TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 454

THE 1926 GERMAN SEAPLANE CONTEST

PART I: LESSONS TAUGHT

By F. Seewald

PART II: METHOD OF RATING

By H. Blenk and F. Liebers

From the 1927 Yearbook of the
"Deutsche Versuchsanstalt für Luftfahrt"

Washington
March, 1928

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PART I.

LESSONS OF THE 1926 GERMAN SEAPLANE CONTEST.*

By F. Seewald.

After seaplane construction had for years received relatively little encouragement in Germany, all the seaplane constructors were invited to compete in the 1926 German seaplane contest. This contest was intended to afford them the opportunity to measure their productive ability with one another and to give them incentives for further development. In consideration of the hard times, they were not to be encouraged to build special racing seaplanes, which would be of no further use, but the intention was to promote the building of seaplanes which would have equal prospects of success for whatever purpose they were designed, provided they were really good seaplanes. A basis of comparison had, therefore, to be provided for the different types of seaplanes. The solution of this problem was very important. It was surprising that none of the many persons who wrote about the seaplane contest did not discuss this problem. Hence it seems all the more important to consider it here.

*"Erfahrungen aus dem Deutschen Seeflug-Wettbewerb 1926," Sixty-Second Report of the D.V.L. ("Deutsche Versuchsanstalt für Luftfahrt"), 1927 Yearbook of the D.V.L., pp. 26-30.

In the discussion of the rating method, we can restrict ourselves to the consideration of the fundamental assumptions. All the rest is simply a matter of calculation, which does not require discussion, provided the fundamental principles are accepted. The whole process of rating consists in measuring the climbing speed, flying weight and carrying capacity of a seaplane and then using these data as the basis of a construction problem. We then calculate the answer to the problem, "If a seaplane has a certain climbing speed, a certain carrying capacity (useful load), and a certain flying weight (full load), what horizontal speed can reasonably be expected of it in the present state of aviation?" In other words, "What speed would be attained by a seaplane considered normal in the present state of aviation and having the same climbing speed, carrying capacity and flying weight?" The ratio of the actually measured speed to that calculated for the normal seaplane then constituted a criterion for the excellence of the seaplane to be tested. In order to simplify this problem and put it in a practical mathematical form, various assumptions are made regarding the properties of the normal seaplane, which will be explained in what follows.

1. Mean values are assumed for the aerodynamic coefficients c_w, ϵ and c_a^3/c_w^2 and the propeller efficiency η, as determined with good seaplanes.

2. The mean value for known engines is adopted as the engine weight per horsepower.

3. The ratio of the dead load to the full load is given a mean value, as determined by experience.

4. The carrying capacity or useful load is not given its true value, but is converted into total fuel-carrying capacity and the corresponding maximum flight distance. The latter is then introduced into the computations.

Assumption 1 means that a seaplane, which is aerodynamically better than the normal seaplane, is given a higher rating. If it is poorer, it is given a lower rating. This corresponds to the principle of the contest. A given construction problem may, however, compel a deviation from the aerodynamically best shape, as, for example, the installation of a cabin for passengers or bulky goods. The rating is then lowered, even when the poorer aerodynamical relations are necessitated by the nature of the construction problem. The effect on the rating, however, is not very great for fairly normal shapes. Moreover, attention is called to the fact that a single definite numerical value for the coefficients of the normal seaplane suffices only when the compared airplanes are somewhat similar in size, weight, etc. In the seaplane contest, however, such narrow limits were established by the rules and regulations that this condition may be regarded as satisfactorily fulfilled. In other cases these coefficients would have to be made variable according to the character of the seaplanes.

Assumption 2 means that the lighter engine per horsepower will be rewarded and the heavier one penalized, which is in the sense of the rating. This applies, however, only when the engine powers do not differ much from one another. (In the South Germany flight, for example, engines ranging from 20 to 240 HP. were used. The weight per horsepower was naturally more favorable for the 220 HP. engine than for the 20 HP. engine. As regards assumption 2, seaplanes with large engines have the advantage of seaplanes with small engines. When the participation of engines of very different powers is to be expected, this circumstance can nevertheless be easily taken into account.)

Assumption 3, that the weight of an empty seaplane stands in a definite ratio to its total flying weight, is justified in so far as the heavier seaplane is penalized in relation to the lighter one. This is correct, however, only in comparing seaplanes having the same safety factor. If a seaplane, however, is built with an exceptionally large safety factor with respect to its intended use, it is naturally heavier than another and stands lower in the rating. In this point, an adaptation to the strength of the seaplane would be necessary.

Assumption 4 means that the capacity of the airplane will be rated by so much higher, the lower the fuel consumption is. This is simply to rate the fuel consumption, which is extremely important in its relation to the flight range. Whether the fuel consumption is rated in this or in some other way is, in the ultimate analysis, only a matter of preference.

These are the fundamental principles of the rating process. With the aid of these assumptions, the laws of the mechanics of flight can be applied to the problem. This method produced the rating formulas which were published in the rules and regulations (See "Zeitschrift für Flugtechnik und Motorluftschiffahrt," 1926, p.34). This method of rating was proposed by G. Madelung. It has been thoroughly justified in its fundamental principles by the results of the seaplane contest. Although many details are capable of improvement, it has nevertheless been demonstrated that this method can serve as the basis for further development. In order to enable specialists to assist in the development, this report is followed by a thorough discussion of the details of the rating process (Part II). It is hopes that this discussion will awake an interest in the very difficult task of developing an accurate method for rating seaplanes.

The Course of the Contest

The measurements necessary for rating a seaplane were made in the technical contest. This task was performed by the D.V.L., as the agent of the board of management of the contest. The determination of seaplane performances is generally not a very simple task. It must be made with very great care if reliable data are to be obtained. The task is naturally rendered more difficult by the fact that the measurements have to be made in a place not equipped for the purpose and simultaneously for a large number of seaplanes. In future contests this fact must be borne in mind. As far as possible, technical contests should be held at the D.V.L. (German Experimental Institute for Aviation), which is much better equipped for such a task than any other place.

After the data were determined, the measured speed of each seaplane was compared with the speed of the normal seaplane, whose properties, as above explained, were established by the coefficients. The ratio of the speed attained to the speed of the normal seaplane constitutes the rating coefficient. In the seaplane contest, a seaplane was adopted as the normal seaplane, which had very high performances in every field, such as could be attained only by a special seaplane. Of course no seaplane can do this simultaneously in every field. The same seaplane cannot have a very high climbing speed and a very high horizontal speed and simultaneously a high carrying capacity. This is naturally unimportant for the rating which is only relative. It is only mentioned in order not to allow the impression to prevail that the measured performances lie below the normal, which is not at all the case. On the contrary, performances have been attained by the best seaplanes, which must be designated as especially good.

In the determination of the rating coefficients, we must bear in mind what has been said above regarding the fundamental assumptions (e.g., that a seaplane built to withstand great stresses, will naturally obtain a lower valuation than a seaplane which, in view of its use, does not require so great strength). The value of the individual data will not be affected by this fact, since no assumptions are embodied in them. They represent practical results which can be computed and can render valuable service in the most widely differing tasks.

The results of the technical contest are shown in Figure 1. In addition to the quantities which are decisive for the rating, there are also calculated and introduced the quantities which are decisive for the judging of a seaplane, such as the distance and speed coefficients, on the basis of the experimental results. The high-flight coefficient can be reliably calculated only from the ceiling, which was not measured. Hence it is omitted here. Some uncertainty attaches to the speed and distance coefficients, in so far as the engine power, which must be known for their determination, was assumed to equal the normal power. In truth the engines, in so far as they were equipped with a corresponding carburetor, worked with altitude gas, even when near the ground, and hence with a considerably higher power. No further discussion of the technical power tests is necessary. This is the special advantake of the rating method employed, that all the quantities, required for judging the seaplane, appear in the computation itself.

All the participants fully understood the requirements of the technical contest and each one endeavored to assist, to the best of his ability, in the troublesome and tedious tasks, such as weighing, etc. We have especially in mind the Heinkel Airplane Works, which graciously placed its weighing room continuously at our disposal, although this interfered considerably with its own work of building five airplanes which took part in the contest.

Endurance Flights

While the technical performance tests were for the purpose of determining the performances of the airplanes in comparatively short test flights, the airplanes also had to demonstrate their ability in endurance flights of over 4000 km (2486 miles).

The endurance flight was designed chiefly as a test for the engines and the crews. In order to give an idea of the whole course of the contest, the state of the rating on each of the endurance-flight days is plotted in Figure 1, from which everything worth knowing can be learned. It is first seen that all the curves fall rapidly on the first endurance-flight day. If an airplane had flown the whole distance at its maximum speed, this curve would have been a horizontal line. Since it is obvious, however, that no airplane can fly such a long distance at its maximum speed, the rating coefficients all lie lower than those of the technical performance test. An especially rapid fall always indicates a long loss of time caused by injuries to the airplane or engine. The curve for airplane No. 7 is of especial interest. It is seen how the rating fell on the first day (due to replacing the engine). It is then seen, however, how this loss was gradually made up on all the succeeding days, a splendid performance of the crew and of the seaplane. The rating coefficients illustrated by the curves were announced every evening. This proves that formulatory rating, regarding which many doubts have been expressed in the past, can be successfully employed even in an endurance-flight contest.

On the occasion of some of the engine failures, which occurred during the first days of the endurance flight, there appeared, in a portion of the press, heated attacks on German aircraft engine construction. It must, of course, be left to the engine builders to demonstrate the excellence of their engines. Since, however, the question is of supreme importance, it seems proper to the author, on the basis of the impressions which he received as a neutral observer on the spot, to question the justification of these attacks.

The adverse criticisms were based on the fact that, from the beginning of the contest, a disproportionate number of the flights were discontinued, or the airplanes had to make forced landings. One should not conclude too hastily, however, without further information, that the engines were poor. If the reporters had looked for the causes, they would have found that, in most of the cases, the engine was not to blame, but that a fuel or water pipe had broken, a tank had sprung a leak, or something of the kind had happened. Even the best engine cannot function under such conditions. The frequency of such injuries was due to the fact that most of the seaplanes were newly developed types which had left the factory only a few days before the contest. There was no time for the customary trial flights, which are necessary for thoroughly testing new types, so as to discover and eliminate the many slight defects which become apparent only in flight. So far as the writer could discover, there were only three instances of genuine engine trouble on German engines during the whole contest and one of these was remedied with the means on board. In any matter where chance plays so great a role, a reliable conclusion can be reached only on the basis of a large number of observations and, in this sense, three is not a very large number. Of the two seaplanes, equipped with German engines, which were lost during the endurance contest, the accident to one of them (No. 11) had nothing to do with the engine. The seaplane was forced to alight by the bad weather and was demolished by a steamboat. In the case of the other seaplane (No. 2), the cause of the stalling of the engine was not determined. It is not at all certain as to whether the engine actually broke down or some cause outside the engine necessitated the disastrous forced landing. It may be remarked, moreover, that chronic troubles developed in several foreign engines and even one of the most promising seaplanes was lost due to the stalling of its Jupiter engine. It would be wrong to pronounce judgment here without further information.

Seaworthiness Contest

After the seaplanes had passed the endurance test, they had to show, in the seaworthiness test, that they could meet the requirements imposed on them by bad weather. Their future development must show to what degree seaplanes of the size now built can be made seaworthy and how much it is possible to increase the seawerthiness by increasing the size of the seaplanes. So much appears certain, however, that for present-day seaplanes, alighting successfully, even in a wind of force 4 according to Beaufort's scale ("Seegang vier"), is largely a matter of chance. For example, one of the three seaplanes which passed the seaworthiness test in the forenoon, broke a float in the afternoon in alighting under much easier conditions. At present, luck seems to play a decisive role in alighting on or taking off from a rough sea. From the present standpoint, it is perhaps justifiable to say that the maximum seaworthiness of a seaplane lies in its airworthiness. When seaplanes become so dependable that forced alightings no longer occur, they will then be also seaworthy. Only the future can show whether real seaworthiness is attainable in any other way.

Incentives for Future Contests

One object of this article is to discover the lessons applicable to future contests. Though many writers have alreads expressed their opinions on this problem, it still seems far from being solved. This is doubtless partially due to divergent views regarding the objects of such contests. The distinction between sportive and technical contests is not entirely clear. We must distinguish between contests for aircraft and contests for their crews. In the former case the contest is purely technical and has nothing to do with sport. In the latter case, it is pure sport, which has to do with technics only in that it utilizes aircraft as implements of sport.

All previous contests (at least in Germany) were between the aircraft, and their object was to give aircraft constructors an incentive for intensive, progressive work, the prizes being intended to recompense them, so far as possible, for their successful research and experimental work and to assist them in its continuance. It was surely the desire of the prize founders, who gave so much money for the purpose, to produce a beneficial effect on the technical side of aviation. All these contests should therefore have been purely technical, but such was not always the case.

If it is asked whether the appointed goal has been attained, it may be answered that, in comparison with previous contests, the 1926 German seaplane contest represents important progress, principally because of the method of rating employed. The results of the technical contest were, however, partially obscured by the inability, in the endurance flights, to separate wholly the skill of the crew and the element of luck from the performances of the seaplanes themselves. A definite separation of these influences must be undertaken, however, in order to rate and compare the seaplanes. Hence the principle holds true for all contests which involve the rating of aircraft, that the less the element of sport is involved, the better the results.

Another lesson of the seaplane contest is that the time limit for entries should be adhered to and belated aircraft should not be admitted. If entirely untested and belated aircraft are admitted, the contest is hurt, in that the performances of such aircraft can, naturally, not be the best. By frequently recurring accidents the impression of great unreliability is produced, which hurts the effect of the contest and the prestige of aviation in general. As explained above, the German engines, due to the circumstance that the seaplanes had not been sufficiently tested, acquired a bad reputation which they did not merit. On the contrary, it should be required of every participating aircraft, that it should be finished several weeks before the beginning of the contest and make a trial or acceptance flight. The producer then has time to try out the aircraft and the crew has the opportunity to become familiar with it, as is essential for every contest.

The rating in future aviation contests should probably follow somewhat the same lines as in the 1926 seaplane contest. A refinement of the rating method should be sought and can doubtless be attained. Moreover, all the factors must be measured which affect the efficiency of the aircraft, whether they affect the rating or not. In the above-described method of rating, the engine power was eliminated and was therefore not measured. The constructor who desires to utilize the lessons of the contest must, however, know the engine power. Without it, he cannot determine why one aircraft was better than another. In order, therefore, to make practical use of the lessons learned, there is need of more comprehensive measurements, which require much time and labor.

All that has thus far been said assumes that the contests are for complete aircraft. It is still a serious question, however, as to whether this very expensive method is the only one which can benefit aviation. It seems as though complete success can be attained only when aircraft contests are combined with tests of the different structural parts. Aircraft performances involve many circumstances whose individual effect cannot be determined from the total performance. In order to make progress, we must, however, know the effect of each individual part. Hence, contests should be instituted for such parts, e.g., propellers, floats or wheels, skids, individual parts of the driving gear, devices for reducing the landing speed, etc. Such contests would have the advantage of putting the contestants to far less expense than in previous contests, which would enable the participation of many who could not afford to construct whole aircraft. With the same financial resources as in the previous contests, it would be possible for a contestant who had performed some special service in any field to reserve enough of his prize money for continuing his work. In this way the object of contests could probably be most fully attained. At longer intervals, contests should of course be held for complete aircraft, in order to determine the direction of other contests. It seems a little previous, however, to mention individual problems. These can be solved, one at a time, as the technical and financial resources become available. The task of successfully conducting such a contest, in which a single technical goal is sought, is much easier than in the previous contests. The combination of technical and sport performance caused confusion in the principles of the contests, which could not be remedied by even the best method of rating.

In addition to such contests, which are essentially technical, it seems necessary, in the interest of the rising generation, to institute contests for the crews, in which the efficiency of the crews is made the sole object of the rating. The accomplishment of this task must be left to the proper sport authorities and will not be further discussed here. Surely no insurmountable difficulties will arise, however, provided a definite separation is made in the above-indicated sense. On this basis, it will doubtless be possible to obtain more satisfactory results in the flight contests, both from the technical and sportive viewpoints, than has hitherto been the case.

TABLE I.

Contest No.	Seaplane type	Contestant	Pilot	Wing area* m^2	Engine	Nominal rating HP.	Weight empty kg	Useful load kg	Full load kg
1	LFG V 59	Luftfahrzeug-Ges. m.b.H., Werft Stralsund	Fischer	52.0	BMW IV	230	--	--	--
2	LFG V 60		Haase	52.0	BMW IV	230	1348.2	651.8	2000.0
3	LFG V 61		v. Reppert	52.0	Bristol-Jupiter	420	1471.7	818.3	2290.0
4	C 29	Caspar-Werke A.G. Travemünde	Berthold	47.0	Hispano-Suiza	400	--	--	--
5	Robbe Ro VII	Rohrbach-Metall-Flugzeugbau G.m.b.H., Berlin SW.68	Landmann	40.0	BMW IV	2 x 230	2026.5	1220.0	3246.5
6	Robbe Ro VII		Roth	40.0	BMW IV	2 x 230	--	--	--
7	W 33	Junkers-Flugzeugwerk A.G., Metall-Flugzeugbau, Dessau	Langanke	43.0	Junkers L 5	310	1413.0	687.0	2100.0
8	W 34		Zimmermann	43.0	Bristol-Rhone-Jupiter	420	1422.5	677.5	2100.0
9	HE 5	Ernst Heinkel, Flugzeugwerke G.m.b.H., Warnemünde	v. Gronau	46.7	Napier-Lion	450	1634.5	865.5	2500.0
10	HE 5		v. Dewitz	46.7	Gnome-Rhone-Jup.	420	1515.5	984.5	2500.0
11	HD 24		Geisler	50.1	BMW IV	230	1411.0	669.0	2080.0
12	HD 24		Spies	50.1	BMW IV	230	1384.5	736.5	2121.0
13	W 3	Ernst Gerbrecht, Werden-Ruhr	Schüler	--	Thulin	3 x 110	--	--	--
14	Do E	Dornier-Metallbauten G.m.b.H., Friedrichshafen	Coeler	--	Gnome-Jupiter	420	--	--	--
15	Do E		Klausbruch	--	Gnome-Jupiter	420	--	--	--
16	Junkers A 20	Severa G.m.b.H., Berlin W.35	Friedensburg	--	Junkers L 5	210	1139.3	633.7	1773.0
17	S i	Ernst Heinkel, Flugzeugwerke G.m.b.H., Warnemünde	Starke	--	Rolls Royce Eagle	360	1697.0	778.0	2475.0
18	U 13 Bayern	Udet-Flugzeugbau G.m.b.H., München-Ramersdorf	Ritter	--	BMW VI	450	--	--	--

*As stated by contestant.

TABLE I (Cont.)

Contest No.	Seaplane type	Useful load / Weight empty	Max. meas. speed km/h	Take-off speed km/h	Calculated speed km/h	Climbing time 1000-2000 m min.	Fuel consumption kg/km	Flight range km	Rating coef. Tech. performance test W_{techn}	Rating coef. Main contest W_{final}	Speed coef. $\frac{\eta}{\epsilon}$	Endurance flight coef. $\frac{\eta}{c_W}$
1	LFG V 59	--	--	--	--	--	--	--	--	--	--	--
2	LFG V 60	0.484	147	74	383.6	8.47	0.238	906	0.383	--	12.8	4.7
3	LFG V 61	0.556	178	84	385.2	6.15	0.509	825	0.462	--	12.5	3.6
4	C 29	--	--	--	--	--	--	--	--	--	--	--
5	Robbe Ro VII	0.602	191	121	--	6.46	--	--	--	--	--	--
6	Robbe Ro VII	--	--	--	--	7.35	--	--	--	--	--	--
7	W 33	0.486	194	89	320.0	5.40	0.217	1196	0.606	0.4425	18.1	4.9
8	W 34	0.476	202	83	320.8	3.87	0.337	810	0.630	--	15.1	3.7
9	HE 5	0.530	203	105	336.0	3.95	0.431	943	0.604	0.5365	15.5	4.2
10	HE 5	0.650	195	88	301.6	5.30	0.404	1434	0.647	0.5640*	14.7	4.3
11	HD 24	0.475	163	--	454.2	12.75	0.394	575	0.359	--	16.8	5.5
12	HD 24	0.532	168	95	372.8	7.10	0.323	932	0.451	0.3690	18.5	5.7
13	W 3	--	--	--	--	--	--	--	--	--	--	--
14	Do E	--	--	--	--	--	--	--	--	--	--	--
15	Do E	--	--	--	--	--	--	--	--	--	--	--
16	Junkers A 20	0.556	197	96	308.2	4.62	0.282	723	0.639	0.394*	--	--
17	S i	0.458	180.5	84	450.0	7.26	0.521	633	0.401	0.371*	--	--
18	U 13 Bayern	--	--	--	--	--	--	--	--	--	--	--

*Failed in seaworthiness test and was not considered in awards.

PART II.

METHOD OF RATING EMPLOYED IN THE 1926 GERMAN SEAPLANE CONTEST.*

By H. Blenk and F. Liebers.

I. Introduction

The object of the 1926 seaplane contest was to produce an efficient postal seaplane. The requirements for the seaplane were accurately designated, while the following characteristics were to be specially rated, namely, horizontal speed, climbing ability, maximum flight distance and economy of building materials.

The mathematical form of representing these characteristics, so as to enable a numerical rating of them proceeds from the rules and regulations for the seaplane contest. Still the selection of the principle which formed the basis of the rating, as well as the derivation of the rating formulas, was quite a difficult task. For this reason the rating method and its mathematical expression will be explained more fully here.

*"Das Wertungsverfahren im Deutschen Seeflug-Wettbewerb 1926," Sixty-Third Report of the D.V.L. ("Deutsche Versuchsanstalt für Luftfahrt") in 1927 Yearbook of the D.V.L., pp. 31-34.

II. Fundamental Principle of the Rating

The rating principle is based on a universal fundamental consideration. This consideration may yet become important for a large number of contests. It is especially applicable to conditions in Germany, whose aviation is in a poor economic condition. This consideration reads:*

The regulations must be so couched as to enable (within definite limits) seaplanes of all types to participate in the contest. No narrowly circumscribed construction problem must be presented and no particular flight performance must be rated alone or have preponderating weight, but the regulations must be so worded that all types of like excellence will receive the same rating.

In order to render this possible, the meaning of the "excellence" of a type must first be defined. The following is a very clear and comprehensive definition. A type is good, when the necessary cost is as small as possible and when its performances are as great as possible. The ratio of the performances to the cost of a given type must be as large as possible. This ratio is the important one for the user. For him, all the intermediate values, such as, for example, engine power or wing area, are of no importance.

The above definition of "excellence" raises the further ques-

*The ideas set forth in what follows are taken chiefly from G. Madelung. See also explanations ("Erlauterungen") of the D.V.L. regarding the rules and regulations for the 1926 German Seaplane Contest at the close of Part I of the rules and regulations ("Ausschreibung").

tions as to what is meant by "cost" and "performances." The latter term has already been defined in the regulations by the requirements for a seaplane to have a high speed, good climbing ability and a long flight range.

The "cost" components are: cost of production, cost of upkeep, and length of life. It is not easy to express these quantities numerically. An imperfect but quite practical approximation to the total of the cost factors is the weight of the empty airplane (dead load). A refinement of the term "cost" is conceivable, though this would render it more difficult to express numerically and greatly increase the labor of computation. (Compare the definition of "cost" ("Aufwand") in the Rules and Regulations for the 1926 South Germany Land Flight, where it includes the cost of providing shelter for passengers and freight.)

III. Practical Application of the Rating Idea

After thus defining cost and performances, there comes the practical application of the abovementioned principle, according to which the rating is to be done. The ratio of cost to performances cannot be written immediately after the separate partial performances have been determined, because the total performance is not simply the sum of the individual performances. If, for example, the horizontal speed of an aircraft is increased by altering the wing area at the expense of the climbing speed, the total performance remains the same, though the arithmetical sum of the performance factors is different. It is recognized that the intimate relation of the different flight performances must be considered. This relation is determined by the mechanics of flight, from which it is found to what degree the improvement of a partial performance by altering an intermediate quantity, as, for example, the wing area, engine power, carrying capacity, etc., impairs some other partial performance or increases the cost. In a more accurate investigation (See Section IV), the equations of flight mechanics show that, when the cost and two partial performances are known (e.g., in the abovementioned case, the dead load, the flight range, and the climbing speed), the other performances (e.g., the maximum horizontal speed) for a predetermined excellence of construction, which represents a definite status of aviation, can have one and only one precise value.

Hence, if two aircraft have three like partial performances and if the other performances do not agree, the two airplanes are not equally good. In this very obvious way, all aircraft can be compared with respect to their structural excellence.

This is the practical way in which the abovementioned rating is made. In the present case of the seaplane contest, the cost (dead load) and two partial performances, namely, the flight range and the climbing time from an altitude of 1000 m (3281 ft.) to an altitude of 2000 m (6562 ft.), are determined for each seaplane. It is then possible to calculate the value of the other performances (maximum horizontal speed) according to the present technical status of aviation. The actual performance (maximum measured speed) is then compared with this "theoretical performance."

The last question, still to be answered, concerns the "present technical status of aviation." This is a purely empirical matter. In order to represent it numerically, we must combine all the quantities which characterize the various departments of work in present-day aviation. The status of engine construction is characterized by the engine weight per horsepower (τ kg/HP) and by the fuel consumption per horsepower-hour (b kg/HP/h). The status of propeller construction is characterized by the propeller efficiency η. The status of aircraft statics and construction is characterized by the ratio of the weight of the airplane without power plant to the full load (ζ). The status of aerodynamics is characterized by the coefficient of drag in horizontal flight (c_{w_H}), the power coefficient in climbing ($c_w/c_a^{1.5}$) and the L/D ratio (ϵ).

For comparing the contesting seaplanes in the designated sense, the standard chosen was a seaplane which represented the present technical status of aviation through the following coefficients. These coefficients represent mean values for good seaplanes:

η_H = 0.65, propeller efficiency in horizontal flight and in climbing flight;

η = 0.65, propeller efficiency in the endurance flight;

ζ = 0.35, ratio of seaplane without power plant to full load;

τ = 1.5 kg/HP, power loading of engine;

c_{w_H} = 0.05, drag coefficient in horizontal flight;

$\dfrac{c_w}{c_a^{1.5}}$ = 0.09, power coefficient in climbing flight;

ϵ = coefficient of glide or L/D ratio in endurance flight;

b = 0.22 kg/HP/h, fuel consumption per HP/hr. in endurance flight.

These coefficients define an endless series of so-called "standard" aircraft. The measured horizontal speed of a contesting seaplane will now be compared with the speed of the standard seaplane which has the same dead load, the same flight range, and the same climbing speed as the contesting seaplane. This is the above-named "theoretical performance."

IV. Mathematical Derivation of the Rating Formulas

In order to express the rating numerically, we must determine the relations between the different partial performances. We will then be prepared to calculate the speed of the standard seaplane, or, which amounts to the same thing, the theoretical speed for the same standard excellence of construction, from the measured quantities (dead load, flight range and climbing speed).

1. Explanation of the Symbols

G (kg), flying weight or full load;

G_L (kg), weight empty or dead load;

G_Z (kg), carrying capacity or useful load;

G_T (kg), empty weight of power plant or engine;

G_F	(kg),	empty weight of aircraft without power plant;
G_D	(kg),	service load;
N_O	(HP),	engine power on ground;
N_z	(HP),	" " at altitude z;
F	(m^2),	wing area;
γ	(kg/m^3),	air density;
g	(m/s^2),	acceleration due to gravity;
w_z	(m/s),	climbing speed at altitude z;
v_H	(m/s),	horizontal speed;
t	(s),	climbing time from 1000 m to 2000 m;
S	(km),	flight range with 400 kg (882 lb.) service load.

The coefficients given in Section III are also used.

The following relations hold good:

Full load equals dead load plus useful load:

$$G = G_L + G_Z \tag{2}$$

Dead load equals empty weight of aircraft without power plant, plus empty weight of power plant:

$$G_L = G_F + G_T .$$

Moreover, the power loading

$$\frac{G}{N_\Theta} = \frac{\text{Full load}}{\text{Horsepower of engine at sea level}}$$

appears repeatedly in what follows.

By using $\tau = \frac{G_T}{N_O}$ (See Section III), this value may be expressed as follows:

$$\frac{N_O}{G} = \frac{1}{\tau} \frac{G_T}{G}$$

or, according to equations (2) and (3),

$$\frac{N_O}{G} = \frac{1}{\tau} \frac{G_L - G_F}{G_L + G_Z} .$$

By introducing $\zeta = \frac{G}{G_F}$ (See Section III) this becomes

$$\frac{N_O}{G} = \frac{1}{\tau} \frac{G_L - \zeta G}{G_L + G_Z}$$

or, by using equation (2),

$$\frac{N_O}{G} = \frac{1 - \zeta}{\tau} \frac{1 - \frac{\zeta}{1 - \zeta} \frac{G_Z}{G_L}}{1 + \frac{G_Z}{G_L}} .$$

For abbreviation, we now introduce

$$\Lambda = \frac{1 + \frac{G_Z}{G_L}}{1 - \frac{\zeta}{1 - \zeta} \frac{G_Z}{G_L}} \tag{4}$$

Hence, $\frac{N_O}{G}$ receives the following form:

$$\frac{N_O}{G} = \frac{1 - \zeta}{\tau} \frac{1}{\Lambda} \tag{5}$$

2. Relation between Horizontal Speed v_H, Climbing Time t and Λ.

On the assumption of a definite structural excellence, i.e., of definite values (See Section III), the flight performances still depend on the engine power N and the wing area F. Hence, in order to determine the relation between the individual performances, these quantities must be essentially eliminated from the equations of mechanical flight.

The horizontal speed v_H is expressed by the equation

$$75\ N_0 \eta_H = c_{wH} \frac{\gamma_0}{2g} F\ v_H{}^3, \tag{6}$$

and the climbing speed w_z at altitude z by

$$w_z = \frac{75\ N_z \eta_H}{G} - \sqrt{\frac{2g}{\gamma_z}\ \frac{G}{F} \left(\frac{c_w{}^2}{c_a{}^3}\right)_{min}} \tag{7}$$

If equation (6) is transformed

$$\frac{G}{F} = \frac{c_{w_H}}{75 \eta_H} \frac{\gamma_0}{2g} \frac{G}{N_0} v_H{}^3$$

and equation (5) is taken into account, we obtain

$$\frac{G}{F} = \frac{c_{w_H}}{75 \eta_H} \frac{\gamma_0}{2g} \frac{\tau}{1 - \zeta} v_H{}^3 \tag{8}$$

For the loss in engine power with altitude, we make the usual assumption

$$N_z = \nu_z\ N_0.$$

If equation (5) is used, $\frac{N_z}{G}$ can be written

$$\frac{N_z}{G} = \nu_z \frac{N_0}{G} = \nu_z \frac{1 - \zeta}{\tau} \frac{1}{\Lambda} \tag{9}$$

If equations (8) and (9) are now introduced into equation (7), we get

$$w_z = 75\eta_H \nu_z \frac{1 - \zeta}{\tau} \frac{1}{\Lambda} - \sqrt{\frac{c_{w_H}}{75\eta_H} \frac{\gamma_0}{\gamma_z} \frac{\tau}{1 - \zeta} \left(\frac{c_w{}^2}{c_a{}^3}\right)_{min} v_H{}^3 \Lambda} \tag{10}$$

Thus the engine power N and the wing area F are eliminated and a relation is established between climbing speed and horizontal speed.

For abbreviation we further introduce:

$$\left.\begin{aligned} \kappa_1 &= 75\eta_H \frac{1 - \zeta}{\tau} \\ \kappa_2 &= \gamma_0 \, c_{w_H} \left(\frac{c_w{}^2}{c_a{}^3}\right)_{min} \end{aligned}\right\} \tag{10a}$$

Equation (10) then becomes

$$w_z = \kappa_1 \frac{\nu_z}{\Lambda} - \sqrt{\frac{\kappa_2}{\kappa_1} \frac{1}{\gamma_z} v_H{}^3 \Lambda} \tag{11}$$

On a normal day we can put

$$\gamma_z = 1.242 - 0.1153 \, z \tag{12}$$

for 1 km $\leqq z \leqq$ 2 km (with an error of less than 1%) and

$$\frac{1}{\sqrt{\gamma_z}} = 0.890 + 0.05133\ z \qquad (13)$$

From equation (13) we then obtain for ν_z at the same altitude according to Hoff's formula

$$\nu_z = \frac{1}{0.85}\left(\frac{\gamma_z}{\gamma_0} - 0.15\right) = 0.9925 - 0.1084\ z \qquad (14)$$

so that, when z is measured in meters, we obtain

$$w_z = 0.9925\ \frac{\kappa_1}{\Lambda} - 0.890\sqrt{\frac{\kappa_2}{\kappa_1}\ v_H{}^3\Lambda}\ \cdots\cdots$$

$$- \frac{z}{1000}\left(0.1084\ \frac{\kappa_1}{\Lambda} + 0.05133\sqrt{\frac{\kappa_2}{\kappa_1}\ v_H{}^3\Lambda}\right) \qquad (15)$$

for the climbing speed.

In the seaplane contest, the climbing speed was computed from the climbing time between the altitudes of 1000 and 2000 m (3281 and 6562 feet). This is obtained from equation (15) by the integration

$$t = \int_{1000}^{2000} \frac{d_z}{w_z} = \frac{1000\,\Lambda}{0.1084\ \kappa_1 + 0.05133\sqrt{\frac{\kappa_2}{\kappa_1}\ v_H{}^3\Lambda^3}}\ .$$

$$\cdot \ln \frac{0.8841\ \kappa_1 - 0.9413\sqrt{\frac{\kappa_2}{\kappa_1}\ v_H{}^3\Lambda^3}}{0.7757\ \kappa_1 - 0.9927\sqrt{\frac{\kappa_2}{\kappa_1}\ v_H{}^3\Lambda^3}} \qquad (16)$$

If we here introduce the coefficients for the standard seaplane (Section III), we obtain the first rating formula

$$t = \frac{1000\,\Lambda}{2.292+0.0002514\,(v_H\Lambda)^{3/2}}\ \ln \frac{18.67-0.00461\,(v_H\Lambda)^{3/2}}{16.39-0.00486\,(v_H\Lambda)^{3/2}} \qquad (17)$$

The inversion of this ratio, which was done graphically, yielded v_H as the function of t and Λ (or of $\frac{G_Z}{G_L}$, according to equation (4). This relation is shown in the upper part of Figure 2.

3. Relation between Dead Load G_L, flight range S and Λ.

The flight range was also rated in the seaplane contest. This was defined as the distance the seaplane could fly, when the useful load, with the exception of 400 kg (882 lb.) service load (G_D), consisted entirely of fuel. According to this definition,

$$S = \frac{(G_Z - G_D)\ v_H}{b\ N_O}\ 3.6 \qquad (18)$$

In order to eliminate the engine power N_O, we use the power equation for horizontal flight near the ground,

$$N_O = \frac{W\ v_H}{75\eta} \qquad (W = \text{drag})$$

On taking the relation $W = \epsilon\ G$ into account, we obtain for equation (18)

$$S = \frac{75\eta\cdot 3.6}{b\ \epsilon}\ \frac{G_Z - G_D}{G} = \kappa_3\ \frac{G_Z - G_D}{G} \qquad (19)$$

in which

$$\kappa_3 = \frac{75\eta\cdot 3.6}{b\ \epsilon}\ .$$

By the introduction of $G = G_Z + G_L$ into equation (19) and its solution for G_Z, we obtain

$$G_Z = \frac{G_D}{1 - \frac{S}{\kappa_3}\left(1 + \frac{G_L}{G_Z}\right)} \tag{20}$$

If we now introduce into equation (20) the coefficients for the standard seaplane (Section III), we obtain the second rating formula

$$G_Z = \frac{400}{1 - \frac{S}{8860}\left(1 + \frac{G_L}{G_Z}\right)} \tag{21}$$

which brings out G_Z as a function of S and $\frac{G_L}{G_Z}$.

The equation

$$G_L = \frac{400}{\frac{G_Z}{G_L} - \frac{S}{8860}\left(\frac{G_Z}{G_L} + 1\right)} \tag{22}$$

derived from equation (21) yields G_L as a function of S and $\frac{G_Z}{G_L}$. This relation is represented by the lower part of Figure 2.

4. Conclusion

If we now consider the curves in Figure 2 and the rating formulas (17) and (21), we find in them a definite relation between the flight performances (v_H, t, S) and the "cost" (G_L) for the standard seaplane, i.e., the quantitative relation, in which these quantities stand to one another, if a seaplane is built to correspond to the technical status of aviation set forth in Section III. From another viewpoint, Figure 2 and formulas (17) and (21) afford the possibility of comparing any seaplane with the corresponding standard seaplane. If the test seaplane is well built, it must have the same horizontal speed as the standard seaplane having the same climbing speed, flight range and dead load as the test seaplane ($v_{H_{theoretical}} = v_{H_{measured}}$). If the test seaplane really has, however, a different horizontal speed, the ratio $v_{H_{meas.}} : v_{H_{theo.}}$ is then a definite designation of its structural excellence.

How easily the rating coefficient $v_{H_{meas.}} : v_{H_{theo.}}$ can be found by means of a graph is obvious from the example given, according to which a seaplane of "standard" excellence, with a dead load of 1535 kg (3384 lb.), a flight range of 1400 km (870 mi.) and a climbing time of 8 minutes from 1000 to 2000 m would have a horizontal speed of 347 km (215.7 mi.) per hour.

Translation by Dwight M. Miner,
National Advisory Committee
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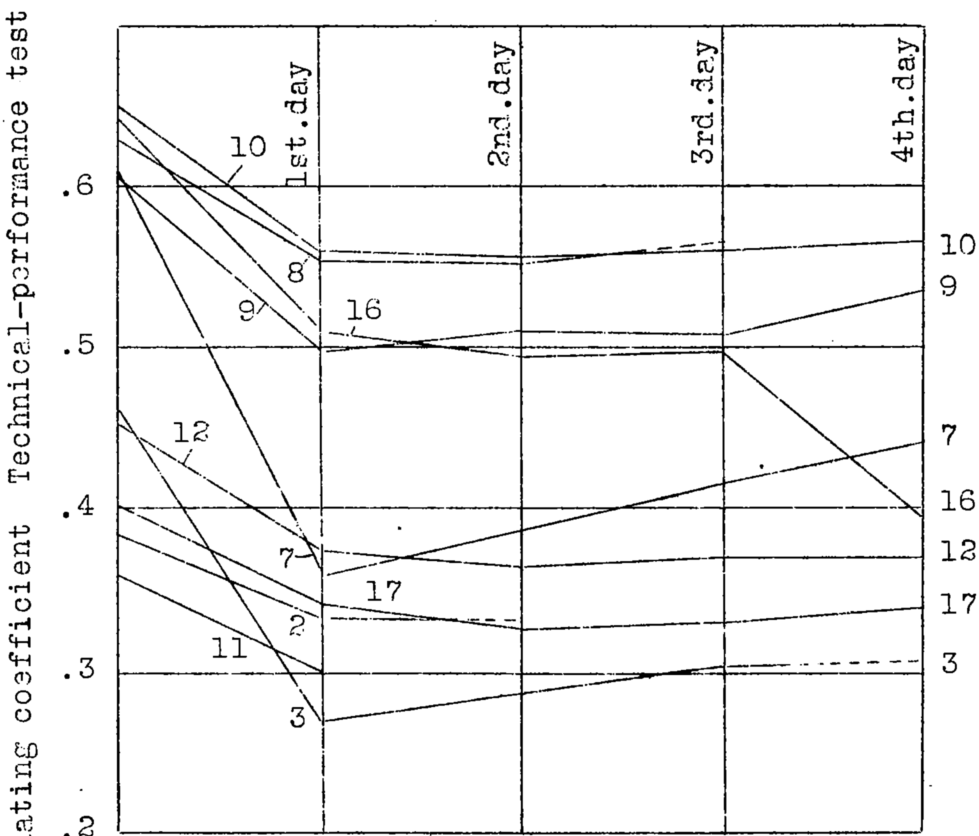
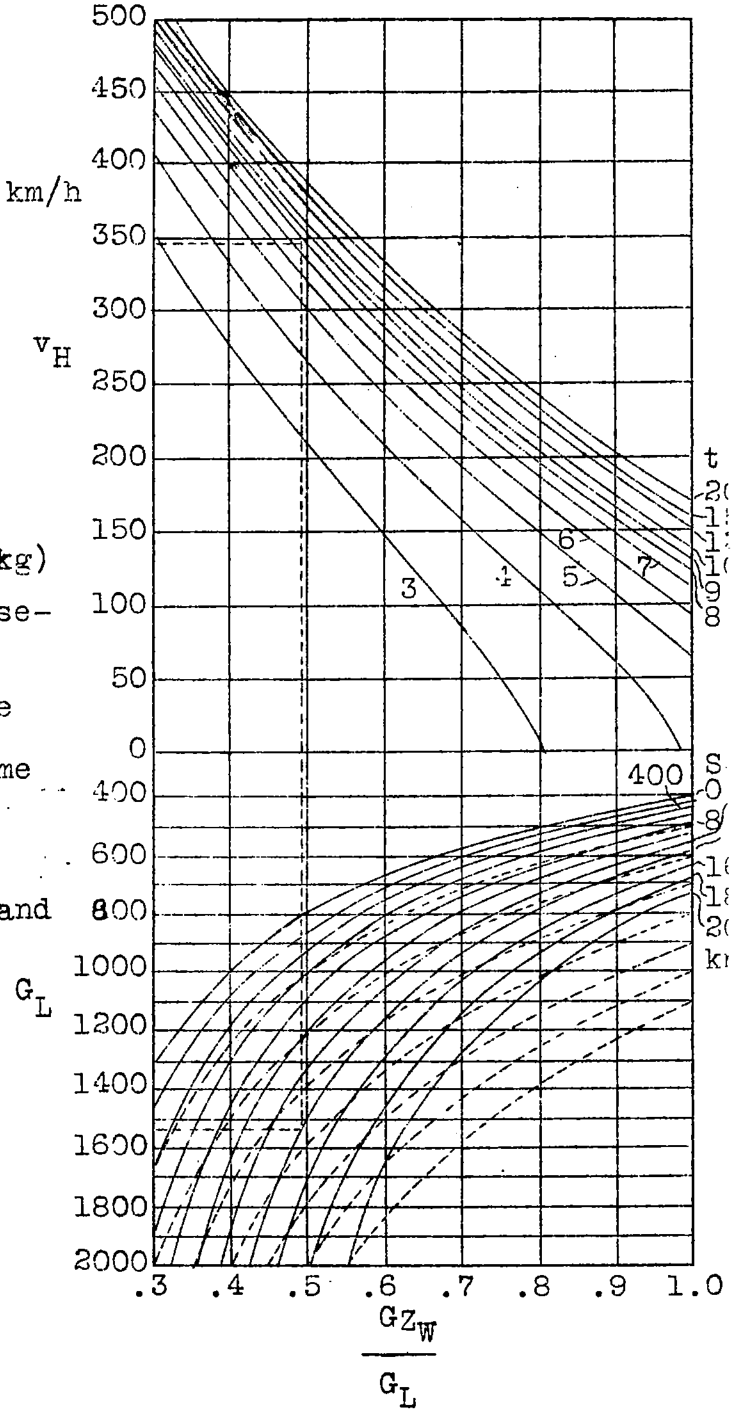


Fig.1 Rating during coast flight.



G_L=dead load(kg)

G_{Z_W}=ratable useful load(kg)

S=flight range (km)

t=climbing time from 1000 to 2000 m

v_H=horizontal speed of the standard seaplane (km/h)

G_L=1535 kg

S =1400 km

$\frac{G_{Z_W}}{G_L}$=0.498

t =8 min

v_H=347 km/h

Fig.2 Relation between dead load, flight range, climbing time and horizontal speed of seaplane.