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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 434

GLIDER CONSTRUCTION AND DESIGN

By Alfried Gymnich

From "Der Gleit- und Segelflugzeugbau"

Washington
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 434.

GLIDER CONSTRUCTION AND DESIGN.*

We have already made a brief survey of some of the most successful and interesting gliders (See N.A.C.A. Technical Memorandum No. 433). If, however, we should undertake to classify the individual types, we would encounter difficulties. Aircraft, which at first glance we would have taken for "soarers," often could make only simple gliding flights and indeed, were often unable to fly at all, while on the other hand, excellent soaring flights were sometimes made with very primitive appearing gliders. Airplanes, like the Schulz and Peyret tandem monoplanes, gave unexpected results and still further obliterated the boundaries between gliders and soarers. This is doubtless due in part to differences in the skill of the pilots and in part to overlooking small details, which can render even the best soarer useless. The endeavor to draw a strict line between gliders and soarers has therefore been recently abandoned and the following classification adopted:

1. Gliders controlled by shifting the weight of the body;
2. Gliders controlled by rudders;
3. Gliders controlled by the wings.

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*Translation from Chapter IV, Sec. 1-3, "Der Gleit- und Segelflugzeugbau," by Alfried Gymnich. Published by Richard Carl Schmidt & Co., Berlin, 1925.

Class 1.- Gliders controlled by shifting the weight of the body are called "hang gliders." Most engineless airplanes of the first development period, as the time previous to the first engine flight may be designated, belong to this class. This was perfectly natural because hang gliders were the simplest and least expensive to build. It is obvious that this primitive method of control set definite limits to the weight of the glider. Moreover, this method of control, because it is not sufficiently responsive and sensitive, is effectual only in a weak wind. Strong winds or gusts are dangerous, even with the most skillful maneuvering. Hence the hang glider can play only a subordinate rol~~l~~e in the further development of soaring flight. Even for school and training purposes, it is by no means such an ideal aircraft as it is often pictured, because the start, flight and landing require more courage and skill than for any other aircraft. Presence of mind and quickness of decision are prime requisites, due to the low flight altitude. The advantages of the hang glider are its ease of disassembling and its small weight and size, which facilitate its stowing and transportation at a low cost. The beginner would do better, however, to make his first flights on a seat glider, so he can give his whole attention to the piloting.

Class 2.- The hang glider lost in importance through the introduction of wing warping by the Wright Brothers for maintaining the lateral stability, and subsequently of aileron control by the French. The superiority of gliders controlled by special organs was so evident that the hang glider was entirely crowded out of the second development period (the interval between the first engine flight and the first Rhön contest). Control by means of rudders was more effective, whereby the performances were naturally increased.

Most of the rudder-controlled gliders were biplanes, the same as in engine flight. This was due to their greater strength and smaller wing loading. The mutual bracing of the two wings with struts and wires made the biplane statically a self-contained system. At the same time a given wing area could be obtained with a smaller span. At first, even on rudder-controlled gliders of the Wright pattern, the control organs were located partly in front of and partly behind the wings. On the development of the fuselage biplane, the forward control surfaces were shifted to the rear end of the fuselage. Through the cantilever type of construction, introduced by Professor Junkers, the monoplane again assumed importance and, even in the first Rhön contest, demonstrated its great superiority. At the same sinking speed, the flight speed increased through the elimination of all outside struts and wires. The gliding angle was thus reduced, which also promoted progress in soaring flight. All the best soarers are rudder-controlled cantilever monoplanes. This does not mean, however, that the cantilever monoplane with tail control surfaces must be regarded as the standard for static soaring flight. For the exercise of dynamic soaring flight, there proved to be defects which led to the construction of gliders which we have put in the third class as "wing controlled" gliders and which were developed independently of engine-driven airplanes. It is known that static soaring flight depends on the utilization of air currents deflected upward by local obstacles, or of upward thermal currents. No special requirements needed to be met in order to enable this utilization. Static soaring flight can be accomplished with any normal, well-balanced glider or engine airplane, without reference to the gliding angle or favorable aerodynamic design. This was sufficiently demonstrated by Thoret's soaring flight at Biskra in Algiers with a normal Hanriot training biplane with a shut-off 80 HP. LeRhone engine, and by the world endurance record of Schulz on the old Rhön glider, which could not be admitted at that time by the Technical Committee, due to its lack of structural strength. Obviously a glider with a lower sinking speed would not require so strong a vertical wind as one with a higher sinking speed. It would be a mistake, however, to assume that for this reason an airplane for static soaring flight would have to be designed with the smallest possible wing loading and minimum sinking speed. Such an airplane would be practically possible only by disregarding aerodynamic efficiency, since a very light airplane requires external struts and wires, the structural drag of which would consume most of the forward speed, so that such an aircraft would not be able to overcome even a light head wind. Just for this reason a medium wing loading and cantilever wing structure is desirable, in order to maintain forward motion against stronger winds. It might, however, be desired to have a low flight speed in order to retain one's position in the upward-wind zone, as was illustrated by the endurance flight of Schulz who, without flying in curves, simply allowed himself to be driven back and forth over the dune by the wind. In this instance the low flight speed of his aircraft, due to its great structural drag, was very much to his advantage. The design of a glider would naturally be more or less adapted to the landing conditions and the mean wind velocity.

Tail-controlled gliders were found to be too slow to respond to the controls for the fullest utilization of the wind energy. Due to the lack of a suitable instrument for determining the strength and direction of a gust before it strikes the aircraft, the pilot can only depend on his feeling. He perceives from the steering controls or the lifting effect of the wind on the wings, that the wind velocity is increasing and, without knowing its strength and direction, actuates the elevator, in order to give the wings a greater angle of attack for the purpose of utilizing the increased wind velocity. Some time elapses before the angle of attack is increased by the action of the elevator, and most of the gust has passed by before it can be utilized. Therefore, for increasing the angle of attack more quickly, it was first sought to obtain a greater maneuverability in the longitudinal direction by shortening the fuselage. The resulting shorter lever arm necessitated greater rudder deflections or larger rudders. Dynamic soaring flight was not promoted, however, in this way any more than by the tailless type witha pronounced sweep back or with wing tips extended far back like the "Charlotte." The conditions are different in an irregular ascending wind. Here the gusts strike the wings at a greater angle of attack, so that the utilization of the gust follows automatically. An essential condition is that the whole glider must be struck by the gust because, if only one wing is hit, the rudder deflection, for maintaining the equilibrium, acts as a brake and neutralizes the one-sided gain.

Class 3.- It was therefore logical to make the wings maneuverable, so as to take direct advantage of the gusts, although our natural pattern, the bird, hardly changes his angle of attack for utilizing the gusts. Two methods have been tried, the same as in the development of the warping devices. By the first method the wings are made very warpable by means of suitable devices. By the second method, the wings are rotatable about the main spar. Both these methods have been used. The first is technically more difficult, but gives better results. On the one hand, the wings are so connected that a positive deflection of one wing will be accompanied by a negative deflection of the other wing while, on the other hand, by using two control sticks, either wing can be deflected independently of the other. Both wings can also be rotated simultaneously as a unit, as demonstrated on the "Geheimrat." It cannot be maintained, however, that gliders with wing control were better than the ones controlled by tail surfaces and ordinary ailerons. In fact, all the best records were made by the latter type, and the frequent serious accidents with the former type were not encouraging for further experimentation with that type. Moreover, it is practically impossible to determine mathematically the forces and stresses developed in flight by an adjustable wing, although it is known that they greatly exceed the stresses developed on gliders with fixed wings. The former are often underestimated, as demonstrated by the many failures of wing-controlled gliders. It would be regrettable, however, for the experiments to be discontinued. It might be advisable first to acquire sufficient experience in piloting such gliders, all the more since the object of wing-controlled gliders is to utilize the irregularities of the wind, i.e., the attainment of dynamic soaring flight. In order to prevent over-control, attempts were made to hold hinged wings at a certain angle of attack by springs or rubber cables, so that they would yield under increased wind pressure and automatically reduce the angle of attack. No important records, however, have yet been made with such gliders. The use of elastic cables only produced a complication of the successful wings with flexible trailing edges, although the reduction of the angle of attack of flexible wings is equivalent to changing their profile. The Zeise-Nesemann glider had flexible wings which adapted themselves automatically to the wind pressure. A gliding angle of 1/20 was attained by this glider in still air, although its aspect ratio was not especially favorable. Unfortunately, the glider met with an accident, and its promising initial successes could not be followed up.

A very interesting design, properly belonging, however, to Class 2, was originated by Klemperer. In order to detect gusts before they reached the wings, he designed and built a glider of the "Enten" type. With this type, the gusts first strike the horizontal control surfaces, which are situated far forward. The pilot detects the increase in the wind velocity by its effect on the control stick and increases the angle of attack by raising the elevator, or by depressing it in the event of a lull. This type automatically utilizes wind-velocity variations to a greater or less degree, since any pressure increase under the forward horizontal control surfaces automatically raises the nose of the fuselage and increases the angle of attack, or vice versa. Only a few trial flights were made with this glider in the 1922 Rhön contest, and unfortunately it was not entered in the 1923 contest. Further experiments with the "Enten" type, so-called from its resemblance to a flying duck ("Enten"), are very desirable.

The best results have been obtained with gliders of Class 2 and, among these, by the ones with the most favorable aspect ratio, i.e., with relatively large span and small chord. It should be borne in mind, however, that thus far, all soaring flights have been static soaring flights. A few dynamic flights may have been assisted by soaring-flight effects, but no purely dynamic soaring flight has thus far been made. It is therefore impossible to predict, even approximately, in what direction soaring-flight research will progress. Possibly the soaring flight of the future will not fall in either of the three classes..

There are two principal reasons why we have not made more progress toward the solution of the problem of soaring flight. In the first place, the wind pulsations have not been sufficiently investigated to enable us to understand the technical side of the problem and, in the second place, many constructors turned their attention too soon to the construction of light airplanes, because the prospects of early success were better in this field. In this connection the decisive factor may have been that a glider (or "soarer") immediately loses its soaring-flight characteristics on the installation of an engine with a propeller and ceases to differ from other light airplanes which were developed from engine-driven airplanes. The installation of an engine in a glider is therefore premature, at least so long as we are dependent on the propeller. No one can yet say that soaring flight will ever succeed, but it is just as unreasonable to deny its possibility. Every great invention was considered impossible shortly before it was made, and was then soon accepted as a matter of course by the great majority.

Building Materials and Parts

Wood is the principal building material for gliders, although it is now possible to make just as light metal structures. This is due to the difficulty of working the metal and to the fact that gliders are now made mostly by clubs and private individuals, who seldom have the special tools and machinery required for metal construction. Moreover, wood is more easily repaired than metal. It would be desirable, however, for metal (particularly duralumin, which is used so much in the construction of engine-driven airplanes) to be more used in glider construction, especially for the fuselage. The uniform strength of metal enables more accurate calculations than the strength of wood, which is known to be subject to great fluctuations. In using wood, therefore, the calculations must be based on the lowest of the given strength values. Of course only perfectly air-dried wood can be used. It must be absolutely free from knots and must be cut parallel to the grain. Even air-dried wood is subject, however, to "working," i.e., if the humidity of the air increases, the wood absorbs moisture and expands;

in the opposite case, the wood dries and shrinks. These changes occur chiefly at right angles to the grain, the wood "working" but very little in the direction of the grain. Since we know these properties of wood, we must adopt suitable precautions to prevent it from working. In the first place we must, wherever possible, use plywood, which can be bought from the manufacturers in thicknesses from 1 mm (0.04 in.) up. Moreover, the finished frame should be painted or varnished and all external parts carefully shellacked. The strength and physical characteristics of ordinary woods differ greatly and their uses differ correspondingly. Full information is given in Table I. Duralumin and steel tubes are used for control rods; sheet steel for fittings, wire "ropes" for operating the rudders and cables for bracing the wings. Duralumin is an alloy of aluminum, copper, manganese and magnesium, the aluminum constituting about 90%. Its specific gravity is about 2.8, and its breaking strength about 3500-4500 kg/cm^2 (50000-64000 lb./sq.in.). For airplane construction, it is as good as, if not superior to steel tubing on account of its much lower density. Detailed information on the weights of Mannesmann steel tubes and duralumin tubes is given in Tables VI and VII. Moreover, duralumin parts, due to their low-melting point (650°C. = 1202°F.), can be welded with a soldering lamp, thus dispensing with a welding plant.

The term "Kabel" (cable) denotes a number of small wires twisted into a bundle, while the term "Seil" (rope) denotes a cable made by twisting together several strands of several wires each. The latter is more flexible than the former and is always used when it has to pass over pulleys. However, since it stretches more than the former, the former is almost always used for the direct transmission of forces. For soarer and glider construction, diameters of 2-5 mm (0.08-0.02 in.) suffice for either kind of cables. It is hardly necessary to mention that both kinds must be made of steel, since iron wires stretch too much and are not elastic enough. The strengths of both kinds of cables are given in Tables III and IV. Piano wires with a breaking strength of 250-300 kg/mm^2 (355600-426700 lb./sq.in.) were used. Rusty wires do not generally have half the strength of bright ones.

Light, closely woven linen or cotton cloth is used for covering the wings and sometimes the fuselage, linen being preferable, due to its longer fibers, its greater strength and greater durability. It should be strong and light and fine-meshed. In any case the fabric must contain no sizing nor finish, since this would obstruct the penetration of the "dope." The dope now commonly used is the so-called "Cellon-Emaillit," also recently called "Cellemit," which can be bought ready for application. In the liquid state this substance is inflammable and must be handled accordingly. On doping, the fabric becomes taut, small wrinkles vanish and its surface becomes smooth and perfectly water-tight. The dope can be easily applied with a brush. In about an hour the doped surface is perfectly dry and taut. Its strength is increased about 50% by the customary three coats.

Cold glue is used exclusively, since this is less affected by water. It is a mixture of casein and chalk, often with the addition of special substances like ammonia, resin, etc., and is sold in the powder form in sealed receptacles. This powder is mixed with an equal quantity of water, taking care to avoid the formation of lumps, and allowed to stand 15-20 minutes before using. Special attention is given to the consistency of the mixture, since thin glue does not possess the requisite strength. Only the quantity required for immediate use should be mixed, as it begins to lose its strength after a few hours. Any that is more than a day old should not be used. The powder must be kept in closed boxes to protect it from moisture.

The fittings, etc., can be protected from rust by plating with copper or nickel, though the most durable covering is zinc, which is also proof against sea water. A good oil paint is likewise effective. The metal is cleaned and covered with a thin quick-drying linseed-oil paint containing some good coloring material. When thoroughly dry, a coat of varnish is added. Thick coats of paint cause blistering. Brace wires can likewise be covered with anti-rust varnish. Control cables and pulleys are best lubricated with acid-free mineral oils like vaseline, which must be frequently renewed.

The individual structural parts and fittings naturally depend on the design and must be specially made. Bolts, turnbuckles, screw eyes, etc., can be bought ready-made. The illustrations require no explanation. The strength of the turnbuckles is given in Table VIII.

TABLE I.

Properties and Uses of the Most Common Woods.

Kind	Spec. Gravity		Color	Properties and Uses
	Dry	Green		
Birch	0.75	0.95	White to Yellow	Tough, difficult to split, not very hard, durable in dry form. Used as plywood to cover fuselage and leading edge of wing, also as webs for spars and struts.
Ash	0.90	1.05	Gray to Grayish White	Hard and tough, difficult to split, strong, flexible, elastic, durable. Excellent for runners, edge strips, front fuselage spars or any parts to be bent or strongly stressed.
Pine	0.65	0.85	Yellowish White to Reddish	Soft, easily split. pitchy, quite durable. Used for spar and strut flanges, bulkheads, fuselage and auxiliary spars, struts, etc.
Spruce	0.50	0.80	Yellowish White to Reddish	Soft, easily split, pitchy, durable. Shrinks but little. Suitable for fuselage spars, hollow and grooved wing spars. Difficult to obtain free from knots.
Fir	0.60	0.85	Whitish	Soft, tough, not very pitchy, durable when dry, shrinks little, splits easily, somewhat harder than spruce. Same uses as pine and spruce.

Table I (Cont.)

Properties and Uses of the Most Common Woods.

Kind	Spec. Gravity		Color	Properties and Uses
	Dry	Green		
Elm	0.70	0.95	Yellowish to Brownish	Hard, very tough and strong, elastic, durable, difficult to split. Shrinks but little. For uses, see Ash.
Gabun	0.45	–	Reddish to Red	Very soft and light, difficult to plane. Used for filling and in plywood for fuselage floor, but not for spar webs.
Maple	0.70	0.90	White	Hard and strong, tough, difficult to split, durable when dry. Used as plywood for all purposes.

TABLE II.

Strength Coefficients of Different Kinds of Wood

Kind	Tensile Strength		Compressive strength with grain
	Across grain	With grain	
	kg/cm² lb./sq.in.	kg/cm² lb./sq.in.	
Ash	20-50 285-711	850-1100 12090-15646	350-450 4978-6401
Spruce	20-40 285-569	500-800 7112-11379	250-400 3556-5689
Pine	20-40 285-569	500-850 7112-12090	400-450 5689-6401
Fir	20-40 285-569	500-900 7112-12801	300-400 4267-5689
Elm	30-50 427-711	600-900 8534-12801	300-400 4267-5689

Kind	Bending strength	Shearing Strength	
		Across grain	With grain
	kg/cm² lb./sq.in.	kg/cm² lb./sq.in.	kg/cm² lb./sq.in.
Ash	400-900 5689-12801	200 2845	30 427
Spruce	400-500 5689-7112	250 3556	50 711
Pine	1000-1100 14224-15646	300 4267	60 853
Fir	500-800 7112-11379	250 3556	50 711
Elm	450-1000 6401-14224	300 4267	60 853

TABLE III.

Wire Cables

Diameter of Cable		Diameter of Wire		Breaking Strength	
mm	in.	mm	in.	kg/mm^2	lb./sq.in.
2.8	0.1102	0.40	0.0157	1160	1649926.00
3.1	0.1220	0.45	0.0177	1470	2090854.50
3.5	0.1378	0.50	0.0197	1816	2582987.60
3.9	0.1535	0.55	0.0217	2190	3114946.50
4.2	0.1654	0.60	0.0236	2615	3719445.25
4.5	0.1772	0.65	0.0256	3070	4366614.50
5.0	0.1969	0.70	0.0276	3560	5063566.00

TABLE IV.

Wire Ropes

Diameter of rope		No. of wires	No. of strands	Diameter of each wire		Breaking strength	
mm	in.			mm	in.	kg/mm^2	lb./sq.in.
1.8	0.0709	42	6	0.20	0.00787	330	469376
2.3	0.0906	42	6	0.25	0.00984	510	725399
2.4	0.0945	72	6	0.20	0.00787	565	803628
2.7	0.1063	42	6	0.30	0.01181	740	1052539
3.0	0.1181	72	6	0.25	0.00984	885	1258780
3.2	0.1260	42	6	0.35	0.01377	1010	1436574
3.6	0.1417	42	6	0.40	0.01574	1300	1849055

TABLE V.

Weight of Sheet Iron and Steel

Thickness		Wrought Iron		Soft Steel		Hard Steel	
mm	in.	kg/m²	lb./sq.ft.	kg/m²	lb./sq.ft.	kg/m²	lb./sq.ft.
0.5	0.01969	3.90	0.7988	3.93	0.8049	3.93	0.8049
1.0	0.03937	7.80	1.5976	7.85	1.6078	7.85	1.6078
1.5	0.05906	11.70	2.3964	11.87	2.4312	11.77	2.4107
2.0	0.07874	15.60	3.1952	15.70	3.2156	15.70	3.2156

TABLE VI.

Weights of Mannesmann Steel Tubes

	Thickness of Walls			
Outside diameter	0.5 mm 0.02 in.	1.00 mm 0.04 in.	1.5 mm 0.06 in.	2.0 mm 0.08 in.
mm in.	kg/m lb./ft.	kg/m lb./ft.	kg/m lb./ft.	kg/m lb./ft.
10 0.39	0.116 0.078	0.221 0.149	0.312 0.210	0.391 0.263
20 0.79	0.239 0.161	0.466 0.313	0.679 0.456	0.882 0.593
30 1.18	0.361 0.243	0.711 0.478	1.048 0.704	1.372 0.932
35 1.38	0.423 0.284	0.833 0.560	1.231 0.827	1.616 1.086

TABLE VII.

Weights of Duralumin Tubes

Outside diameter	Thickness of Walls				
	1.0 mm 0.04 in.	1.5 mm 0.06 in.	2.0 mm 0.08 in.	2.5 mm 0.98 in.	3.0 mm 1.18 in.
mm in.	kg/m lb./ft.	kg/m lb./ft.	kg/m lb./ft.	kg/m lb./ft.	kg/m lb./ft.
10 0.39	0.085 0.057	0.133 0.089	0.185 0.124	0.241 0.162	0.301 0.202
20 0.79	0.162 0.109	0.248 0.167	0.340 0.228	0.434 0.292	0.533 0.358
30 1.18	0.240 0.161	0.365 0.245	0.494 0.332	0.627 0.421	0.786 0.528
40 1.58	0.316 0.212	0.480 0.323	0.682 0.458	0.820 0.551	0.997 0.670

TABLE VIII.

Strength of Turnbuckles

d Diameter of screw thread	d^2 Diameter of nut	L Total length of turnbuckle	H Length of thread	E Inside diameter of eye	F Outside diameter of eye	Maximum load
mm in.	mm in.	mm in.	mm in.	mm in.	mm in.	kg lb.
6.35 0.25	10.20 0.40	114.1 4.49	50.8 2.00	4.75 0.19	12.45* 0.49	3200 7055
6.35 0.25	10.20 0.40	114.1 4.49	50.8 2.00	4.75 0.19	12.45* 0.49	2400 5291
4.76 0.19	7.50 0.30	101.5 4.00	44.5 1.75	3.21 0.13	9.53 0.38	1475 3252
4.76 0.19	6.78 0.27	82.5 3.25	31.8 1.25	3.21 0.13	9.47 0.37	1000 2205
4.76 0.19	7.46 0.29	101.5 4.00	44.5 1.75	3.20 0.13	9.42 0.37	1475 3252

*Special steel.

Table VIII (Cont.)

Strength of Turnbuckles

d Diameter of screw thread	d^2 Diameter of nut	L Total length of turnbuckle	H Length of thread	E Inside diameter of eye	F Outside diameter of eye	Maximum load
mm in.	mm in.	mm in.	mm in.	mm in.	mm in.	kg lb.
4.76	6.85	82.5	31.8	3.21	9.53	1250
0.19	0.27	3.25	1.25	0.13	0.38	2756
3.97	5.84	66.7	28.6	2.28	7.83*	1000
0.16	0.23	2.63	1.13	0.09	0.31	2205
3.97	5.84	66.7	28.6	2.28	7.83*	975
0.16	0.23	2.63	1.13	0.09	0.31	2150
3.18	5.96	50.8	20.6	1.83	6.33	570
0.13	0.23	2.00	0.81	0.07	0.25	1257
3.18	4.90	50.8	22.2	1.83	6.05	875
0.13	0.19	2.00	0.87	0.07	0.24	1929
2.38	3.71	44.5	19.1	1.63	4.73*	425
0.09	0.15	1.75	0.75	0.06	0.19	937
2.38	3.71	44.5	19.1	1.63	4.73*	400
0.09	0.15	1.75	0.75	0.06	0.19	882

*Special steel.

This memorandum will be followed by one on "Structural Details of German Gliders," by the same author.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

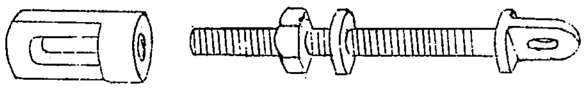

Fig. 1

Fig. 2

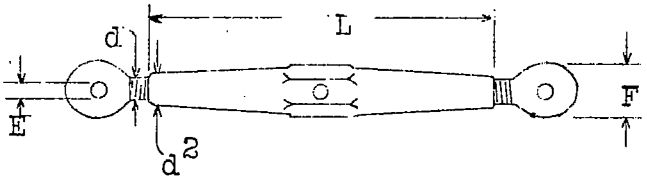

Fig. 3