L-498

RB No. 3D30

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
April 1943 as
Restricted Bulletin 3D30

FLIGHT TESTS OF A GLIDER MODEL TOWED BY TWIN PARALLEL TOWLINES

By Marvin Pitkin and Marion O. McKinney, Jr.

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

L - 498

L-498

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESTRICTED BULLETIN

FLIGHT TESTS OF A GLIDER MODEL TOWED BY TWIN PARALLEL TOWLINES

By Marvin Pitkin and Marion O. McKinney, Jr.

SUMMARY

The stability characteristics of a glider towed by twin parallel towlines have been studied in the NACA free-flight tunnel. A preliminary theoretical analysis of the stability of a glider restrained from yawing was followed by an experimental investigation of the stability of a model towed from fixed tunnel points in such a way as to simulate tow in level flight. A range of dihedral angles from -4° to 10° was covered for towline lengths of 1, 2, and 3 glider-span lengths. In addition, the effect of flight-path angle was investigated. The effect of the glider on the towing aircraft was determined by later tests in which the glider was attached to a free-flying model.

The results of the tests confirm the theoretical analysis and indicate that a pilotless, stable, towed-glider system is possible when twin parallel towcables are used. The degree of lateral stability of such a system was found to be chiefly dependent upon the dihedral angle. Unstable oscillations were observed for large angles of dihedral and divergences were encountered with negative angles of dihedral.

INTRODUCTION

Load-carrying gliders have many military applications. If existing aircraft are utilized as tugs, troops and their full equipment may be transported great distances without sacrificing any of the combat utility of the tug. The glider may be also used to carry additional fuel, which would thereby extend the range of the tugs.

A severe limitation to the scope of glider application, however, is the problem of obtaining satisfactory stability of the towed aircraft. This lack of stability has made it necessary, in most cases to date, that each glider have its own pilot to make the necessary corrections to hold the glider on its course. In blind towing, either at night or in bad weather, the glider pilot loses orientation with the towing aircraft and thus has difficulty in avoiding accidents. It appears extremely desirable, therefore, to attain inherent stability in a towed glider. Some successful work has been done in connection with the problem of towing gliders with single towlines but the problems have been considerable.

In order to reduce the complexity of the problem a dyadic towline system, shown in figure 1, has been devised. This system restrains the glider from yawing, thus limiting the lateral motion to two degrees of freedom and also provides additional lateral stability through action of the towlines. The stability of this glider system has been determined from an analysis of the equations of motion and from tests of a dynamic model in the free-flight tunnel. For simplicity, only the results of the experiments are given in the present report.

APPARATUS

The tests reported herein were made in the NACA free-flight tunnel, a complete description of which will be found in reference 1.

A 1/20-scale model of the Bristol glider-tow target "Skeet" was chosen for the tests, inasmuch as unpublished full-scale data as well as data obtained for single towline tests were available at LMAL. A three-view drawing of the model is given as figure 2. The fuselage consisted of two perpendicular planes each outlining the projected shape of a conventional fuselage. The dimensional characteristics of the full-scale glider are given in the following table:

Wing area, square feet	173
Horizontal tail area, square feet	56.1
Vertical tail area, square feet	10.5
Wing span, feet.	34.4
Over-all length, feet.	29.3

Inasmuch as the original wing loading of the full-scale Bristol glider was too low (2.08 lb per sq ft) to represent the wing loading of a modern load-carrying glider, the model was ballasted to represent a full-scale weight of

2976 pounds and a wing loading of 17.2 pounds per square foot. The mass characteristics of the scaled-up glider are as follows:

Weight, pounds	2976
Wing loading, pounds per square foot	17.2
Center-of-gravity location in percent of M.A.C.	24.0
Moment of inertia about X axis, I_X, slug-feet^2	2596
Moment of inertia about Y axis, I_Y, slug-feet^2	4063
Radius of gyration about X axis, k_X, feet	5.30
Radius of gyration about Y axis, k_Y, feet	6.63

The model was constructed of balsa with conventional control surfaces installed to allow for trim adjustment. Skid fins were mounted on each wing tip to provide for vertical variation of the towline attachment point as shown on figures 1 and 2 and a dihedral-adjustment device was attached to the wings and fuselage.

Provision was made for the installation of 29-percent-span spoilers located inboard at the 17-percent chord line and also for the installation of 25-percent-chord split flaps of 39-percent span located at the inboard portions of the wing.

TESTS

In order to simulate towed flight, the model was attached, for most of the tests, by means of twin parallel cables to the wire mesh screen located just upstream of the test section as shown in figure 1.

Tests were run to investigate the longitudinal stability characteristics of the glider. For these tests, the points of attachment of the towline were at different vertical locations on the glider. These attachment points were located in the YZ plane for all tests.

Tests for determining the lateral stability characteristics of the glider covered a range of dihedral angles between -4° and 10° and were run for glider lift coefficients of 0.30 and 0.75 for towline lengths of 1, 2, and 3 glider-span lengths.

The effects of towing the glider in high and in low positions with respect to the tug were studied and additional tests were made to observe the effects of varying the flight-path angle of the tug.

Finally, the glider was attached to a free-flying model and the behavior of the complete system was observed. The tug represented a 74-foot-span airplane weighing 32,400 pounds with a wing loading of 37.0 pounds per square foot based on the glider scale.

Motion-picture records of each flight were made and correlated with visual observations.

RESULTS AND DISCUSSION

Longitudinal Stability

The longitudinal stability of the glider was found to be dependent mainly upon the vertical location of the towline attachment point on the glider. With the towline attached at points on the Y axis of the glider, the longitudinal behavior was completely satisfactory. Moving the attachment point above or below the center of gravity, however, introduced sharp pitching as well as longitudinal oscillations resembling the phugoid oscillation. The longitudinal behavior of the model was very jerky for these conditions and sustained flights could not be obtained for the larger values of displacement from the center of gravity.

Inasmuch as the model would maintain a constant angle of attack (hence a constant lift coefficient) for any given elevator setting despite variation in airspeed of the towing aircraft, the glider would fly either below or above the level of the tug (low or high tow) depending upon whether the airspeed was low or high. This characteristic of the glider could be utilized for the take-off and landing maneuvers. Thus, on take-off, the glider would be trimmed for cruising speed. The tug would then take off first and fly above the glider inasmuch as the take-off speed of the tug would be below the speed at which the glider could lift its own weight. At higher airspeeds the glider would move back and up relative to the tug, rotating about the tug towline attachment points until, at cruising speed, it would reach the position set for normal flight. For landing, this procedure would be reversed; the glider would drop below the tug as lower speeds were reached and would land first.

Lateral Stability

Criterions.- The stability characteristics of an airplane are those qualities which define the nature of the motion after a deviation from an initial condition of equilibrium. The motion may be oscillatory, consisting of a series of oscillations having a fixed period and a certain rate of increase or decrease in amplitude, or aperiodic with a certain rate of return toward or deviation from the equilibrium position. The preliminary theoretical study indicated that the lateral motions of a glider towed by twin parallel cables would consist of one oscillatory and two aperiodic modes, the damping of which would determine the nature of the glider flights. It is not sufficient, however, for the glider just to be stable - to damp out oscillatory or aperiodic motions - because the glider is limited to the field of motion allowed it by the cables and the towing aircraft. Because of this restriction, the glider may destroy itself, even though its actions are stabilizing, if those actions require a larger field of motion than that allowed by the cables. Three criterions were accordingly used to evaluate the nature of the results obtained in the lateral stability tests. Two of these criterions deal only with the inherent stability of the glider (i.e., damping of the oscillatory and aperiodic motions); whereas the third is concerned with the degree of stability inherent in the glider system, or the "steadiness" of the flight. A condition that damps oscillatory and aperiodic motions moderately can be expected to lead to steadier flight than a condition that damps oscillatory motions heavily but aperiodic motions slightly because smaller corrective motions are required of the glider. Steadiness when used as a flight rating in this report therefore should be considered as an index of the optimum damping and satisfactory nature of glider flights.

Evaluations of the nature of the oscillatory and aperiodic phases of the glider flights were obtained chiefly by examination of motion-picture records, whereas the steadiness ratings were determined by visual observation of flights. Most of the results are therefore necessarily of a qualitative nature.

Effect of dihedral.- The tests to determine the effects of dihedral were conducted at zero flight-path angle with towlines horizontal. The results are presented in table I. Flight ratings are given for the oscillatory mode, the aperiodic mode, and the steadiness of each of the dihedral tests run.

Dihedral angle appeared to be the major parameter determining the stability of the glider flights. For level tow the model would remain steady for small through moderately large, positive dihedral angles. All lateral oscillations and aperiodic motions damped out quickly in this range. Increasing the dihedral above this range led to unstable lateral oscillations and violent divergences occurred when the dihedral was negative. The most steady flights for level tow were obtained for geometric dihedral angles of 4° and 6°.

Effect of tow length.- Increasing the towline length apparently narrowed the range of dihedral angles at which steady satisfactory flights could be obtained and a noticeable lessening of stability was evident for all flights. The action of the cables in resisting sideslip was considerably reduced and introduced problems which had not been encountered for short towlines.

Increased unsteadiness and amplitude of lateral motions were apparent throughout the 2- and 3-span tow tests and the sensitivity of the model to changes in trim was highly increased. Although satisfactory flights for 1-span tows could be obtained for a dihedral range extending roughly between 0° and 8°, satisfactory flights for longer towlines could only be obtained when the dihedral was 4° or 6°. Flights made with dihedral angles of 2° and 0°, although apparently stable insofar as lateral oscillations were concerned, seemingly possessed little resistance to sideslip and sustained flights were difficult or impossible to obtain with such dihedral. Flights made with dihedral angles greater than these values were less stable for flights with the longer towlines than corresponding flights with the shorter towlines and instability occurred at lower dihedral angles.

Effect of elevator setting.- Increasing the elevator setting to increase the lift coefficient lessened the degree of stability in the glider system. This lessening of stability was not noticeable in the 1-span tow tests of the model where the stabilizing action of the cable is large, but was increasingly evident when longer towlines were utilized. As shown in table I, steady, satisfactory flights could not be obtained for 3-span length tows when the glider was trimmed to the higher value of lift coefficient.

Increasing the elevator setting resulted in a shift in the stable dihedral range. Flights made at high lift coefficients became unstable at lower values of geometric dihedral than those made at low lift coefficients but showed better aperiodic motion characteristics for low and negative dihedrals. This effect appears to be primarily due to the change in effective dihedral with angle of attack, resulting in greater effective dihedrals for large values of lift coefficient. Full-scale data from unpublished tests indicate that this difference in effective dihedral due to the change in angle of attack would be of the order of from 2° to 4° and the conclusion may thus be drawn that the stability reversal points for this model occur at approximately the same effective dihedrals.

Effect of tow angle.- The model was most stable and steady when the towlines inclined downward from tug to glider. No case of instability existed for positive dihedral angles until the model approached the level tow position. Increasing the airspeed so that the model flew above the screen towline position had an adverse effect upon the lateral behavior of the model. A reduction in stability was apparent for all high-tow flights, and flights that had marginal stability in the level position became unstable in the high position. The beneficial effect of low tow was particularly emphasized with the longer tow lengths. Fairly satisfactory flights could be obtained at $C_L = 0.75$ even with the 3-span tow, provided that the towlines were considerably inclined downward from the horizontal. Despite elevator setting, no flights could be obtained at 3-span-length tows when the towing speed was increased so that the towlines were even as little as 10° above the level tow position.

Effect of flight path angle.- The theoretical investigation indicated that the stability of the glider was a function of cable tension and that the tension in the cable, for any given glider weight, was primarily a function of the magnitude of the difference $(\gamma_t - \gamma_g)$ where γ represents the flight-path angle and the subscripts t and g identify this angle for the tug and glider, respectively. In either case, γ is considered positive in the attitude for climb. A decrease in γ_g or an increase in γ_t might therefore be expected to increase the tension in the cable and hence the restoring forces of the towline system.

The effect of varying γ_t was first investigated and was found to check the theory. Increasing the flight-path angle of the tunnel to simulate climbing flight led to increased steadiness of all flights tested; whereas decreasing the tunnel angle to simulate diving conditions led to less steady glider flights which were finally terminated when γ_t became equal to γ_g. At this point the cables were completely slack and any tunnel disturbance would cause the model to move about violently. The results of these tests indicated that some means other than elevator setting would have to be provided for increasing γ_g if gliding flights were to be maintained. Inasmuch as either flaps or spoilers accomplish this result by decreasing the lift-drag ratio of the glider, their effects were then investigated. The optimum dihedral angle of 4° was utilized for all tests.

The results of these tests showed that the installation of the partial-span split flaps deflected 45° decreased the γ_g term by only a few degrees, and the flap effects were therefore small. Installation of spoilers covering the inboard 29 percent of the span, however, proved very beneficial to the glider-flight behavior. Completely satisfactory flights could then be obtained at lift coefficients of 0.75 for 3-span-length tows and for tunnel (or tug) flight-path angles varying from 20° climb to 22° glide. Flights were also made for horizontal flight at a lift coefficient of 0.30 and for a tow length of 4 span lengths, but these were only mildly satisfactory and then only for airspeeds at which the glider was below the tug. No flights were possible at 4-span tow lengths when the spoilers were removed.

The results of the flight-path-angle tests tend to explain the previously noted favorable effect of low elevator settings, inasmuch as the γ_g term is larger negatively for the low lift coefficients and thus aids in maintaining tension in the cables.

Effect of glider on towing aircraft.- With the glider attached to a free-flying model the stability of the glider was essentially unchanged and little effect of the glider on the tug was noted. The glider followed the tug through its motions and closely duplicated all lateral and longitudinal maneuvering of the tug. Successful flights were made with towlines of 1 and 2 span lengths. Inasmuch as the tug was in gliding flight, it was necessary to equip the towed glider with spoilers to steepen its gliding angle. A photograph of the glider train in gliding flight is presented as figure 3. The model flight tests indicated that an inherently stable glider system can be obtained through the use of twin parallel towlines.

CONCLUSIONS

Based on preliminary theoretical and experimental investigations of a model of the Bristol glider tow-target "Skeet", the following conclusions are reached:

1. A dyadic system of parallel towlines which imposed a restraint in yaw provided satisfactory inherent stability for a pilotless towed-glider system.

2. The longitudinal stability of the glider was satisfactory, provided that the towline attachment to the glider wing was made at the vertical as well as at the fore-and-aft location of the center of gravity.

3. The lateral stability of the glider was influenced chiefly by the dihedral settings of the wings. The steadiest stable flights were obtained with moderate dihedral angles. Unstable lateral oscillations occurred for large positive dihedral angles while lateral divergences were encountered for negative dihedral angles.

4. Increasing the towline length was detrimental to the lateral stability characteristics of the glider, although successful flights were obtained with a 3-span tow length.

5. Increasing the elevator setting to trim the glider at higher lift coefficients reduced the lateral stability for all glider conditions.

6. A low position of the glider relative to the tug had beneficial effects on the lateral stability; whereas a high position was detrimental.

7. There was a favorable effect of climbing flight upon the stability characteristics of the glider, which resulted in very steady flights for stable configurations. Reducing the flight-path angle below the horizontal, however, seriously lessened the stability of the glider and prevented satisfactory flights at gliding angles greater than a few degrees. Satisfactory glider flights for

negative flight-path angles were obtained, however, by the use of spoilers, which had a highly beneficial effect on the glider stability.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCE

1. Shortal, Joseph A., and Osterhout, Clayton J.: Preliminary Stability and Control Tests in the NACA Free-Flight Wind Tunnel and Correlation with Full-Scale Flight Tests. T.N. No. 810, NACA, 1941.

L-498

TABLE I

LATERAL STABILITY OF A GLIDER TOWED BY TWIN CABLES IN HORIZONTAL FLIGHT[a]

C_L	Angle of dihedral, Γ (deg)	One-span tow length			Two-span tow length			Three-span tow length		
		Oscillatory mode	Aperiodic modes	Steadiness of flight	Oscillatory mode	Aperiodic mode	Steadiness of flight	Oscillatory mode	Aperiodic mode	Steadiness of flight
0.30	-4	?	D	D	--	--	--	--	--	--
.30	-2	A	C	C-	?	D	D	?	D-	D-
.30	0	A	B	C+	?	D+	D	?	D	D
.30	2	A	A	B+	A	C	C	A	D	D
.30	4	A	A	A	A	A	B+	A	A	B
.30	6	B+	A	A	B+	A	B	B	A	B-
.30	8	B-	A	B+	B+	A	B-	B-	A	C
.30	10	C+	A	D+	C	A	C	C-	A	D
0.75	-4	?	D	D	--	--	--	--	--	--
.75	-2	A	B	C	--	--	--	--	--	--
.75	0	A	A	B	?	?	D	--	--	--
.75	2	A	A	B	A	B	C	--	--	--
.75	4	A	A	A	A	A	B+	?	?	D
.75	6	A	A	A	B	A	B	?	?	D
.75	8	C	A	C	D	A	D	--	--	--
.75	10	D	A	D	--	--	--	--	--	--

[a] Evaluation of ratings:

Ratings	Oscillatory mode	Aperiodic mode	Steadiness
A	High degree of oscillatory stability (oscillations damp out quickly)	High degree of convergence	Very steady flight
B	Marginal degree of oscillatory stability (oscillations eventually damp out)	Slight degree of convergence	Steady flight
C	Marginal degree of oscillatory instability (oscillations eventually build up)	Slight degree of divergence	Erratic flight
D	High degree of oscillatory instability (oscillations build up quickly resulting in violent termination of flight)	High degree of divergence	Violently erratic flight
+	Indicates condition slightly better than letter designated		
-	Indicates condition slightly worse than letter designated		
?	Flight too violent to obtain stability rating		
--	Configuration not tested		

L-498

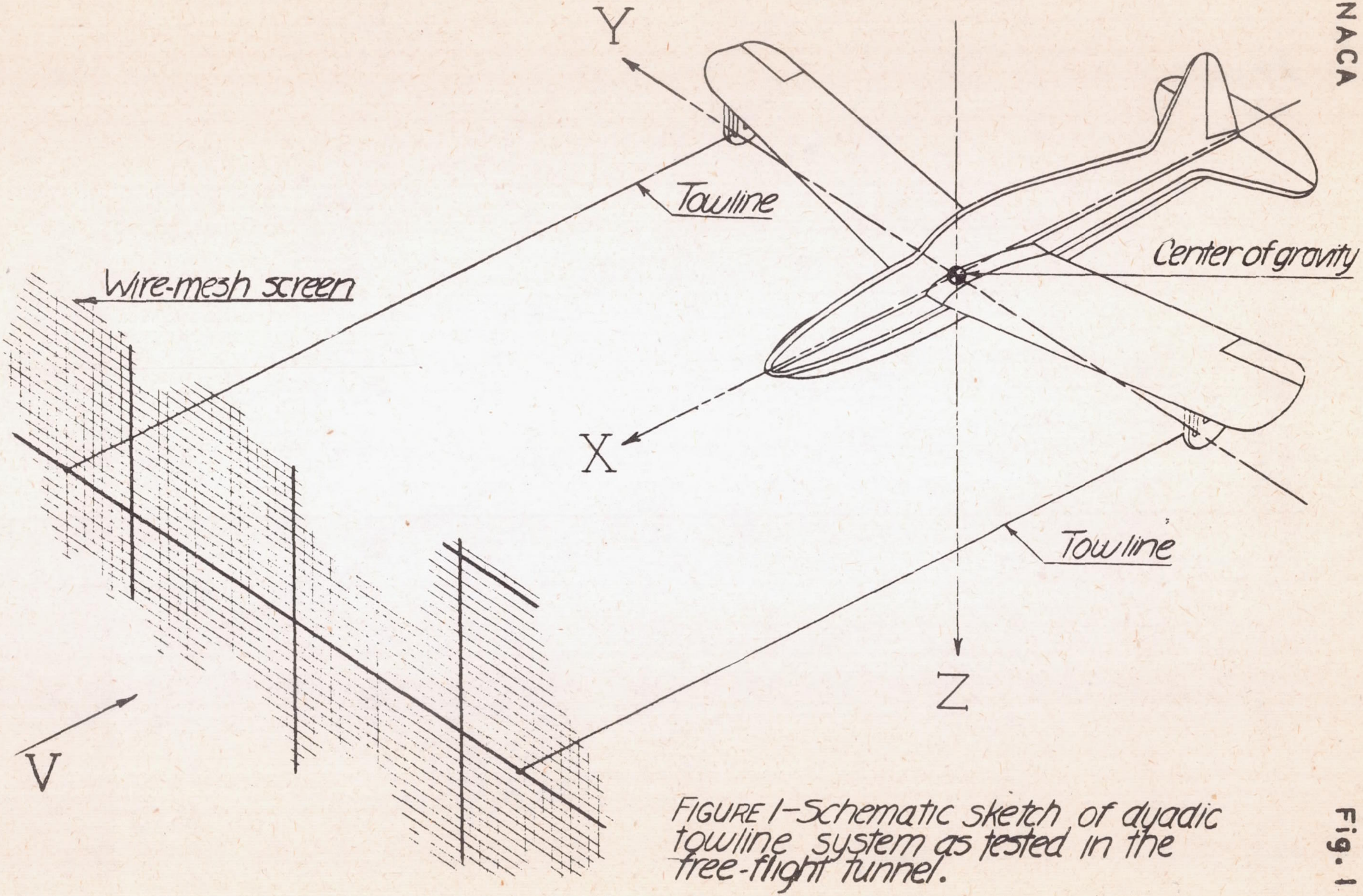

FIGURE 1-Schematic sketch of dyadic towline system as tested in the free-flight tunnel.

L-498

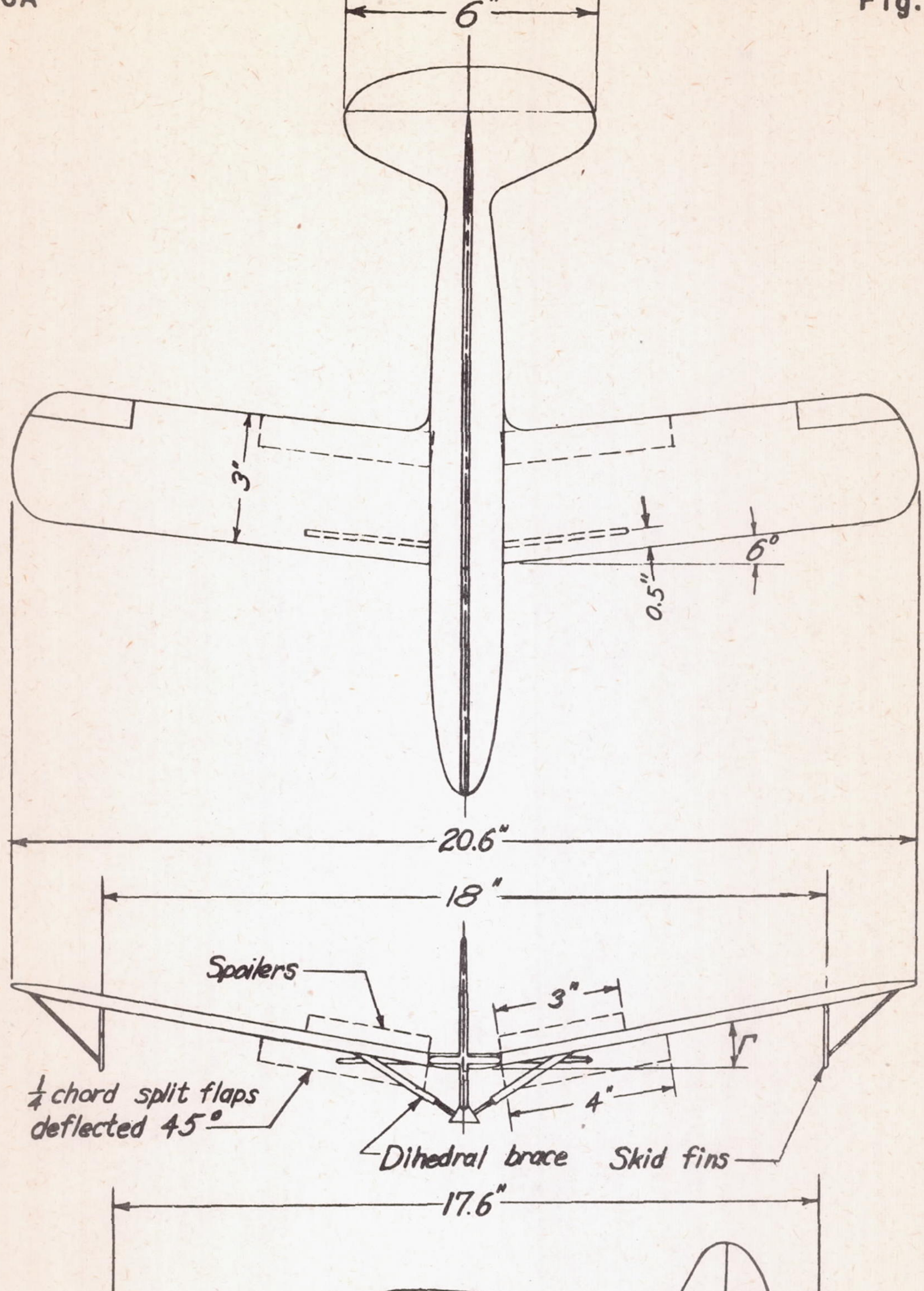

FIGURE 2 – Detail of $\frac{1}{20}$-scale model of the Bristol glider-tow target "Skeet" as tested in free-flight tunnel.

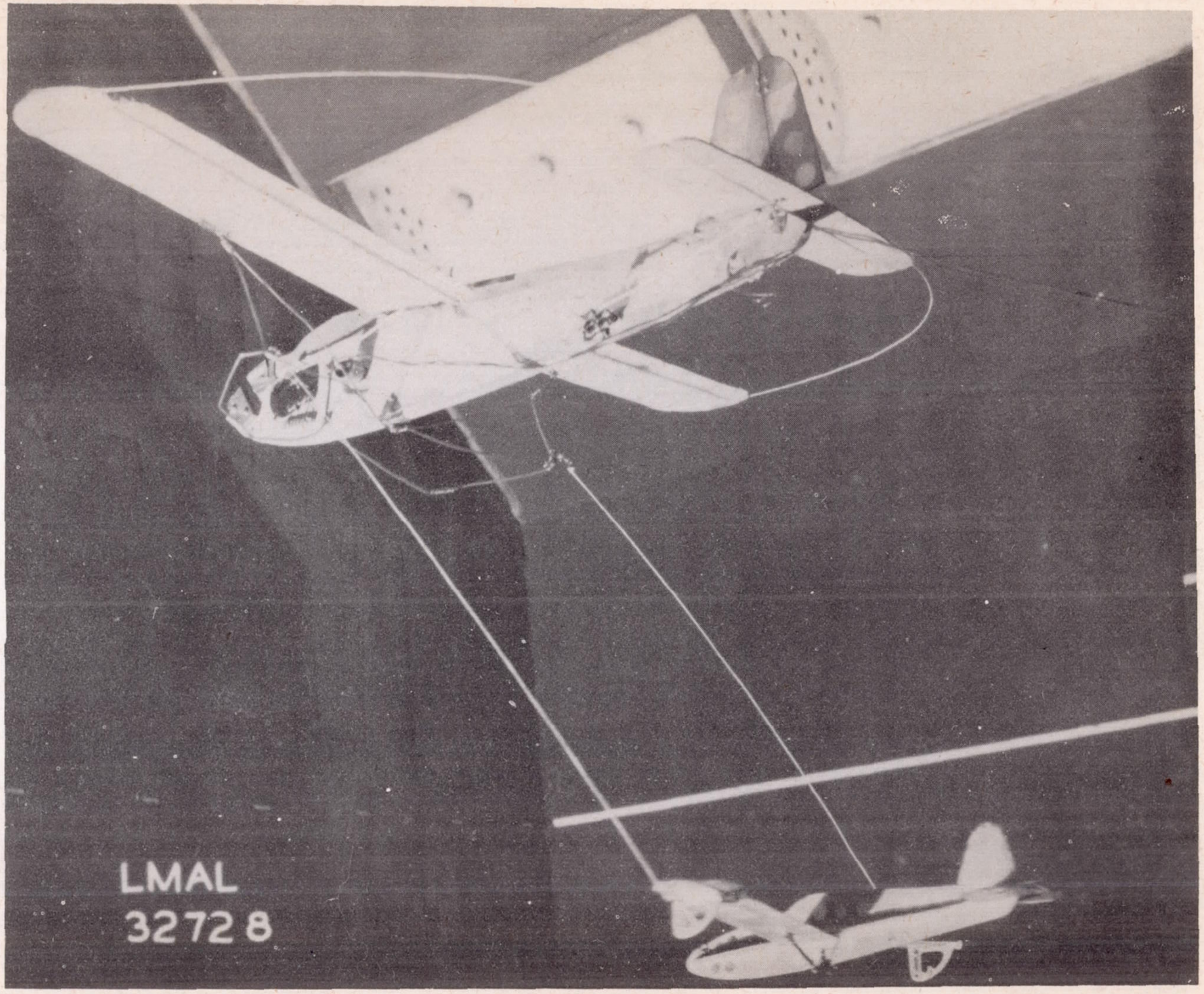

Figure 3.- Photograph of test glider being towed in low position by a free-flying model.