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No. 355

SLIP STREAM EFFECT

By Charles N. Montieth

From "Slipstream," December, 1925

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The horizontal tail surfaces of a new airplane usually are proportional so that the curve of moment about the center of gravity, combined with a similar curve for the wings alone, gives a composite curve which provides a certain specified degree of static stability.

For the condition of power off, this calculation is reasonably accurate, because the only remaining factor (the moment due to parasite resistance) is, for the usual type of airplane, practically a constant quantity. A constant moment difference means simply a change in the angle of stabilizer setting for balance and has an inappreciable effect on the stability.

For the condition of power on, the calculations are not so simple. With the application of power, there are three additional factors to be considered. These are:

(a) The moment of the propeller thrust about the c.g.;

(b) The change in the velocity of the air over the tail due to the slip stream; and

(c) The change in direction of the air over the tail due to the slip stream.

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Of these factors, two may be calculated with a fair degree of accuracy. The thrust may be calculated from the propeller characteristics, and knowing the position of the thrust line with respect to the c.g., the product of the two gives the moment due to the thrust. The ratio of the slip stream velocity to the air speed of the airplane can be calculated by the method outlined in N.A.C.A. Technical Report No. 194, although experience shows that the velocities calculated by this method are too large for use in tail surface calculations.

Fig. 1 is the result of a flight test with a DH-4b airplane, in which the velocity of the air was measured at several points two feet ahead of the stabilizer. The data are given as the ratio of the speed of the air over the tail, power on, to that for power off. This ratio is plotted against the ratio of the speed of the airplane to the maximum horizontal speed so that the data may be applied for other airplanes. The air speed over the tail with the power off was found to be nine-tenths the speed of the airplane for all air speeds in the normal flight range.

Nothing definite is known regarding the change of direction of the air over the tail due to the slip stream. If there were no change in direction, the increased velocity of air over the tail surfaces would give the airplane greater stability. For most airplanes (those having a center of thrust somewhere near the c.g.) the reverse is the case: that is, the airplane is less stable with power on than it is with power off, the effect being most pronounced at low speeds.

In a report on the "Longitudinal Stability of Airplanes" (McCook Field ADM 711), Mr. E. Dormoy gives the results of a number of flight tests, one series of which gives data sufficient for a rough calculation of the change in direction of air over the tail plane due to the slip stream. (The data in Fig. 1 were taken from this report.) These tests were made on the Engineering Division CO-6, an observation airplane mounting the Liberty engine. In the first airplane, the engine was inverted, the thrust line being six inches above the c.g. Later, the engine mounting was changed to the upright position, the thrust line being seven inches below the c.g. Flight tests were made with both arrangements, the curves of elevator angles necessary for balance being plotted against air speed. The results are shown in Fig. 2. The conditions with power off were independent of the engine arrangement.

Fig. 3 shows similar data for the airplane with the inverted engine, power on, with a change in stabilizer setting of three degrees. The conditions for power off were affected in the same way and are therefore omitted from this figure. From Fig. 3 may be determined the amount of stabilizer movement equivalent to one degree of elevator movement.

This could be checked by wind tunnel data but unfortunately, the wind tunnel tests for this airplane were made with but one stabilizer setting. However, Dormoy found that, for tail surfaces of approximately the proportions used on the CO-6, the stabilizer movement may be considered to be approximately half that of the elevator necessary to produce the same moment about the c.g.

Referring to Fig. 2, it is readily seen that the thrust moment may be eliminated without attempting actually to calculate it. The curve for the power on condition, assuming that the thrust line passes through the c.g., is given in Fig. 2. The difference between this curve and that for power off gives the elevator movement necessary to counteract the two influences:

(a) The increased speed of air over the tail; and

(b) The change in direction of the air.

The thrust moment has been eliminated without making any assumption as to its magnitude. The elevator movement, and the corresponding stabilizer movement, using for conversion the ratios given in Table I, are shown in Table II.

It will be noted that these are all down movements, which means that the change in load due to the presence of the slip stream makes the airplane more tail-heavy.

In order to eliminate the changing speed of the air, it is necessary to assume that the elevator angles vary as the forces on the tail, and consequently that these angles vary as the square of the speed of air over the tail. With this assumption, dividing the last column of Table II by the square of the ratios taken from Fig. 1, there remain only the angular settings of the stabilizer necessary to balance the effect of the change in the direction of the air stream. As the CO-6 is an airplane closely resembling the DH-4b, it is felt that the data in Fig. 1 are directly applicable. The maximum speed of the CO-6 taken from flight tests, is 134 M.P.H.

The data are plotted in Fig. 4, column 2 being taken as the basis for plotting.

Dormoy points out that the slip stream, being of a relatively higher velocity than the surrounding air, keeps the direction of the air passing the tail more nearly constant than it is with power off. This being the case, it has the same effect as an increase in downwash. Consequently, the data in Fig. 4 may be treated as the "apparent" increase in downwash due to the presence of the slip stream.

It is admitted that the data are derived by a method decidedly indirect and unscientific. However, in the absence of other data on the subject, designers may find it useful in calculations for predicting the conditions of stability of an airplane with power on.

Table I.

Air speed	Elev. mov. for 3 deg. stab. mov.	Stab. mov. for 1 deg. elev. mov.
130 M.P.H.	4.7 deg.	0.64 deg.
120 "	4.6 "	0.65 "
110 "	4.5 "	0.66 "
100 "	4.45 "	0.67 "
90 "	4.4 "	0.68 "
80 "	4.3 "	0.70 "
70 "	3.9 "	0.77 "
60 "	3.4 "	0.88 "

Table II

Air speed	Elevator Movement	Corresp. Stab. Mov.
130 M.P.H.	1.20 deg.	0.77 deg.
120 "	1.40 "	0.91 "
110 "	1.70 "	1.12 "
100 "	2.0 "	1.34 "
90 "	2.4 "	1.63 "
80 "	3.0 "	2.10 "
70 "	3.8 "	2.92 "
60 "	5.0 "	4.40 "

Table III

Air speed	V/V_{max}	$\frac{V_t(\text{pow. on})}{V_t(\text{pow. off})}$	$(V_{tn}/V_{tf})^2$	Stab. Ang.	Stab. Ang. Due to direct. alone
120	0.895	1.16	1.34	0.91	0.68
130	0.97	1.15	1.32	0.77	0.58
110	0.82	1.175	1.38	1.12	0.81
100	0.75	1.19	1.41	1.34	0.95
90	0.67	1.22	1.48	1.63	1.10
80	0.60	1.25	1.56	2.10	1.35
70	0.52	1.29	1.66	2.92	1.76
60	0.45	1.34	1.80	4.40	2.44

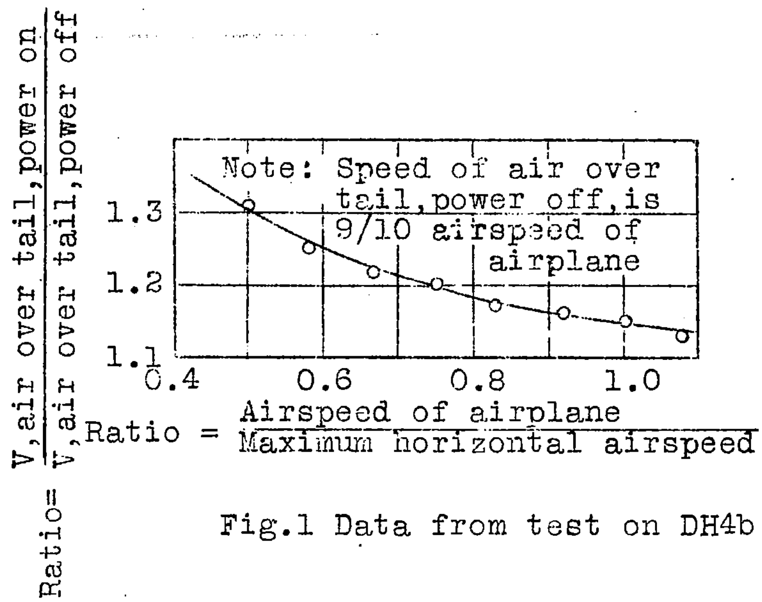
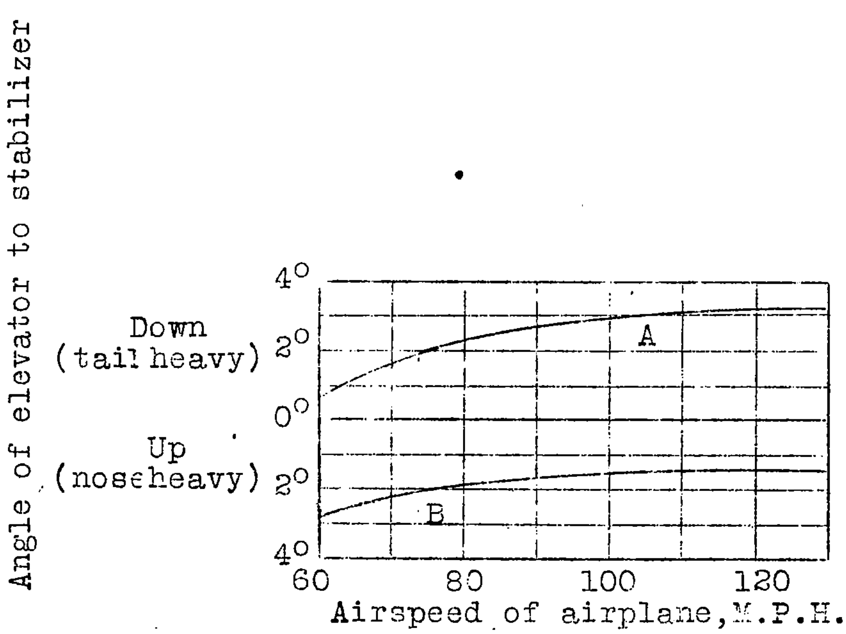
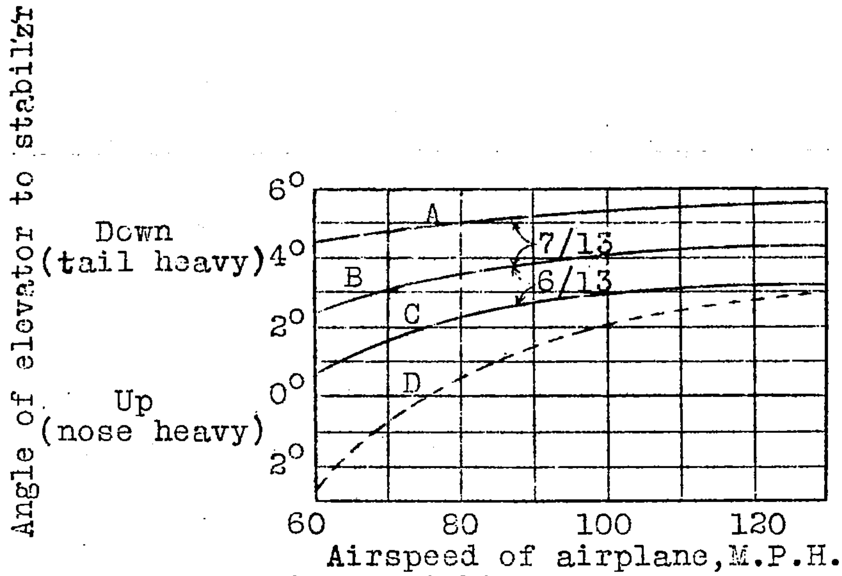


Fig.1 Data from test on DH4b



A = Power on,stabilizer at -2° to thrust line.
B = Power on,stabilizer at +1° to thrust line.

Fig.2 Eng.Div.C.O.-6 airplane.
Engine inverted,thrust line 6in. above the c.g.



A = Power on, engine upright.
Thrust line 7in. below c.g.
B = Calculated curve, power on,
thrust line through the c.g.
C = Power on, engine inverted,
thrust line 6in. above c.g.
D = Power off.

Fig.3 Eng. Div. C.O.-6 airplane.

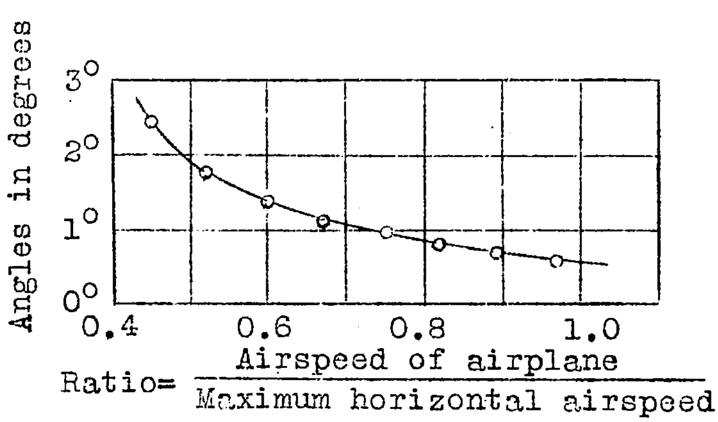


Fig.4 Eng. Div. C.O.-6 airplane.
Apparent increase in downwash due to the slipstream.