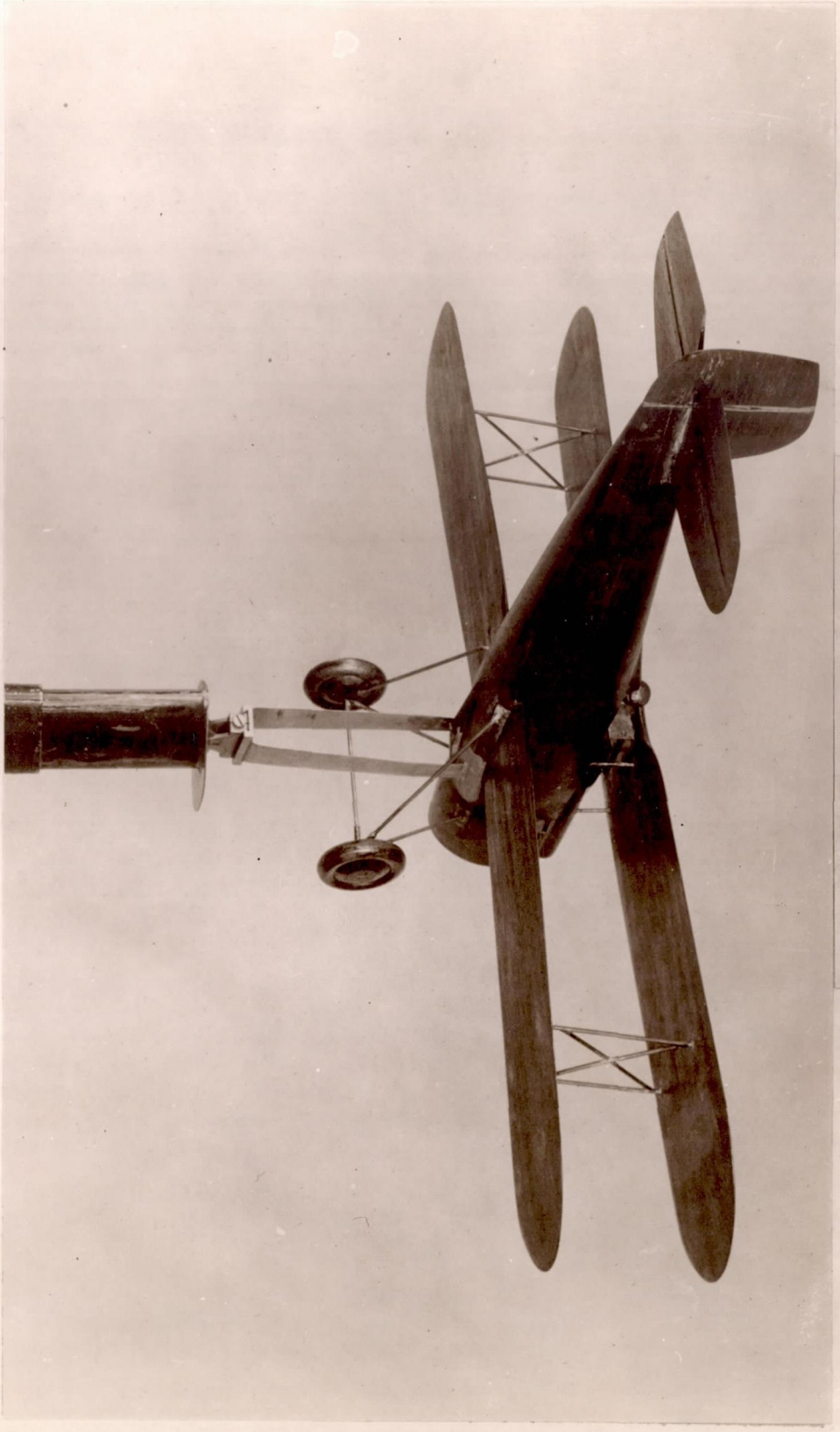

Fig.1 Model of No.43 airplane.