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TECHNICAL MEMORANDUMS
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 980

AIR TRANSPORT BY GLIDERS
SOME TECHNICAL OBSERVATIONS
By Wieslaw Stepniewski

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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AIR TRANSPORT BY GLIDERS*

SOME TECHNICAL OBSERVATIONS

By Wieslaw Stepniewski

There is no doubt that much thought is being given to the problem of the transport of great numbers of troops quickly by air. One method which has received a great deal of attention in Germany is that of towing trains of troop-carrying gliders behind airplanes.

A study of the aeronautical considerations involved reveals several interesting fundamental facts. For instance, the ratio of the weight of the train of gliders to the weight of the towing airplane directly influences the speed of the whole combination. The higher the speed of the towing airplane the more efficient the "train" will be. The Me 110, for example, could tow gliders totaling four times its own weight and maintain a cruising speed of about 110 miles per hour. A slower, heavier machine would not be able to lift such a great multiple of its own weight.

This short analysis may be useful in determining the real tactical possibilities of "glider trains" and in adopting the course to be followed in possible studies of these questions. In this analysis most prominent are:

- (a) The power required for the train in level flight;
- (b) its speed;
- (c) climb, and
- (d) the type of airplane best suited for towing as well as design requirements for transport gliders.

*The Aeroplane, vol. 60, no. 1561, April 25, 1941, pp. 476-77.

To simplify the problem of finding the power required in level flight by a train composed of the towing airplane and n gliders, we shall suppose that the towing airplane and gliders are flying practically at the same level. This assumption is justified as from the piloting point of view this is the most convenient position for both the pilot of the towing airplane as well as the pilot of the glider. Furthermore this is the most likely position if transport gliders are to be coupled in "line astern" formations as suggested in The Aeroplane of November 15, 1940. If this assumption is made, we can neglect the vertical forces from the towing cables, and simplify the discussion.

The total thrust T required in the level flight of the glider train as a whole will be:

$$T = T_a + \eta T_g \quad (1)$$

Where T_a is the thrust required by the towing airplane, T_g the thrust required by each glider.

We know that the thrust required in level flight at the speed V may be expressed as: $T = W/E$.

Where W is the total weight of the airplane and E the lift to drag ratio at the flying speed V . Then we have:

$$T = (W_a/E_a) + \eta (W_g/E_g) \quad (2)$$

If both sides of this equation are multiplied by V , the left side will express the effective horsepower - the power really required in level flight. If the propeller efficiency is denoted by η and the power P is given in brake horsepower (W in lb, V in ft/sec), we get from (2):

$$550 \eta P = W_a (V/E_a) + \eta W_g (V/E_g) \quad (3)$$

or:

$$550 \eta (P/W_a) = V/E_a + \eta (W_g/W_a) (V/E_g) \quad (3a)$$

But V/E_a can be considered as the sinking speed of the airplane in a power-off glide (without considering the drag of the stopped propellers) at the speed V . V/E_g can be considered also as the sinking speed of the glider

in a glide at the same air speed V . The quantity $550 \eta (P/Wa)$ represents the rate of climb of the towing airplane which would be obtained if the entire effective horsepower ηP were utilized to overcome the force of gravity. We will call this quantity the fictitious rate of climb and denote it by V_{cf} .

If the sinking speed in a glide is denoted V_z , we may write equation (3a) in a form which will be more convenient:

$$V_{cf} = 550 \eta (P/Wa) = V_{za} + \eta (Wg/Wa - V_{zg}) \quad (3b)$$

If the relations between the sinking speed and the air speed in a glide $V_z = f(V)$, that is, the so-called "speed polar diagram," are known for the towing airplane (without the propellers) as well as for the gliders composing the train, we can determine the speed polar diagram of the train as a whole which, in turn, will provide a very easy solution of several fundamental problems of flight mechanics.*

There is no difficulty in establishing the speed polar diagram of the glider or the airplane, if, for instance, the results of wind-tunnel tests are known, as well as the wing loading and the air density at the operational height. If no wind-tunnel data are available, we may estimate this diagram fairly accurately by considering the aspect ratio of the wing and adopting the minimum drag coefficient of the aircraft C_{Dmin} .

If the speed polar diagrams of the airplane and the gliders are known, the speed polar diagram of the train as a whole may be easily established.

For example, the upper part of the diagram on figure 1 represents the speed polar diagram of the glider, the lower part the same diagram of the airplane. The flying speed axis (horizontal scale) is common for both aircraft. To obtain the speed polar diagram of the train as a whole

* Readers interested in the method of the estimation of performance by means of the speed polar diagram are referred to the author's investigation, "The Prediction of Performance," Aircraft Engineering, November and December 1940.

according to the right side of equation (3b), we have to add to the ordinates of the speed polar diagram of the airplane the corresponding ordinates of the diagram of the glider multiplied by the factor $\eta W_g/W_a$, or by the ratio of the total weight of the "glider-wagons" to the total weight of the towing airplane.

We can find the level flight speed of the train at a height h , at the cruising or all-out power of the towing airplane, using equation (3b), if η and P at this height are known. Equation (3b) states that, in level flight, the fictitious rate of climb $V_{cf} = 550 \eta (P/W_a)$ is equal to the sinking speed of the train as a whole.

If the speed polar diagram of the train is established and the value of the effective horsepower per unit of weight of the airplane is known, we represent this value on the vertical scale (fig. 1) and trace a line parallel to the V axis to the intersection with the speed polar diagram of the train. The abscissa of this point of intersection gives the flying speed.

It can be shown very easily* that the rate of climb V_c of the glider train, at a flying speed V , will be:

$$V_c = 550 \eta (P/W_a) - \left\{ V_{za} + \eta (W_g/W_a) (V_{zg}) \right\} \quad (4)$$

With the aid of the speed polar diagram of the train, this can be found as the difference between the value representing V_{cf} (or $\eta (P/W_a)$) and the ordinate of the point on the speed polar diagram of the train corresponding to the flying speed V (fig. 2). It is obvious that the maximum rate of climb $V_{c \max}$ will be obtained when flying at the speed corresponding to the minimum ordinate of the speed polar diagram of the train. Its value will be:

$$V_{c \max} = 550 \eta (P_{\max}/W_a) - V_{zt \min} \quad (4a)$$

where $V_{zt \min}$ is the minimum ordinate of the speed polar diagram of the train.

* According to the method explained by the author in Aircraft Engineering.

The speed appropriate to the maximum range of a glider train in no-wind conditions is found as the abscissa of the point of tangent of the speed polar diagram with a straight line drawn from the origin of the coordinates (fig. 3). If there is a wind, this tangent passes through the extremity of the vector representing the wind (to the left for a tail wind $+W$, to the right for a head wind $-W$). (See fig. 3.)

The above-established relations being a good instrument for discussing the fundamental problems of the flight of glider trains, we can now try to reach some conclusions as to the type of gliders and towing airplanes to be used.

Obviously the top and cruising speeds of the train will be inferior to the respective speeds of the towing airplane alone. The decrease in speed will depend on the sinking speed of the gliders and on the factor $\eta (W_g/W_a)$, which is on the ratio of the weight of the "carriages" to the weight of the "locomotive." The influence of this factor will be the same if a number of gliders or a single glider, with a weight equal to the sum of their weights, is used. The question whether one or two big gliders or a number of smaller ones should be used can, therefore, be answered only with reference to design difficulties, possible gains in the weight of the gliders, piloting and ground handling difficulties and suitability for tactical purposes.

With regard to the minimum sinking speed, smaller gliders may be preferable (as greater aspect ratios can be used), but the difference will probably not be very marked. Probably the drag of gliders of both categories will be nearly the same; so their speed polar diagrams should be practically identical, provided the wing loading is the same.

Some indications about the best wing loading may be obtained by considering the power required in flight. As indicated by figure 1, the reduction of the speed of the train as compared with the speed of the towing airplane depends on the value of the ratio $\eta (W_g/W_a)$. With regard to the power required in flight, the small sinking speeds of the glider ought to correspond to the cruising speed of the train. In other words, if the total weight of all carriages is not great, then small sinking speeds of the glider should correspond to high flying speeds

which entail high wing loadings. As the total weight of the towed gliders increases, the small sinking speeds should shift forward the lower flying speeds, which allows for lower values of W_g/S_g .

Probably practical considerations will prevent the requirements of power economy being entirely satisfied as the stalling speed of the gliders should not exceed 65-70 miles per hour, out of regard for the landing (mostly on unknown ground) as well as for the take-off run (which increases approximately with the square of the stalling speed). If simple lift-increasing devices are used to give a maximum lift coefficient $C_{Lmax} = 1.7$, the practical upper limit of wing loading will be of the order of $W_g/S_g = 20$ pounds per square foot.

If this value is adopted and the minimum drag of the transport glider is estimated as $C_{Dmin} = 0.02$ and an average aspect ratio of 12, we shall see how such glider or gliders are cooperating with different towing airplanes "as a whole." For this purpose the approximate speed polar diagram of a glider with such characteristics is drawn on the upper part of figure 4.

On the lower part we trace (thin line) the speed polar diagram at sea level of a modern fighter-bomber (for example, a Messerschmitt Me 110), of low drag ($C_{Dmin} = 0.023$ according to wind tunnel tests) and high wing loading ($W_a/S_a = 35$ lb/sq ft). The dotted line represents the speed polar diagram of an airplane of rather obsolete type, with higher drag ($C_{Dmin} = 0.034$) and lower wing loading ($W_a/S_a = 1.7$ lb/sq ft). The effective power loading ($\eta P/W$) will also be different for both categories of aircraft. Adopting $\eta = 0.77$ it will be of the order of $\eta P/W = 0.115$ brake horsepower per pound for the Me 110 and approximately 0.055 brake horsepower per pound for the older bomber fully loaded, which may increase to 0.075 brake horsepower per pound if the load is reduced.

We establish the speed polar diagram of the train as a whole, adopting the Me 110 characteristics and assuming that the weight of the glider carriages is equal to twice, three, and four times the weight of the towing airplane (see the speed polar diagrams in the lower part of figure 4).

We see from figure 4 that if the glider train is towed by a modern fighter-bomber with a great power surplus, its rate of climb at sea level will be considerable (about 1100 ft/min with two 1150-hp engines), even if the total weight of the gliders is four times the total weight of the airplane ($W_a = 14,800$ lb), and the top level speed will be about 130 miles per hour.

A bomber of older design would be unable to "lift" such a multiple of its total weight because of a lower value of η (P/W). The top and cruising speeds of such a train would also be greatly reduced.

Modern aircraft of greater aerodynamic cleanness are undoubtedly more efficient, as a lower percentage of the power is used to overcome their own drag and a greater part can be devoted to the work of towing. However, it does not follow that bombers of older design should not be used as towing airplanes as they can also lift a considerable weight of carriages because of their greater flying weight (though the weight of the ratio of carriages and engines will not be so good). A definite answer can, therefore, be given only by comparing real aircraft, if the tactical requirements for speed and ceiling* are known. This should present no difficulty if the above-explained method is used.

* According to the method explained by the author in Aircraft Engineering.

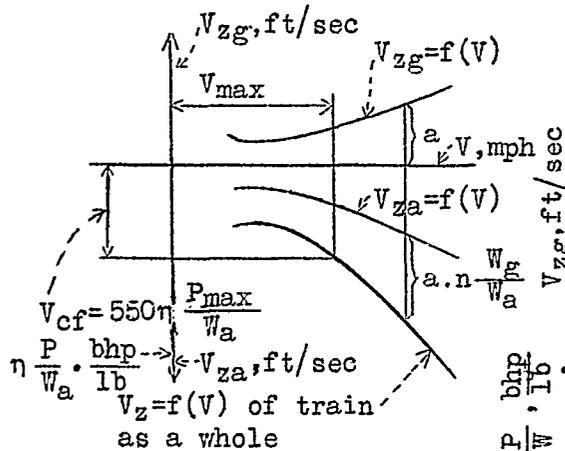


Figure 1.- Determination of the substitute speed polar diagram of the glider train. Finding the level flight speed of the train (for ex., V_{max}).

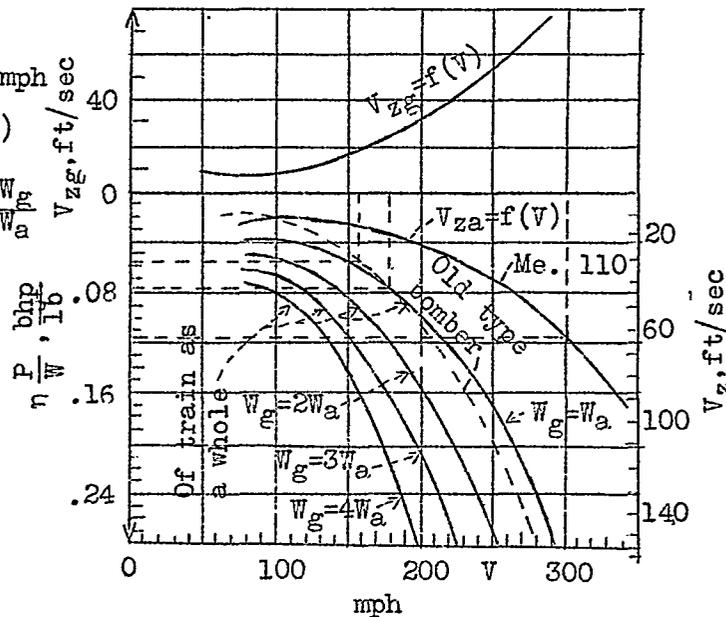


Figure 4.- Substitute speed polar diagrams (at sea level) of the trains composed of fighter bomber, Messerschmitt Me 110 and glider sets of different weights.

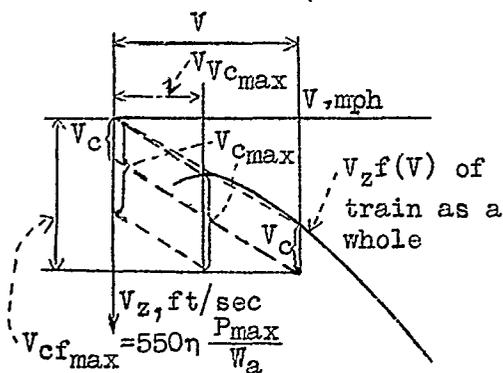


Figure 2.- Rate of climb V_c of the glider train at given speed V and V_{cmax} .

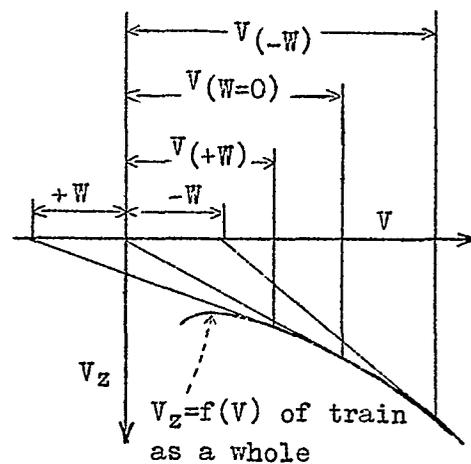


Figure 3.- Flying speeds of the glider train corresponding to the maximum range for no wind conditions ($W=0$), tail wind ($+W$) and head wind ($-W$).



TOWING IN TRIPLICATE.—Three German sailplanes towed by a Focke Wulf Fw 44J Stieglitz two-seat trainer (150 h.p. Siemens Sh 14A motor) at the Frankfurt military aerodrome at Rebstock. The sailplanes are towed through a three-way bridle which permits two of them to be flown side-by-side.

Figure 5

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