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SOME IDEAS ON RACING SEAPLANES

By Giovanni Pegna

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I. INTRODUCTION

Seaplane racing for the Schneider Cup has stimulated designers to the realization of ever increasing values of the ratio between the effective power of the engine-propeller group and the head resistance or drag. This has led to the production of some remarkable seaplanes. The 2,500 hp Rolls-Royce "S.6" engine, this year's cup winner, is indeed a remarkable achievement. Equally remarkable is the single propeller capable of utilizing so much power with such a high degree of efficiency.

In Italy, though with less fortunate results, there was constructed for the 1931 contest a power plant consisting of two tandem engines and two coaxial propellers rotating in opposite directions. I believe the useful power in the two cases can be of the same order of magnitude, both in absolute value and in proportion to the weight. This is a mechanical accomplishment which seemed impossible till a short time ago. I instinctively foresaw the progress to be made simultaneously in both respects, namely, increase in the engine power and decrease in the parasite resistance or drag.

This result, however, is difficult to obtain, due to the fact that engine improvements involve laboratory tests under special conditions, while aerodynamic progress requires actual flight tests on new airplane types. These tests often constitute a serious human game in which the life of some brave young pilot is at stake.

Now, however, after this method has been almost exclusively employed by Italian and British designers and builders, a better method has been found for solving the

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* "Alcune Idee sugli Idrovolanti da Corsa." Rivista Aeronautica, June, 1932, pp. 461-516. (Dedicated to Italo Balbo, Italian Minister of Aeronautics.)

aerodynamic problem, which will produce aircraft with the minimum drag. I have employed this method for ten years, having designed seven types of racing seaplanes and constructed some of them.

I have been unfortunate in various ways, but still hope that I or some one else, starting with the principles I am about to explain or with similar ones, may produce a perfect racing seaplane, perfect in the sense that its low-altitude speed with a helicoidal propeller will be the practical upper limit of human attainment.

In addition to the seven racing seaplanes, I am now designing an eighth seaplane which is not strictly a racer, although even better adapted for attaining the maximum speed, which is the aim of every aircraft designer. This is an "all-wing" seaplane without fuselage, and everybody realizes that this is the type (as indicated by Junkers in 1910 and as the objective of specialists and enthusiasts ever since) to be adopted in the near future for long flights. The nondimensional or absolute polar of this eighth seaplane is indicated by the letter Y in Figure 13.

2. BOAT SEAPLANE

In 1920, in the magazine which I then owned and published, "L'Aeronautica" (May, 1920, p. 29), I wrote "I consider it probable that the highest aircraft speeds above a certain power will be attained by seaplanes." This belief has since been confirmed by actual events, seaplanes having exceeded half the velocity of sound in the Schneider cup races. It has been demonstrated that high speeds are more suitable for seaplanes than for landplanes. This is partly because still water affords a practically unlimited take-off and landing field and partly due to the elimination of the landing gear. This is especially true of racing airplanes whose small dimensions do not easily permit the use of retractable landing gears.

One of the first exemplifications of this principle is shown in Figure 1 and dates from 1921. This seaplane, which was designed for racing but which might be modified for ordinary flight, seems to be aerodynamically the simplest conceivable form for small and medium aircraft with habitable bodies, from which the transition could be gradually made to a seaplane with habitable wings and without fuselage, which I still consider the simplest conceivable airplane and perhaps, therefore, the airplane of the future.

The mechanical and thermodynamic difficulties are obvious, but do not appear serious. The structural difficulties imply small dimensions, while one may be perplexed by the unknown aerodynamic moments produced in flight (which then seemed more dangerous to me than they do now) by raising and lowering the propeller axis.

Structurally the single-piece wing could also be of the V type and mounted under the engine. In this case the part of the wing near the hull would be immersed under conditions of rest and would impart to the seaplane transverse static stability and also dynamic stability in the first part of the process of taking off. The wing could rotate with the engine and thus have a considerable advantage in taking off and in landing.

The seaplane floated on the stabilizer and elevator, but I immediately thought of using a perfectly movable stabilizer and soon succeeded in doing so on my pursuit plane P 2 (figs. 2 and 3), which had a wing similar to that of the Pc 1 and the Rondine. With this I believe the pilot could control the seaplane in any attitude of the propeller axis. In the case of a wing rotating with the power plant, it is now possible to connect it with the horizontal empennage in such manner that the wing and the stabilizer would always have the desired reciprocal angular difference in phase.

I believe that the Pc 1 would afford an interesting object for study and the possibility, especially in combination with the Pc 7, of reducing the midsection of the hull to a minimum. It should be noted, with respect to what I have just said regarding the Pc 1 that the hull and the wing would share in floating the seaplane, because the wing would be covered according to the Fokker method and would therefore assist with its tips (or with its central portion in the case of a low wing) in producing the hydrostatic and hydrodynamic lift and in imparting transverse stability to the whole seaplane in the initial phase of taking off.

The hull of the Pc 1 was designed by Arrigoni, and its construction was begun by the Bastianelli Company of Rome (makers of the contemporaneous seaplane PRB which was described in "All the World's Aircraft" of that time), but on which work was suspended for reasons of economy.

3. CONVENTIONAL RACING SEAPLANE

The pursuit landplane P2 (Piaggio 2), designed by me in 1922 and constructed in part by Pegna-Bonmartini and in part by Piaggio (figs. 2, 3, and 4) was the prototype of the seaplane Pc 2 (Piaggio P4) (fig. 8), which I designed in 1923 for the 1924 Schneider Cup race, but which was not entered.

I had observed that the P2 with Botali and Clement radiators had flight characteristics practically the same as anticipated from wind-tunnel model tests. I had also seen that the P2 without radiators had an excellent fineness ratio (logarithmic polar, fig. 5). I accordingly designed the Piaggio Company's P4 (1923) which is the Pc 2 of my series of racing seaplanes.

Figure 6 shows some of the seaplanes designed in Italy during this period for the Schneider Cup races, while the logarithmic polars of these seaplanes (with the exception of No.6), not corrected for the scale effect, are plotted in Figure 7. The polars serve therefore only for approximate comparisons.

It is obvious that the best seaplane is represented by curve 4, but with a correction for the scale effect, together with the seaplane No. 2 (fig. 6) in Crocco's excellent book "Elementi di aviazione" ("Roma 1211," pp. 274-5, and "Roma 1226," pp. 266-7). The "Roma 1225" was also designed by me as a pursuit seaplane (1923), but was not built. The upper wing, of symmetrical profile, was the same as that of the P2.

In its practical realization, the seaplane No. 4 had probably been impaired by the presumable necessity of altering the shape of the floats, while the Pc 2 had probably been improved. In fact the latter was ranked the highest and committed to Piaggio. Figure 8 shows the structure and assembly of this seaplane.

In designing the final type Pc 3 (fig. 9), I reduced the midsection of the fuselage to its apparent minimum and was obliged, as the result of tank tests with models, to change the shape and volume of the floats. (Figs. 10 and 11.) With these changes, I consider the Pc 3 aerodynamically superior to the Pc 2 and even to seaplane No. 4. (Fig. 6.)

The nondimensional polars of these seaplanes are plotted in Figure 12. The 100 Cr scale is increased in the space to the left of 100 Cr = 2, in order to render more evident the comparison between the head resistance in the vicinity of the practical angles of attack for the maximum speeds.

Aerodynamic progress is shown by the nondimensional polars, for which reason there are plotted in Figures 12 and 13 the representative points of the aerodynamic characteristics of the seaplanes S5 and S6, which I deduced approximately from data published in the technical press. In Figure 13 the polars are for the total supporting surface rather than for the wing alone, as will be explained farther on.

Although the points for the S5 and S6 naturally take account of the scale effect, it is obvious that these seaplanes have the same order of fineness as the Pc 3. Bearing in mind the fact that the Pc 3 had over 16 m^2 (172.2 sq. ft.) of wing area and reducing this area sufficiently to enable the same minimum speed as the S6, we obtain the diagrams in Figure 14, from which, although the Pc 3, thus reduced, must be provided with larger floats in relation to the great weight of the S6, it follows that the latter is aerodynamically similar to the Pc 3. I believe, therefore, that the great increase in speed since 1923 is due more to progress in engine designing than to aerodynamic improvements in the seaplanes themselves.

The Pc 3 was almost completed, as shown by Figures 15 and 16, when work on it was discontinued, solely for administrative reasons. I hope the reader will give me the satisfaction of recognizing my priority in conceiving the seaplane type which subsequently in the Macchi (fig. 17) and Supermarine triumphed in the Schneider Cup races. It seems unnecessary to take exception with regard to the semithick braced wings of the Macchi and Supermarine. Practically both solutions, for the given dimensions, are equivalent, even as regards weight, though the semithick cantilever wing is, on the whole, structurally simpler.

On the other hand, it has been demonstrated that the scale effect is appreciable and favorable for wings of medium thickness with almost symmetrical profiles and with a middle line of double curvature (as, e.g., in the M types of the N.A.C.A.), which was like the wing of the Pc 3 and later like that of the Pc 7.

The structure was light and rigid, so that the wing of the pursuit plane P2, with an area of 20 m^2 (215.3 sq.ft.) and a weight of 220 kg (485 lb.) similar to the 16 m^2 (172.2 sq.ft.) wing of the Pc 3, but less robust (fig. 4), broke at the coefficient 18, with a load of 18,000 kg (39,683 lb.) and brilliantly withstood the severe torsional tests required by the Italian Air Ministry.

This was due to the type of construction, which employed a single box spar with great resistance to flexure and torsion, and also to the elliptical shape of the wing with its greater thickness near the fuselage.

The fuselage was likewise strong torsionally and was attached by four bolts to the lower side of the single-piece wing, thus greatly increasing the torsional rigidity of the whole.

4. THE TWO-ENGINE SEAPLANE Pc 4

In 1927 I was requested by the Italian Air Ministry to design a racing seaplane for the 1929 contest. My first idea is sketched in Figure 18. The central float necessitated the use of two wing-tip floats capable of being let down and retracted mechanically. The propeller shafts were prolonged, in order to impart great fineness to the nacelle containing the engines and pilot.

This seaplane did not satisfy me, however, when I was ready to pass from the sketches to the actual designing. I anticipated difficulty in taking off with a float having such a large longitudinal keel angle between the parts forward and aft of the step. The mechanical control of the lateral floats also appeared rather difficult.

It may be observed that my colleague Marchetti designed and constructed a similar type of racing seaplane, but with two lateral floats instead of the central float and with a tail beam. This seaplane was taken to Calshot, but did not participate in the contest. I reluctantly abandoned this idea, in order to devise some more efficacious solution.

5. THE Pc 5 AND Pc 6 SEAPLANES WITH VARIABLE WING AREA AND CENTRAL RETRACTABLE FLOAT

It is obvious that, if, instead of flying with the fuselage and float in their normal conventional positions which causes considerable aerodynamic interference, it were possible to condense the midship sections of these three elements in the vicinity of the engine and simultaneously their frontal area, it would be possible to increase the speed, with a given weight and power, by increasing the wing loading as compared with that at the minimum speed.

On this basis I designed two types of racing seaplanes, the Pc 5 and Pc 6. (Figs. 19, 20, and 21.) Lateral static stability was obtained by means of two planing fins integral with the float, which gave the appearance of a sesquiplane when the float was let down. In flight, the float with its planing fins is raised mechanically against the fuselage, which is then partially imbedded in a hollow on the top of the float. Simultaneously the planing fins rest against the central part of the main wing, so that the whole becomes a monoplane, thus reducing the drag, while eliminating the interference between the float and fuselage and considerably increasing the wing loading with respect to that in taking off and landing. In experiments personally conducted by myself at La Spezia in 1916, it was demonstrated that the water, which got into the hollow in the top of the float, was quickly expelled on the first acceleration of the seaplane.

The most difficult problem of this solution evidently regarded the raising and lowering of the float, which presented two difficulties, namely, its considerable weight and the unknown aerodynamic forces. While accepting the extra weight of the operating mechanism, there was still need of careful wind-tunnel tests, which I was not able to make, as will soon be explained.

The experiments performed in Göttingen, with a monoplane wing which split into biplane wings, were already known, but positive data were lacking on the effect of the aerodynamic reactions while the lower wing and float were being united with the upper wing. This problem troubled me and, in view of the fact that the maneuver would have to be made by the pilot at a very high speed with a heavy wing loading and perhaps in the presence of vibratory motions of the wings, I abandoned this solution, although I had done much work on it, in order to turn to the Pc 1 or something similar.

6. ORIGINS OF THE Pc 7

I then decided to examine anew the Pc 1, which I have already said seemed to me to represent the simplest architectural expression for a small seaplane with a habitable body. In order to make a thorough study of the types Pc 4 and Pc 5, as well as of the Pc 1, I personally conducted extensive wind-tunnel experiments.

For this purpose my firm constructed a wind tunnel which would also be useful for investigating other subjects. Figure 22 represents the Finalmarina wind tunnel, which is of the modern type with an inclosed test chamber and a guided air stream. The wind tunnel was finished, but I was unable to rig it or put it in functioning condition. I was therefore obliged to modify the seaplane Pc 1, in order to enable the functioning of the propeller, by raising the prow of the seaplane out of the water by means of the device illustrated in the British patent 318858 and in the following Italian patent. (Fig. 23.)

"NEW TYPE OF SEAPLANE

Belonging to the Societá Piaggio and Company

and Engineer Giovanni Pegna, at Genoa

"The subject of this invention is a new type of seaplane in which the air propeller is low with respect to the water line, so that it can not function initially for taking off from the water without the aid of two auxiliary devices, which form the subject of this invention, namely, one or more water propellers and two or more pairs of hydrovanes. The former are designed to impart sufficient speed to the seaplane to raise it on the latter enough to enable the starting of the air propeller or propellers and the ultimate take-off.

"Figures 23-30 represent a few examples of the seaplane which are the subject of the patent.

"In Figures 22-25 the Crocco hydrovanes are used; in Figure 26, the Forlanini; in Figure 27, the Guidoni; in Figures 28-30, the Piaggio-Pegna.

"The water propeller can be driven by a separate engine, or by an engine designed to drive one of the air propellers, by means, in the latter case, of two disconnectable couplings, one for the air propeller and the other for the water propeller. (Fig. 30.)

"The air propellers can be kept horizontal, until the seaplane is sufficiently emersed, by means of suitable stops on their hubs.

"In brief. - Seaplane with air propellers near the water, so as to be unable to function for taking off, until the seaplane has been raised sufficiently by means of one or more water propellers with the aid of hydrovanes, such as the Crocco, Forlanini, Guidoni and Piaggio-Pegna.

"Genoa, September 10, 1928."

During the discussions in other countries on the priority of this invention, I learned that in England, in 1912, a patent had been obtained by Mr. Burney on a similar device, of which I was ignorant when I designed the Pc 7. In adopting this method, I transferred the problem of the aerodynamic field to the hydrodynamic field, which seemed easier to master. The idea of using hydrovanes on seaplanes dates back many years, during which they were experimented with by Forlanini, Crocco, Guidoni and Calderara. In 1911 Forlanini proposed, through the engineer Combi, for me to apply his hydrovanes to a seaplane. Crocco wrote a complete and convincing treatise, "Problemi di aeronautica." Guidoni published a summary of his researches, "Fifteen Years of Naval Aviation," in The Journal of the Royal Aeronautical Society, 1928, pp. 25-64.

The problem was first presented to me in the seaplane constructed in 1916 in the factory of Isotta Fraschini at Milan. (Figs. 31 and 32.) For this seaplane I designed, in addition to an ordinary wooden float, a sheet-steel float (constructed by Bottarlini of the I.F.) with a circular midship section and hydrovanes as shown in Figure 31. For military reasons, the hydrovanes were discarded and the seaplane was flown simply with the ordinary wooden float. (Fig. 32.) It may be of interest to note that this seaplane had a biplane cellule which, I think, could serve as a model even now.

In 1917 I made a series of tests, in the Froude tank at La Spezia, with hydrovanes like those in Figures 28-30, derived from those mentioned above. These tests yielded good results up to speeds of 5 m/s (16.4 ft./sec.) with models 12 cm (4.72 in.) long, with a maximum drag of 1/10 to 1/7 of the weight of the model.

Mindful of these experiments, I began by constructing model No. 1 in Figure 33, which, on being towed by a motor boat, behaved normally up to a speed of 6 m/s (19.7 ft./sec.). For the transverse equilibrium in the first phase of raising the prow, while the hydrovanes were still completely submerged, I mounted two inclined planes under the wing tips, as shown in the figure.

I hoped to overcome this difficulty in practice by providing both hydrovanes with auxiliary vanes operated simultaneously with the ailerons of the principal wings, as stated in the patents on this subject taken out by me in conjunction with my firm. This device would doubtless have proved efficacious, and I therefore prepared to proceed by constructing model No. 2 (fig. 33) without the lateral inclined planes. This model was sent to Rome, as "monoplane X" for wind-tunnel tests. The results of the aerodynamic tests were encouraging. (Fig. 34.)

Continuing my researches, I decided, at the suggestion of General Crocco, to change the wing section of the monoplane X, which was a Curtiss of small lift, and adopted a "Munk" of greater lift though also of greater drag. I was thus enabled to use a considerably smaller wing than in the first case with obvious advantages as regards weight and flexural and torsional rigidity. I thus arrived at the final model of the Pc 7. (Fig. 36.)

The other models represented in Figure 33 served for tests of minor importance, the description of which is not necessary here. The problem, thus posed, seemed simple, but, in reality, presented quite serious and unexpected difficulties.

7. HYDRODYNAMIC CHARACTERISTICS OF THE Pc 7

As is manifest from the foregoing, I intended to abandon with the Pc 1, Pc 5, Pc 6 and Pc 7, the conventional form of racing seaplanes (designed by me in anticipation of the Pc 3), in order to obtain, through ideas which were not new but which were combined in a new way, a seaplane which would be swift not only by reason of the engine power, but also because of the reduced drag.

As already mentioned, I had transferred the difficulties confronting me from the aerodynamic to the hydrodynamic field. I derived no great advantage from this course and immediately encountered so great difficulties that I would have returned to the Pc 1, if I had not already begun the construction of the Pc 7 in the attempt to improve the hydrodynamic characteristics. The reader will surely understand my eagerness for quick results, which made it advisable for me not to abandon that believed to be good for that supposed to be still better.

In the first towing tests, up to 5 to 6 m/s (16.4 to 19.7 ft./sec.), the model behaved in a remarkably regular manner, exactly in accord with my expectations. The prow was raised to the position which made it possible to start the air propeller, while the stern emerged till it was supported only by the small lower hydrovane. (A, fig. 37.) When, however, the model was towed at a greater speed, it began to behave in a more uncertain manner. It sank into the water and continued to move as though it had no hydrovanes. It lost its lateral stability and sometimes suddenly made a complete turn about a longitudinal axis. On investigation this was found to be due to a kind of cavitation. When the speed of the model reached a certain value and the hydrovanes were immersed only one or two centimeters (less than an inch), the water suddenly separated from its rear and was replaced by air. From this moment the lift of the hydrovanes was produced only by their lower surface, and the coefficient Cp dropped to very low values, which were only about 1/4 of the original value. If the phenomenon occurred simultaneously in both hydrovanes, the model sank vertically; otherwise it heeled over, as already mentioned.

I had to resort to protecting screens and began by using two vertical or horizontal diaphragms on the hydrovanes, as shown in Figure 33, hoping thus to obstruct the air current produced by the negative hydrodynamic pressure on the after side of the hydrovanes. It is obvious that, when this negative pressure (which is about 800 times as great in water as in air for the same speed) amounts to about one kg/cm^2 (14.2 lb./sq.in.), it can produce the phenomenon under consideration. It is therefore comprehensible how the said expedient may be efficacious only to a slight degree and that this is due to the physical nature of the phenomenon.

The solution of the problem occurred to me December 18, 1928, eight months after the contest. In my notebook of that date I find the following remarks. "There is need of utilizing, rather than of seeking to eliminate, the phenomenon of cavitation, and of basing the solution on the hydrodynamic pressure on the lower side of the hydrovanes." December 19 I had already concluded all the preceding experiments and those of the day before with the following note. (Fig. 37.) "In the first phase of taking off, when the water propeller was running, the seaplane was supported at A and C. At a higher speed, when the air propeller is running and it is desirable to eliminate the hydrodynamic resistance of the water propeller, the seaplane must be supported at B and C preparatory to taking off. In landing, the seaplane must touch the water at B and C simultaneously, or nearly so. It is therefore necessary to test the hydrovanes A and B in conjunction with C."

These tests yielded good results. There remained only a brief change of speed (from 30 to 36 km (18.6 to 22.4 miles) per hour, during which there was a slight lateral instability, which did not trouble me, because it could be remedied either by auxiliary ailerons, as already mentioned, or by the skill of the pilot, as will be shown.

8. REMARKS ON HYDROVANES WITH AND WITHOUT CIRCULATION

The phenomenon of cavitation on the hydrovanes was foreseeable, though it received but little attention. My forerunners operated at a speed range below that of cavitation and could accordingly construct very good seaplanes without incurring any risk. Forlanini on Lake Maggiore, Crocco at Vigna di Valle and Guidoni in our ports did not establish the effects of the separation of the fluid flow. I myself piloted (1912) Farman seaplanes with Guidoni wings and observed, that the phenomena of taking off and of landing occurred with extraordinary continuity and smoothness. The minimum speed of the Farman, however, was below the critical speed of cavitation for the hydrovanes employed.

In order to foresee in 1928 the existence of this critical speed, I would have had to reflect sufficiently on the possible importance of the aerodynamic or hydrodynamic pressure in the vicinity of the leading edge of a wing, which is expressed by the formula

$$p = 1/2 \rho a V^2$$

where a is a function of the angle of attack and of the location of the point at which the pressure is measured along the profile. On top of a wing, near the leading edge, a may easily have a value of -2.5. For water ρ is about 100, so that we can write

$$p = 50 a V^2$$

and, putting a = 2.5, we find a critical speed of 9 m/s (29.5 ft./sec.), for p = 10,000 kg/cm^2 (142,235 lb./sq.in.). The cavitation must begin at a little higher speed than this, if the hydrovane is at the surface of the water. It is obvious that this must occur at greater speeds with profiles having a lower absolute maximum value of a. This was confirmed by experiments, during which it was found (as appeared logical) that the better profile in this respect is a plano-convex one coming to a point in front, with its upper side having the shape of the arc of a circle.

Remembering that the lift of a wing really originates at a vortex with a transverse axis which is compounded with the field of velocity due to the motion of the wing itself, it may be thought that a discontinuity occurs in the lift and therefore that the suction and the decrease in the lift, when the field intensity corresponds with the surface of the water, assume particular values. The solution of the hydrodynamic problem of Pc 7, as stated in Section 6, therefore signifies the renunciation of the lift with circulation, in order to utilize the lift without circulation, suitable for aquaplaning bodies. Flat stones skipped on the water, sea sleds and aquaplanes are practical examples of the utilization of hydrodynamic lift without circulation.

In substance therefore the Pc 7, when it is supported at B and C (fig. 37), can be likened to a conventional seaplane, from which the floats have been removed with the exception of the portions near and in front of the step and tail. The object of the system of inverted-V hydrovanes of the Pc 7 is to substitute hydrodynamic lift for the hydrostatic lift of ordinary floats.

While I, assisted by the engineer Gabrielli, was conducting the experiments on the hydrovanes with rather primitive means, General Crocco was conducting similar systematic tests in the Froude tank of the Air Ministry with inverted-V hydrovanes similar to those of the Pc 7. He immediately noticed the phenomenon of cavitation and found that the best profile was a plano-convex one.

The results of General Crocco's experiments came to my knowledge in December, 1928, and at this time General Crocco also learned of my experiments, of the difficulties I had encountered and of my solution of the problem as stated in Section 7 of this treatise. While being very grateful to General Crocco for his important suggestions, I was not able to utilize the tests recommended by him, because cavitation inhibited the use of simple hydrovanes at over 70 km/h (43.5 mi./hr.), and necessitated the adoption of aquaplaning surfaces without circulation.*

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* The study of the phenomenon of cavitation, or more properly of the separation of the flow from the top of the immersed hydrovanes, should be pursued with systematic experimentation. In fact this phenomenon is more complex than would appear from my summary. For completely immersed hydrovanes, the critical speed of separation increases with the depth of immersion, while, for hydrovanes frontally inclined and partially emersed, it may go below the minimum speed stated by me. I found a confirmation of this fact many years ago in the vertical arms of a device for testing water-propeller models in the tank at La Spezia. (Concluded at bottom of page 15.)

9. HYDROVANES AND PLANING SURFACES

Figure 35 represents the lift-drag ratios of a flat rectangular plate towed on water at various angles of attack (experiments made in the Froude tank at Budapest). These ratios or efficiencies correspond to an aspect ratio of about 2.5. The efficiency was slightly improved by decreasing the aspect ratio. From Figure 35 it appears that, with a judicious choice of the angles of attack and therefore of the relative positions of the planing surfaces, a ratio of 1:7 can be obtained between the hydrodynamic resistance and the weight of the seaplane, which harmonizes well with the solution adopted for the Pc 7.

In practice, however, the original Pc 7 is inferior for the following reasons.

1) The planing surfaces can not be made frontally horizontal, because, due to the smallness of the wing lift, it would porpoise badly at 100 km/h (62.1 mi./hr.), as was experimentally confirmed with models.

2) It did not seem best for the planing surfaces to be rectangular. The shape and frontal inclination adopted by me (fig. 35), perhaps still far from perfect, have the advantage of a very gradual contact with the water in landing and prevent porpoising.

3) The angle of attack of the planing surfaces is too high when the seaplane is moving with the points A, B and C at the surface of the water. (See section 7 and fig. 37.) It is possible to avoid this by twisting the surfaces so that their geometric angles of attack suitably increase outwardly from their inner extremities.

For these reasons and also because the rear part of the effective portion of the hull is covered with water at a high angle of attack, the actual efficiency of the Pc 7 in its original form (counting both the hydrodynamic and the aerodynamic forces) was not so good as that of the

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(Continued from pate 14.)
The arms were apparently well shaped and moved at zero angle of attack. This difficulty was remedied by means of lenticular profiles like the foregoing, but very slender and smooth.

other racing seaplanes. It is possible to expect some improvement in efficiency in the second form of the seaplane by means already mentioned. Fortunately the water propeller, with which the seaplane was originally equipped and aside from these last considerations, is well adapted to solve the take-off problem of the Pc 7, as shown in Figure 38.

In this figure, the point B corresponds to the instant the pilot starts the air propeller, and the point C to the instant when the air propeller annuls the effect of the water propeller. In the interval between B and C the sum of the two propeller thrusts may be represented by the segment B C, which serves as the bridge of transition from the hydrodynamic propulsion A B to the aerodynamic C D.

Figure 39 presents the diagrams relating to the towing tests of the complete model of the Pc 7. Figure 40 shows the results of the trimming tests, the B group of curves referring to the emersion of the lower horizontal tangent to the propeller disk. The pilot might introduce the air propeller at a very low speed, if the propeller thrust at this speed were sufficient for propulsion, which might happen in a nonracing seaplane. Lastly it should be noted that the landing of the Pc 7 has been criticised. This should present no difficulty.

It is thought that the angle of attack of the planing surfaces is about 3° (fig. 37) with respect to the line of flight at maximum speed. Therefore, in landing at maximum speed, the planing surfaces, even in this limiting case, would yield a positive lift of considerable efficiency and such that the hydrodynamic reaction of the planing surfaces would be forward of the center of gravity. Under these conditions the seaplane would therefore have no tendency to capsize.

On landing, as stated in Section 7, at a suitable speed, i.e., on the points A, B and C, the efficiency of the planing surfaces would be reduced to a minimum of 3 and hence all danger of ducking would be eliminated even in this case. Ducking would result only from landing "under the line of flight" and this, in my opinion, must be avoided.

10. AERODYNAMIC CHARACTERISTICS OF THE Pc 7

These present no notable peculiarities, except the low value of Cr minimum and the high value of $C_{p\ max}/C_{r\ max}$ = 52, unequaled, so far as I know, by any seaplane which has been constructed or tested in a wind tunnel.

Figures 7 and 14 show the logarithmic polar of Pc 7, which coincides practically with that of the monoplane X. Figure 13 shows at 1 the absolute polar of the Pc 7 with respect to the total supporting surface (wing area + horizontal projection of planing surfaces and hydrovanes). The absolute polars of Pc 7 and of the monoplane X (also with respect to the total supporting surface) do not coincide, the latter excelling the former. This depends not so much on the wing profile as on the worsening of the hydrovanes due to the facts presented in Section 7.

Nevertheless the Pc 7, even in its primitive form which can be greatly improved, is much better, even in the absolute sense, than any other racing seaplane known to me. The curves 1, S5 and S6 (fig. 13) enable comparisons.

Absolutely, the Supermarines, the Macchis, the Glosters and the Pc 3 are practically equivalent and, within the limits of errors of estimation which I may have made, have the same maximum total lift. For this reason I felt justified in saying, at the beginning of this treatise, that the world speed record was due more to improvements in the engines than to improvements in the design of the racing seaplanes.

Figure 41 represents the results of a study of the centering of the Pc 7 by the method explained by Crocco in his "Elementi di Aviazione."

11. PROPELLERS

The propellers received special attention. The revolution speed of the engine (800 hp I.F.) was, after reduction, 2,600 r.p.m. and the maximum speed of the seaplane was expected to reach 580 to 600 km/h (360.4 to 372.8 mi./hr.). The tip speed of the propeller blades would therefore be practically that of sound. I would have preferred to use a four-blade propeller, in order to reduce the peripheral velocity, but the same conception of the Pc 7 prevented me from spending time on such a propeller.

Three propellers with steel hubs and adjustable blades of standard steel (fig. 42) were therefore ordered for the Pc 7, and one of these propellers, although contrary to the judgment of the firm, was designed by me with very slender, almost symmetrical plano-convex tip sections. This was an application of my old notions of external ballistics, which reminded me of the advantage of sharpening the ogives of projectiles in order to reduce the head resistance. It is now thought that there is no circulation at the velocity of sound and that, at that velocity, thin flat profiles, are therefore better than the customary ones. In addition to the above-mentioned variable-pitch propellers, I had three made by Caproni of different pitches and of the usual duralumin type. (Fig. 43.)

I preferred the variable-pitch propellers for various reasons, especially because the take-off from the water was facilitated by a suitable adjustment of the pitch. The aerodynamic calculation of the propellers was made with the customary logarithmic diagrams, but the geometric pitch of the tip sections was determined by assuming that the angle of attack for zero lift of the profile was zero with respect to the chord. For the calculation of air propellers, the data contained in certain British publications were also used.

The controllable, swivelling, two-blade duralumin water propeller (fig. 44) was designed on the basis of old model experiments in the Froude tank at La Spezia. Not being able to conduct the tests of this propeller directly on the Pc 7 and it being necessary to attain the maximum reliability of the water propeller before installing it on the Pc 7, my firm first constructed the motorboat shown in Figure 45, with a length of 10 m (32.8 ft.), a width of 2 m (6.56 ft.) and a displacement of 3,000 kg (6,614 lb.), for testing the proposed water propeller in direct drive with a 300 hp engine at 2,000 r.p.m. This motorboat was chosen from among those tested in the tank, because its resistance curve approximated that of the Pc 7 in the tank at Rome.

The motorboat tests served the dual purpose of showing whether the propeller thrust was the one required and whether the physical force required to change the propeller pitch (lever C, fig. 47) was great enough to fatigue the pilot. The propeller thrust was 900 kg (1,984 lb.) at a fixed point, and the thrusts at different propeller speeds could be approximately calculated from a knowledge of the revolution speed and of the speed and corresponding resistance of the boat. After repeated trials, the force required for the lever C was sufficiently reduced by shifting the blade axis. This was accomplished by replacing the original duralumin pivot, which was integral with the blade, by a separate steel pivot as shown in Figure 44 (A). The results corresponded perfectly with our expectations.

12. THE CONSTRUCTION

I encountered many difficulties at first in the design and construction of the Pc 7. This retarded its completion so much as to bring about a suspension of the tests and of my work early in 1930.

The first and most serious obstacle was indecision regarding the type of engine to be used. The engine had to be supplemented by gears for transmitting the force to both propellers and by some device for stopping the air propeller in the horizontal position.

At first the Fiat Company became interested and desired to associate itself with my company and to name the Pc 7 the Piaggio-Fiat. I initiated the project by using the 1,000 hp Fiat engine and transmission gears designed by the Fiat Company.

Subsequently I abandoned the Fiat engine and adopted the Isotta Fraschini engine with the approval of the Italian Air Ministry. My old friend Ginstino Cattaneo, the designer of the I.F. engines, displayed his great genius by interpreting my ideas and translating them into perfect mechanisms.

Figure 47 is a longitudinal diagram of the Pc 7 with the 800 hp I.F. engine. A and B are the transmission gears for the two propellers controlled by the levers C and D. The lever D was so adjusted that, by continuing its course after the gear of the water propeller had been freed, the blades of the latter were given an infinite pitch, so as to practically eliminate their aerodynamic resistance.

The lever C, after throwing the air propeller out of gear, was pushed again and activated the cheek brake E which stopped the propeller. The same lever C then loosened the brake so that the propeller could make a fraction of a turn and be locked in a horizontal position.

The lever C also controlled a rubber valve by means of the lever F. This valve was closed at the instant the air propeller stopped and served to prevent water from entering the fuselage when the seaplane was in the position shown in Figure 46. This valve was opened by the same lever, when actuated in the opposite direction in throwing the air propeller into gear. When it was desired to start the air propeller, the lever C opened the air-intake valves of the carburetors (A, fig. 57), which were closed when the seaplane was at rest. In the latter condition the engine "breathed" through the pilot's hatch.

The whole mechanism functioned as expected, and the slight disadvantages could have been easily overcome by further experimentation. An examination of Figure 47 does not reveal any great difficulties in the construction of the seaplane, but it tested our ingenuity to the utmost to solve the many problems encountered every day. We had no precedent to aid us and the restrictions of space were very severe. After determining the main cross section, modifications were no longer possible.

A number of problems had to be solved as well as possible under the circumstances, e.g., the air intake of the carburetors, the engine exhaust and the oil radiator (fig. 57), three difficult things which functioned fairly well in practice, but needed further improvements which I hoped to make by further experimentation after the contest. For lack of time, I neglected to systematize on skids the controlled hydrovanes, trusting to the skill of the pilot to overcome the brief phase of lateral instability in the water, from 3 to 3.5 m/s (9.8 to 11.5 ft./sec.) of 0.1-scale model. In fact the Pc 7, piloted by Dal Molin, rose on its hydrovanes as shown in Figures 48 and 49 (taken from a motion-picture film).

13. STRUCTURE

The stanch fuselage had many longitudinals running from bow to stern (fig. 50) and was strong and light.

These longitudinals served for attaching the covering, which consisted of a double layer of thin plywood with the interposition of impermeable fabric. Figure 50 shows the engine bearers, the support for the water-propeller gear and the steel reinforcing plates for attaching the fins.

The water-tight tail surfaces (fig. 51) were aerodynamically fine and were covered with plywood. They were separated by the fuselage, and the axis of the air rudder served also for the water rudder. The fuselage had two water-tight bulkheads, and the buoyancy of the seaplane was increased by a covering of thin corrugated aluminum, soldered (A, water-tight covering; B, fuel tanks; fig. 52).

14. THE WING

Figure 53 shows the uncovered wing of the Pc 7. It was first made with two spars, the third spar having been added after I had been asked for a higher safety factor than the one first selected (16 instead of 13). The wing was perfectly water-tight, including the ailerons whose hinges and controls were installed in such manner as to produce no appreciable torsional stress.

The wing was subjected complete, both with and without water radiators, to the measurement of the flexural and torsional vibration period (figs. 54 and 55), in order to determine whether any important régime of the engine was a multiple of the natural vibration of the wing. The wing radiators, shown in Figure 56, had a capacity of 55 l/h (14.52 gal./hr.).

The oil radiator is shown in Figure 57 as it was originally designed, the portholes A for the carburetor air intake being also shown in the same figure. These portholes were opened by the act of starting the air propeller. It is now preferred to cool the oil by means of the water from the principal radiators, by means of a tubular radiator concealed in the fuselage and to put the air-intake holes on top, instead of in the sides of the hull.

In the beginning of 1930 I put in construction the planing surfaces with controlled hydrovanes and the relative controls, but the suspension of the tests also caused the suspension of this work. Figure 58 shows a planing surface ready for the application of a small hydrovane.

15. CHARACTERISTICS OF THE Pc 7

Weight empty	1,416 kg	3,099.70 lb.
Useful load	280 "	617.29 "
Total load	1,686 "	3,716.99 "
Wing area	8.45 m^2	90.95 sq.ft.
Total area	9.88 "	106.35 "
Wing loading	169.5 kg/m^2	34.72 lb./sq.ft.
Engine power	850 hp	838.4 hp
Estimated maximum speed	600 km/h	372.8 mi./hr.
Minimum speed under full load	165 "	102.5 "

WEIGHT DISTRIBUTION

Wing with radiators and water	282.50 kg	622.81 lb.
Fuselage complete	246.80 "	544.10 "
Tail surfaces	44.00 "	97.00 "
Water rudder and propeller	13.70 "	30.20 "
Hydrovanes	86.20 "	190.04 "
Engines with transmission gears	563.00 "	1,241.20 "
Air propeller	28.00 "	61.71 "
General controls	24.50 "	54.00 "
Engine accessories	28.74 "	63.36 "

WEIGHT DISTRIBUTION (Cont.)

Tanks and water-tight boxes	52.15	kg	114.97	lb.
Oil radiator	26.41	"	58.22	"
Fuel, oil and water pipes	20.00	"	44.09	"
Weight empty	1,416.00	"	3,121.70	"

These data show that the principle of the Pc 7 makes it possible to realize a weight of the same order of magnitude as that of a seaplane of the conventional type, with the advantage resulting from the substitution of hydrovanes for floats and the addition of auxiliary devices.

16. THE TESTS

When the water propeller was started the bow of the seaplane was promptly raised, as expected.

One disadvantage was quickly noted. The gear of the water propeller, which functioned perfectly on the motorboat and on the test stand, was flooded with oil and skidded. For this reason, while the engine accelerated, the seaplane settled back in the water, but without harm. Subsequently this defect was partially remedied. There was need of a port in the side of the fuselage for inspection and cleaning, but this was not provided, because the tests were suspended.

Since the Pc 7 could not participate in the contest, it was temporarily abandoned both by my firm and by the Air Ministry.

I hope, however, to be able to resume this work, in which I take a great interest, and perhaps produce practical seaplanes with some advantages as compared with existing seaplanes of small and medium dimensions, especially for use on ships. This would perhaps be the best demonstration that researches regarding high-speed seaplanes are not useless, as some claim, but fruitful of results for the progress of aviation.

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

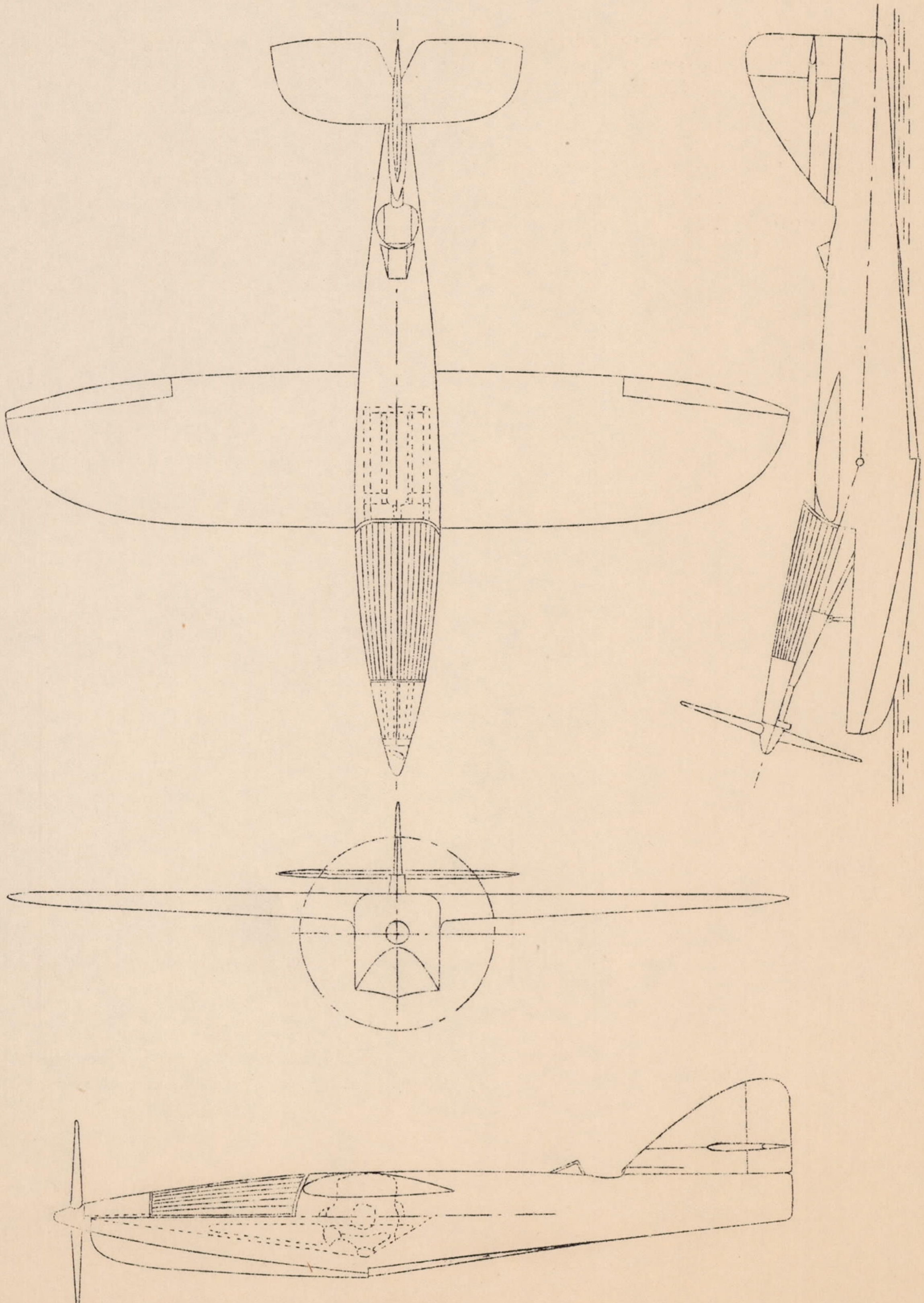


Fig.1

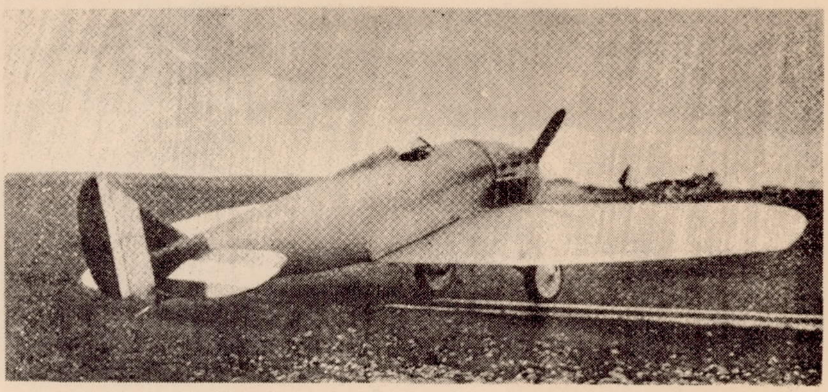


Fig.2

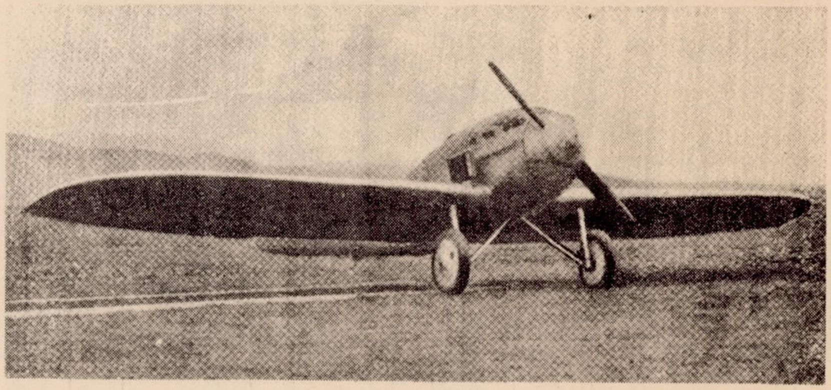


Fig.3

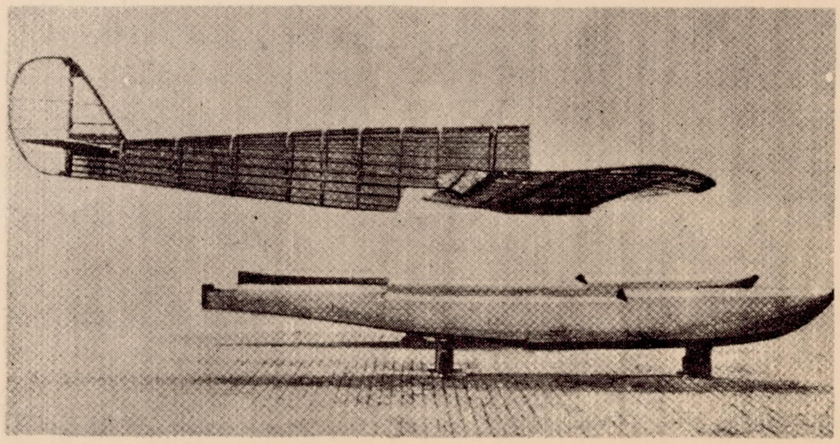


Fig.15

The
Pc 3

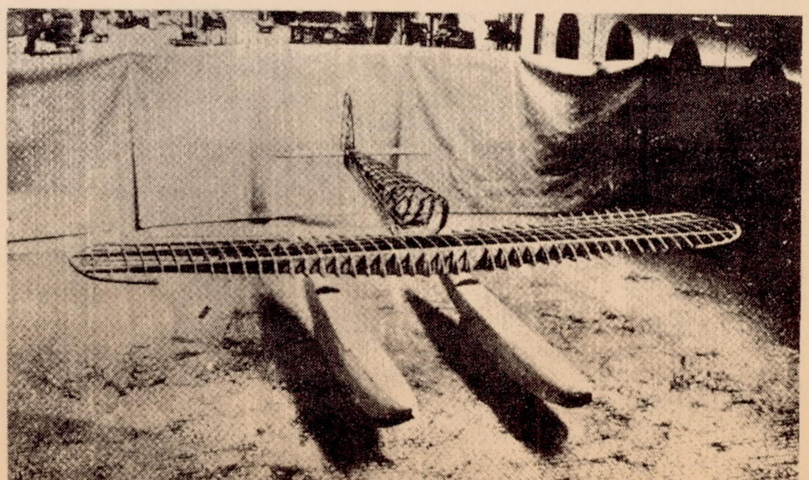


Fig.16

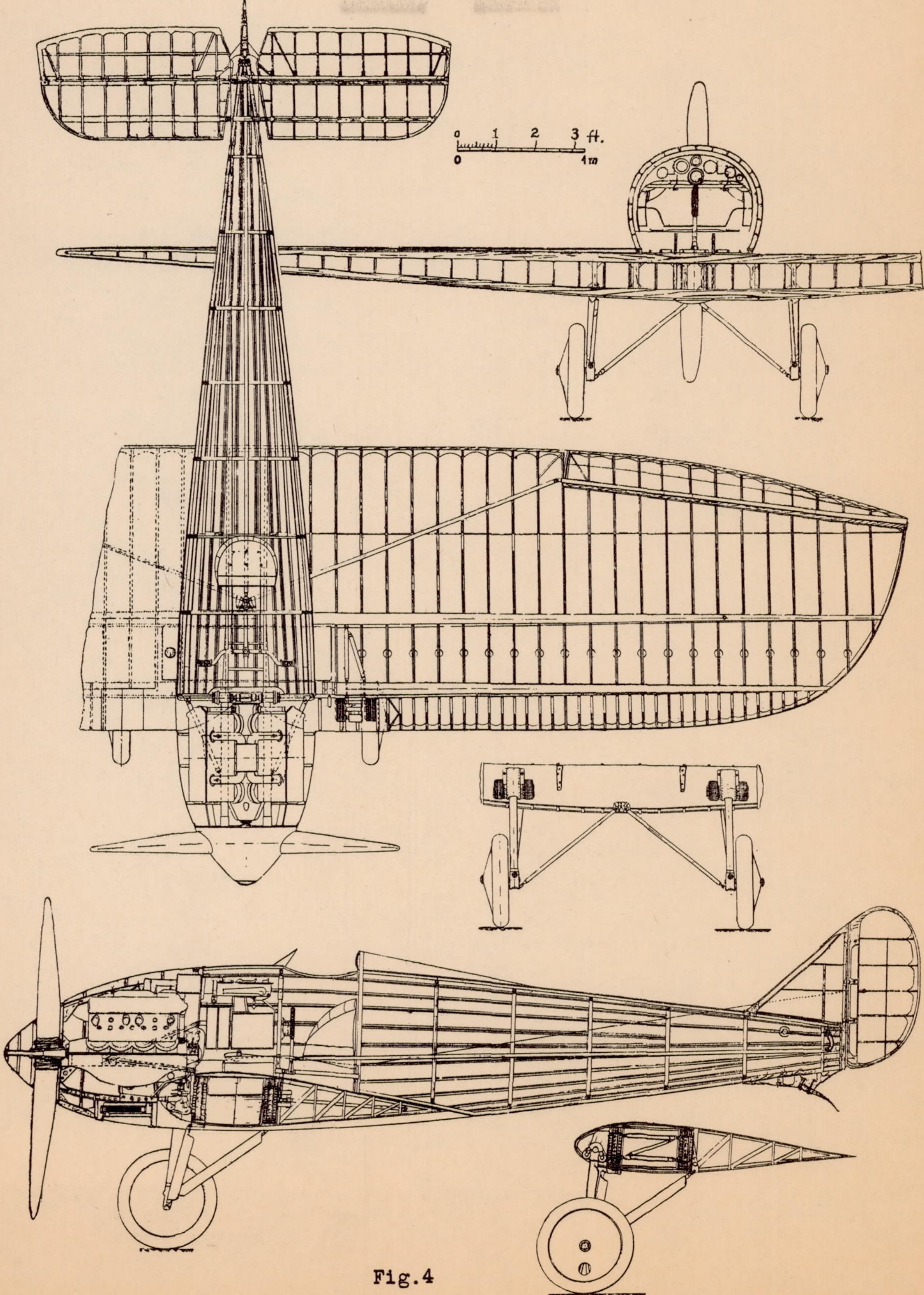


Fig.4

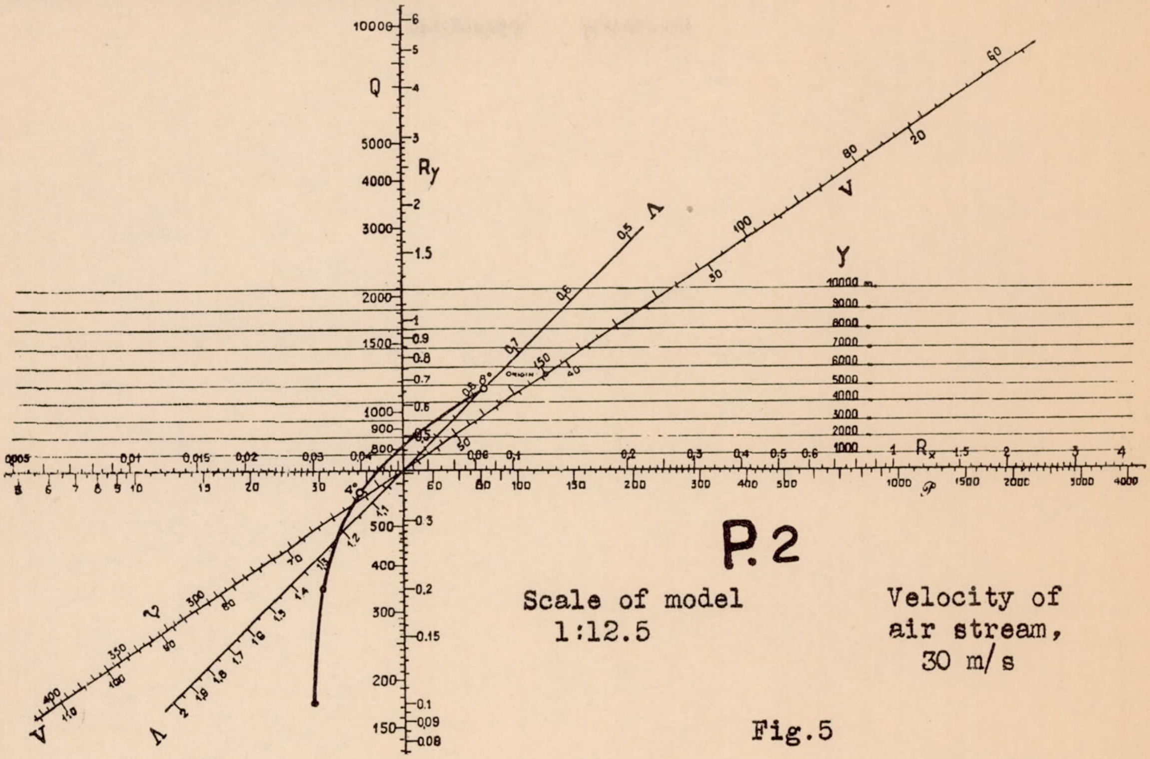

Q
R_y
Λ
V
Y
10000 m
9000
8000
7000
6000
5000
4000
3000
2000
1000
ORIGIN
R_x
P.2
Scale of model
1:12.5
Velocity of
air stream,
30 m/s

Fig.5

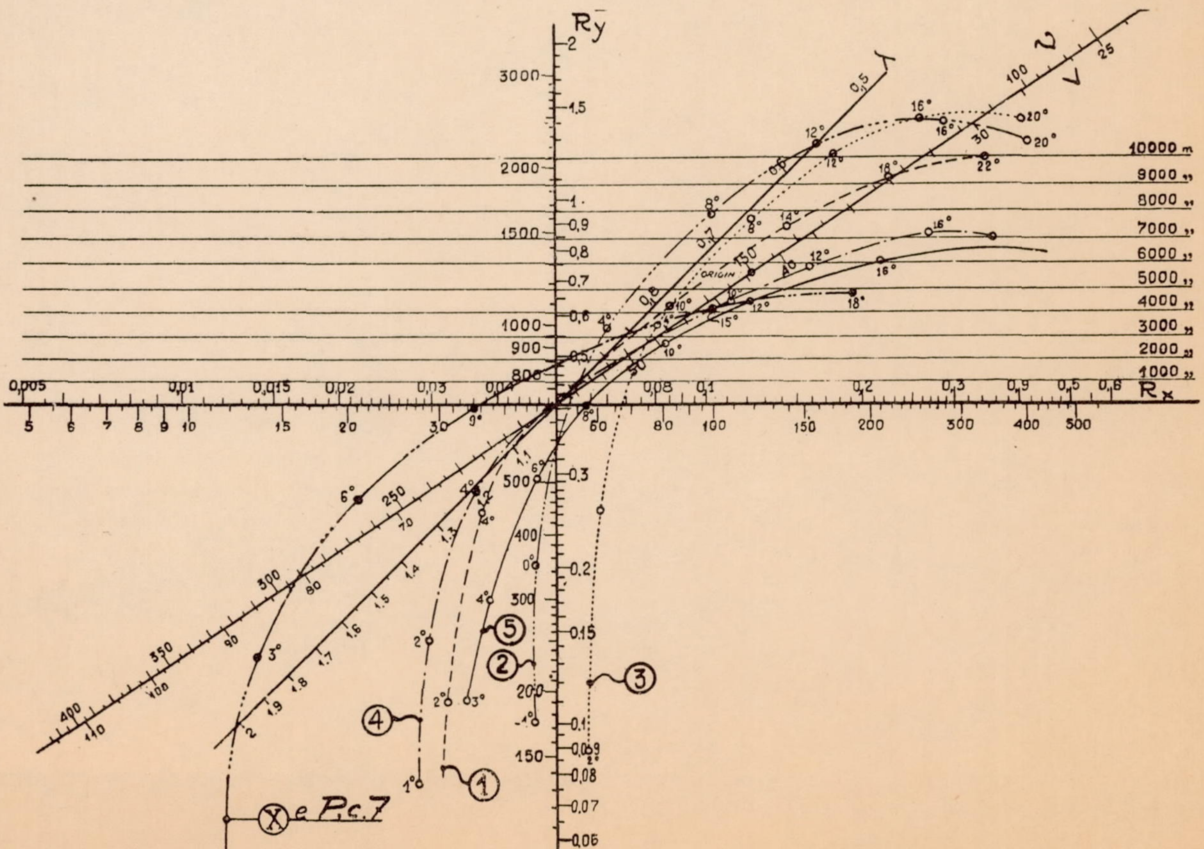

R_y
R_x
V
ORIGIN
10000 m
9000 „
8000 „
7000 „
6000 „
5000 „
4000 „
3000 „
2000 „
1000 „
1
2
3
4
5
X e P.c.7

Fig.7

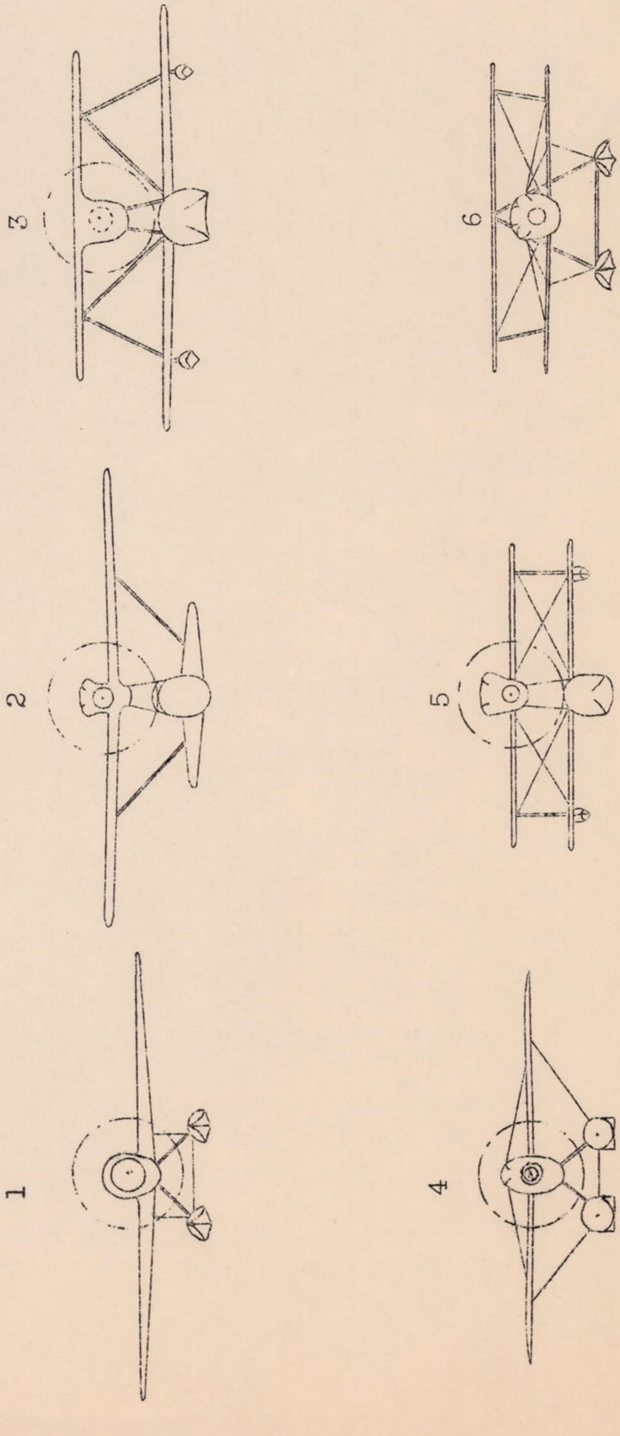
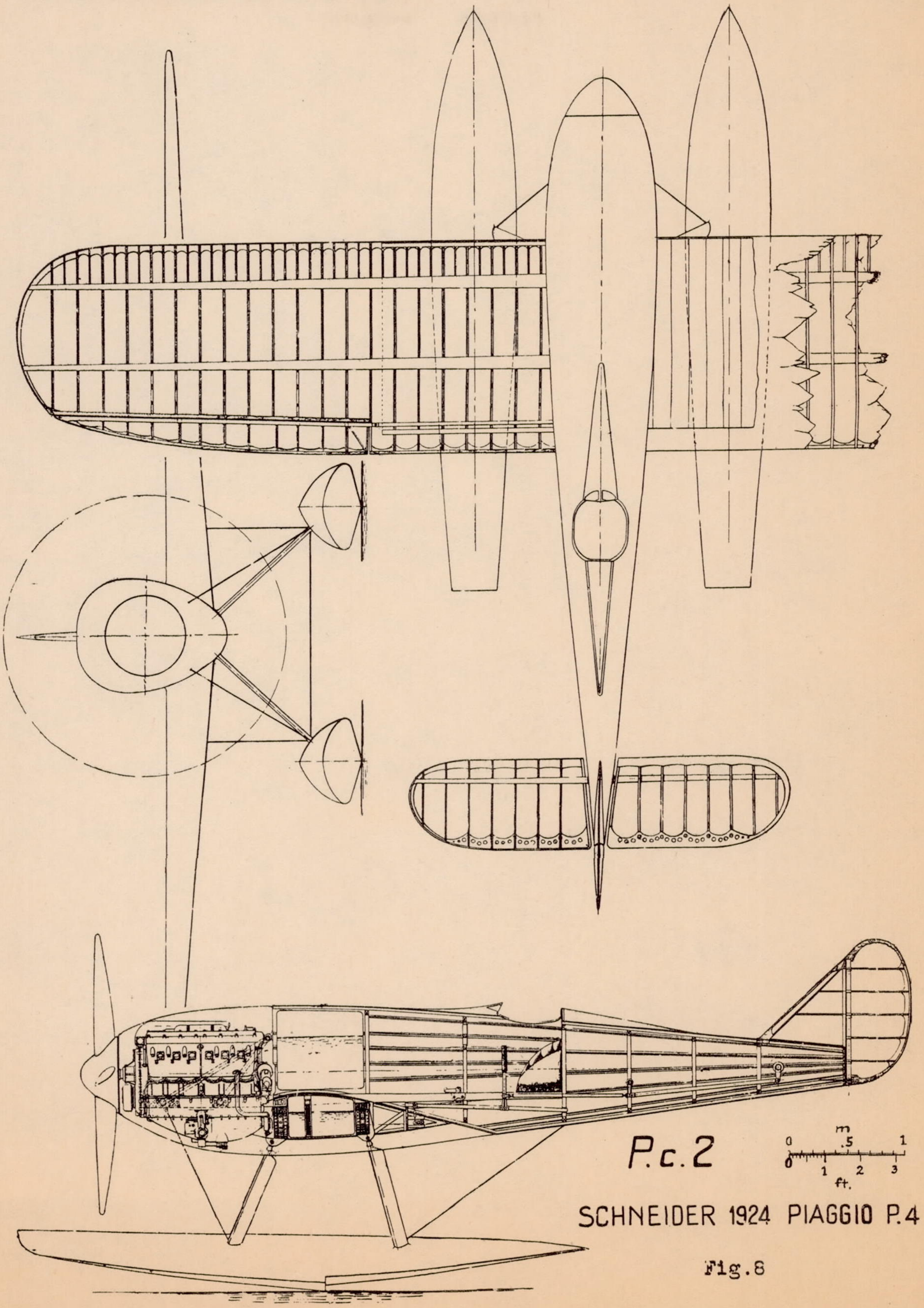


Fig.6



SCHNEIDER 1924 PIAGGIO P.4

Fig.8

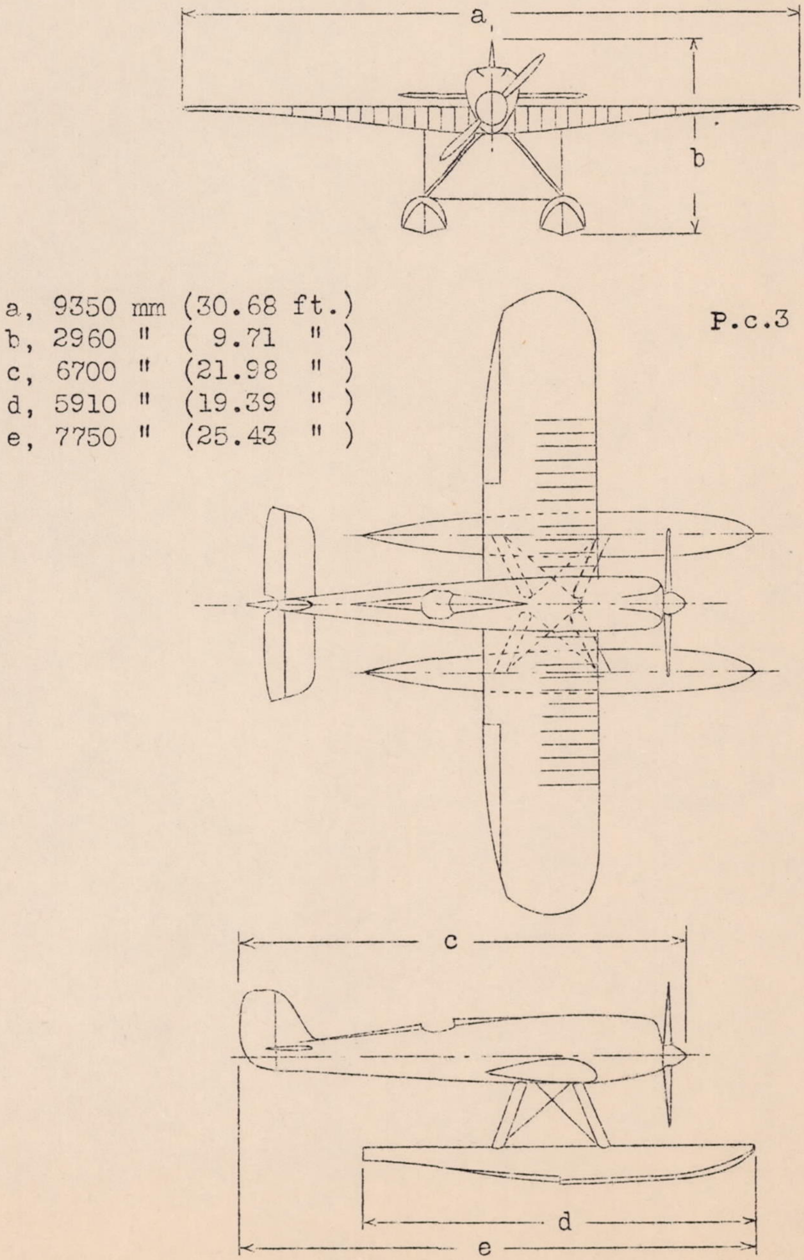
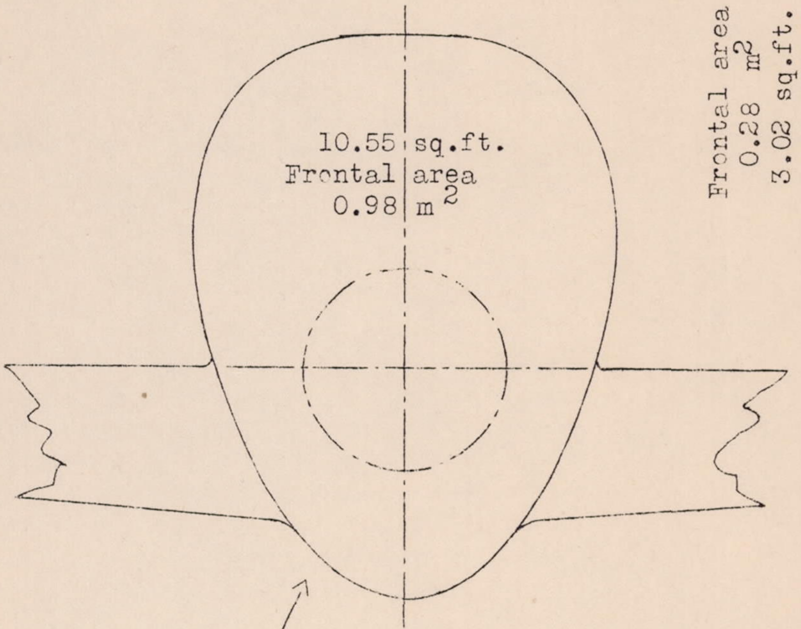
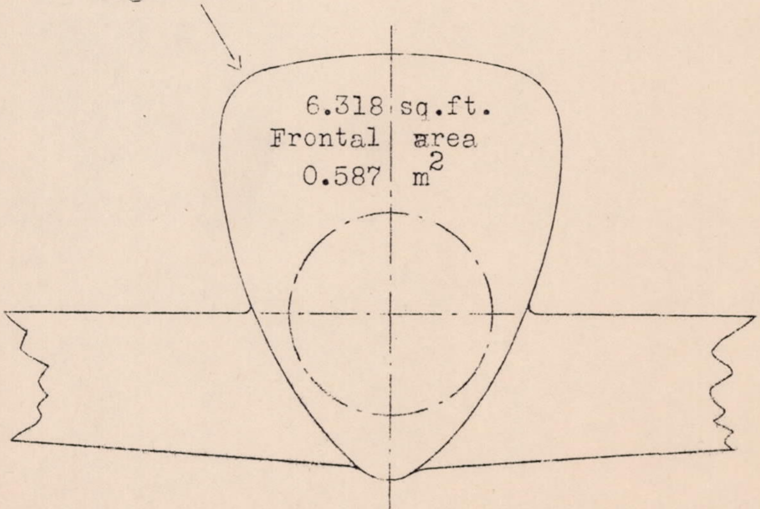

a
b
a, 9350 mm (30.68 ft.)
b, 2960 " (9.71 ")
c, 6700 " (21.98 ")
d, 5910 " (19.39 ")
e, 7750 " (25.43 ")
P.c.3
c
d
e

Fig.9

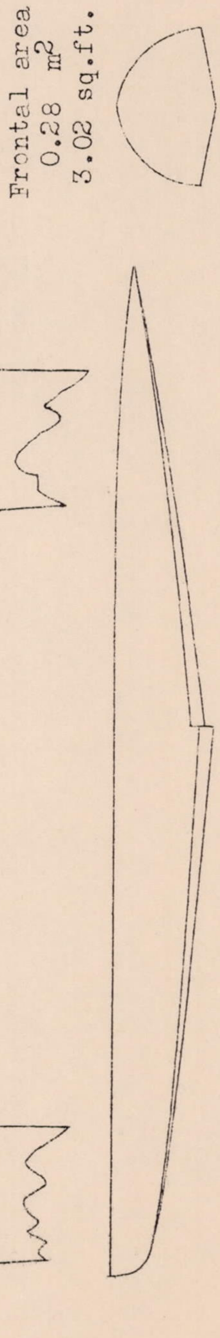


P.c. 2

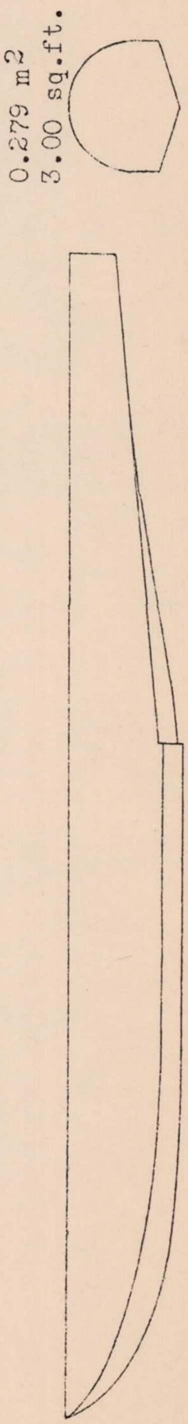
Fig. 10



P.c. 3



P.c. 2



P.c. 3

Fig. 11

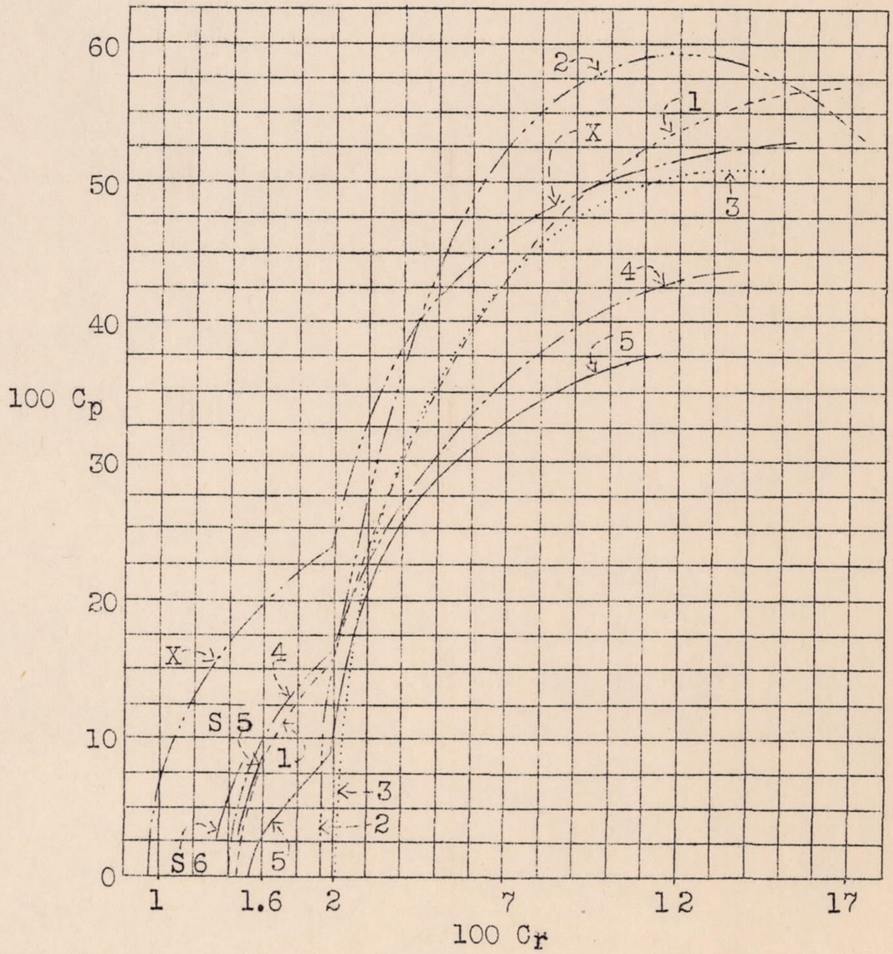


Fig. 12

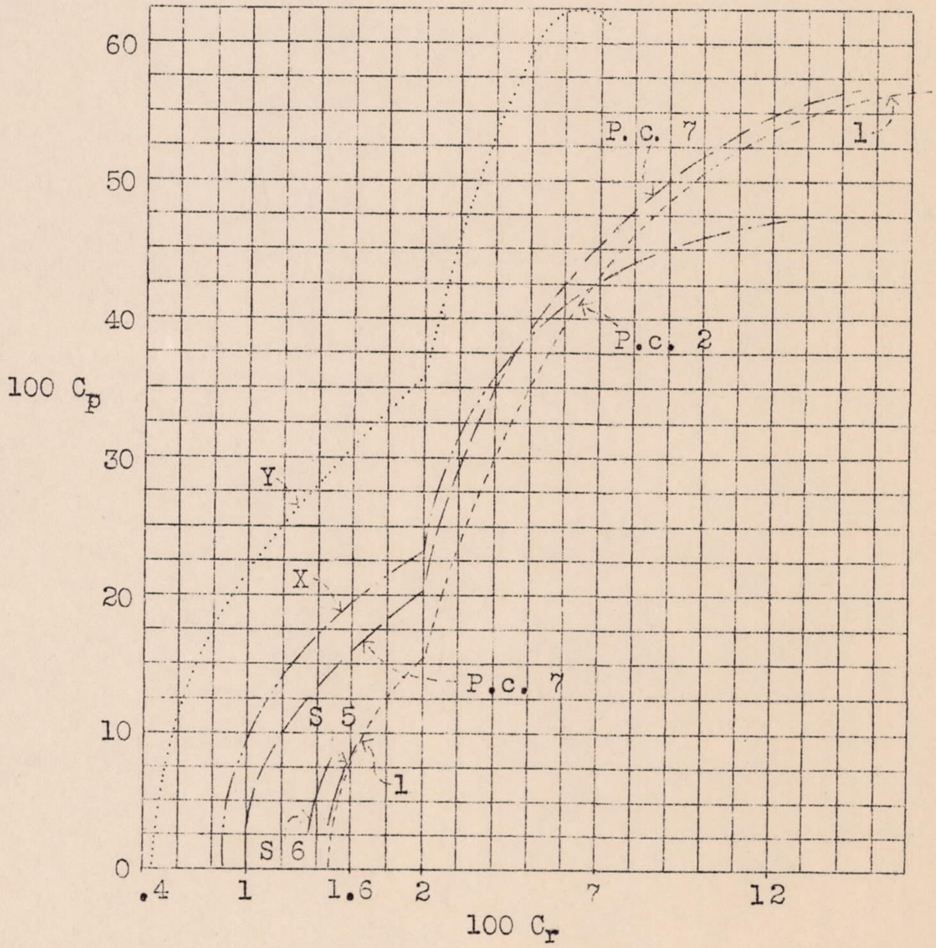


Fig. 13

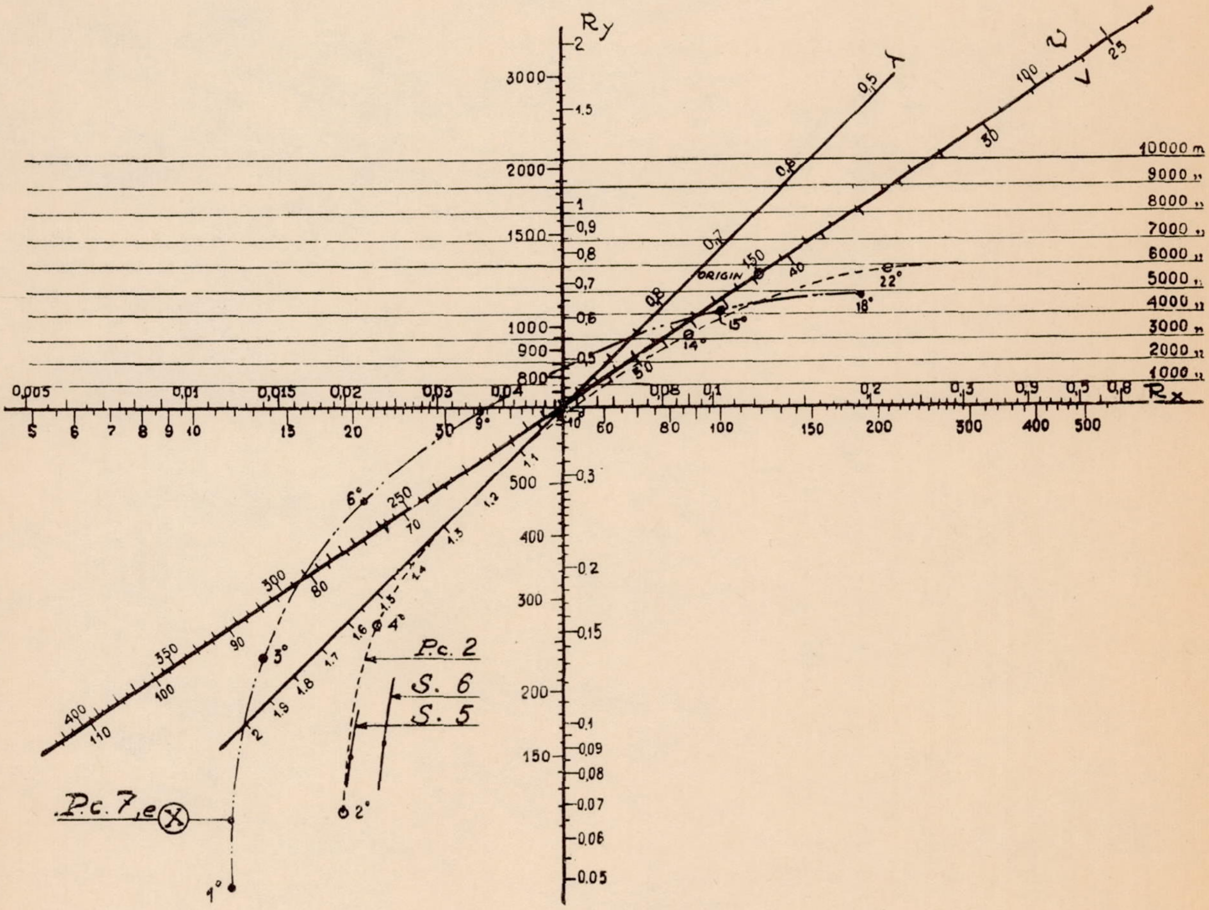
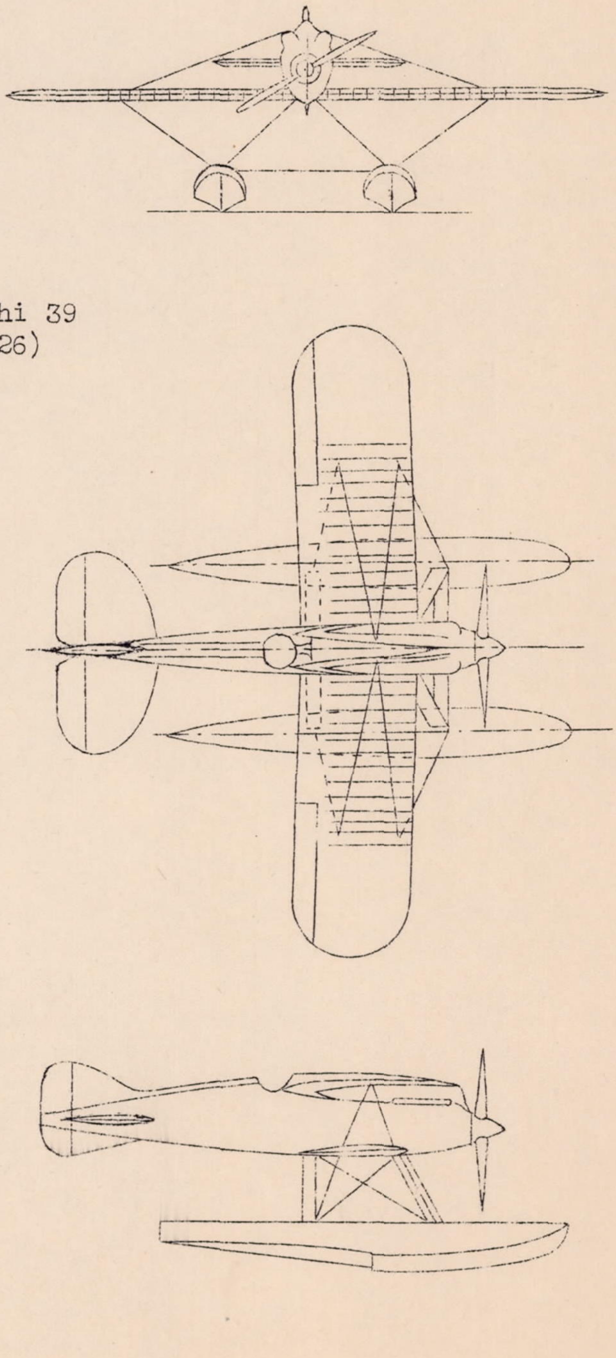

Ry
Rx
10000 m
9000 "
8000 "
7000 "
6000 "
5000 "
4000 "
3000 "
2000 "
1000 "
ORIGIN
P.c. 2
S. 6
S. 5
P.c. 7, e ⊗
1°
2°
3°
4°
6°
9°
14°
15°
18°
22°

Fig.14



Macchi 39
(1926)

Fig. 17

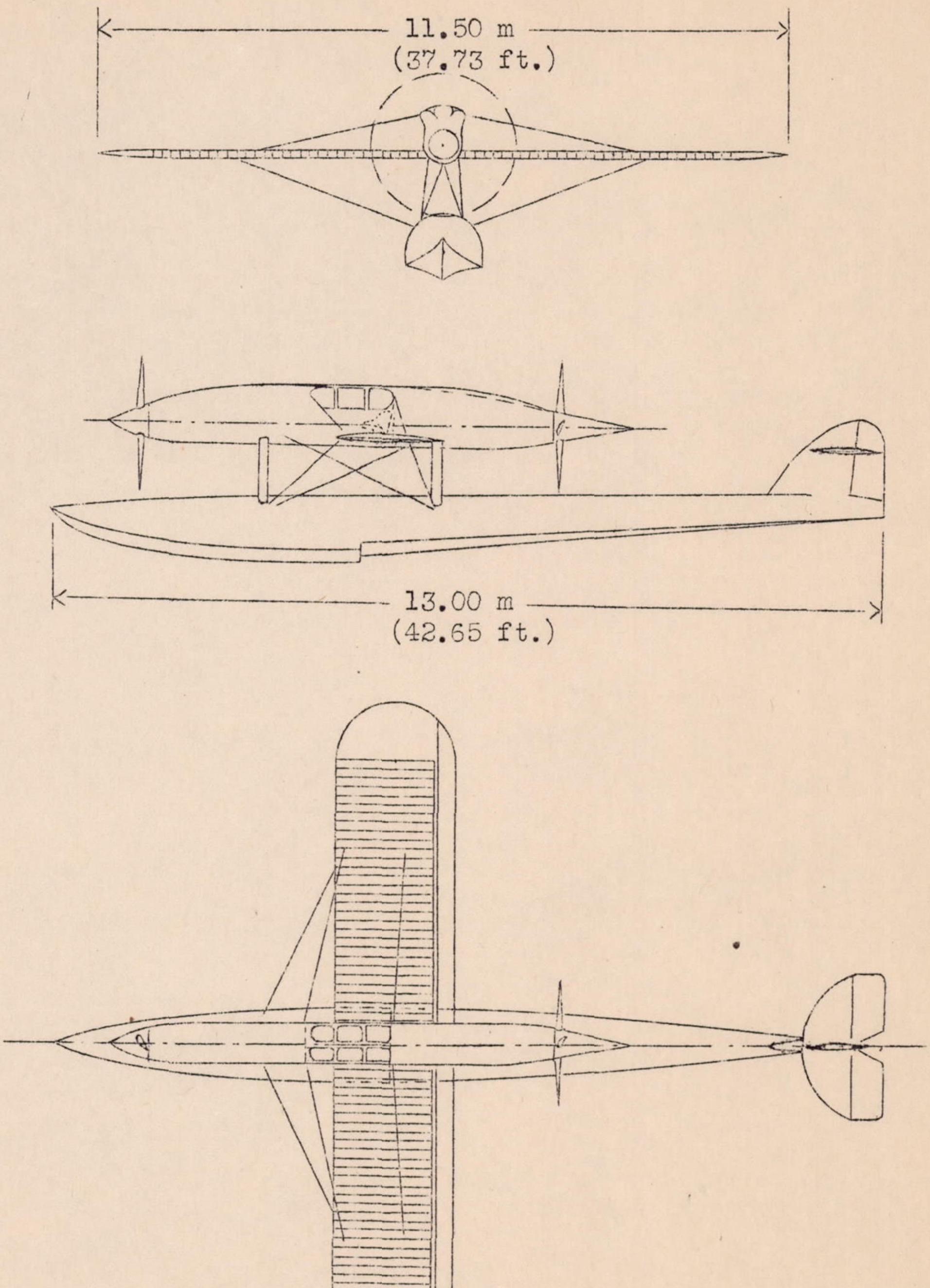


Fig. 18

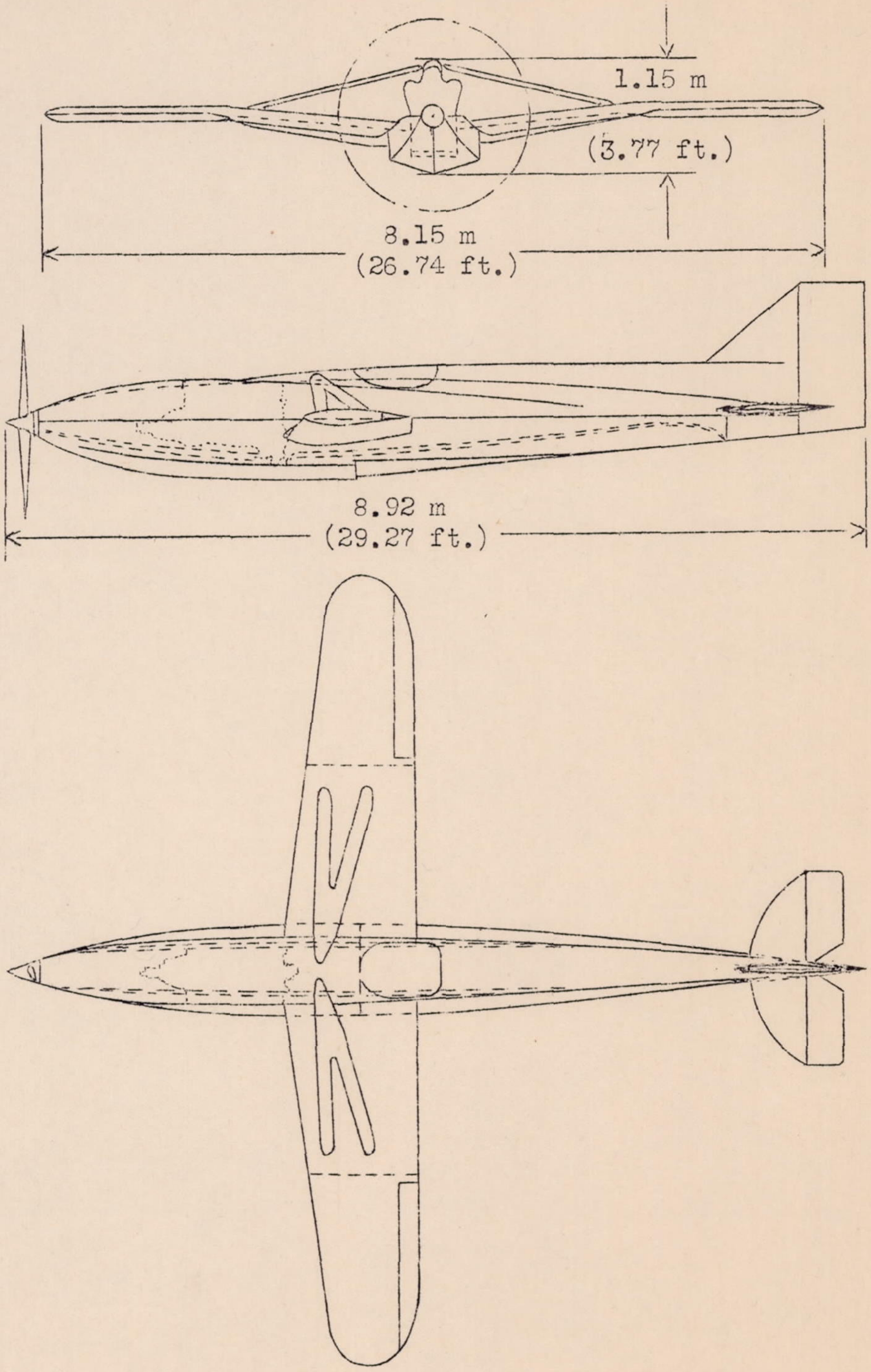


Fig. 19

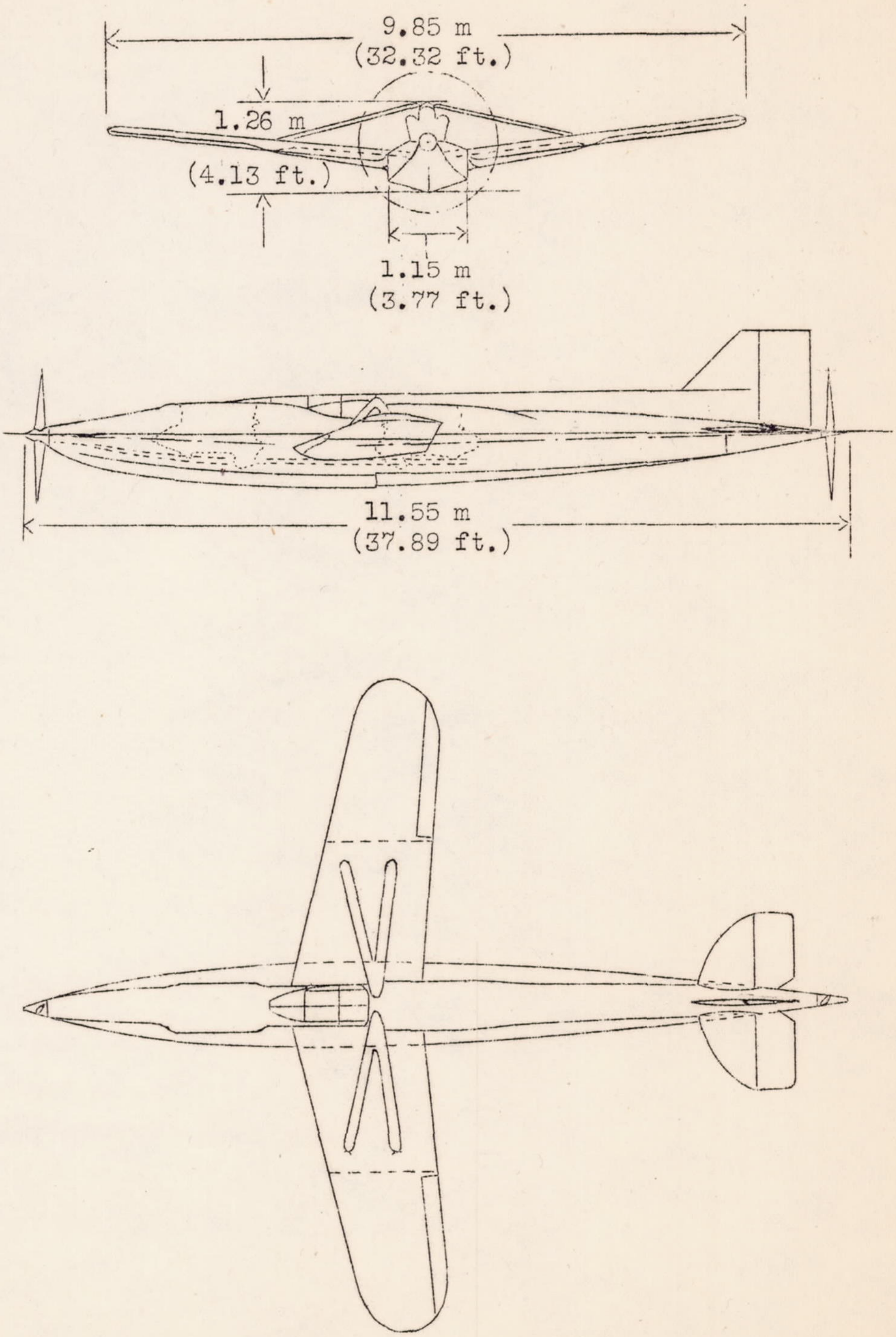


Fig. 20

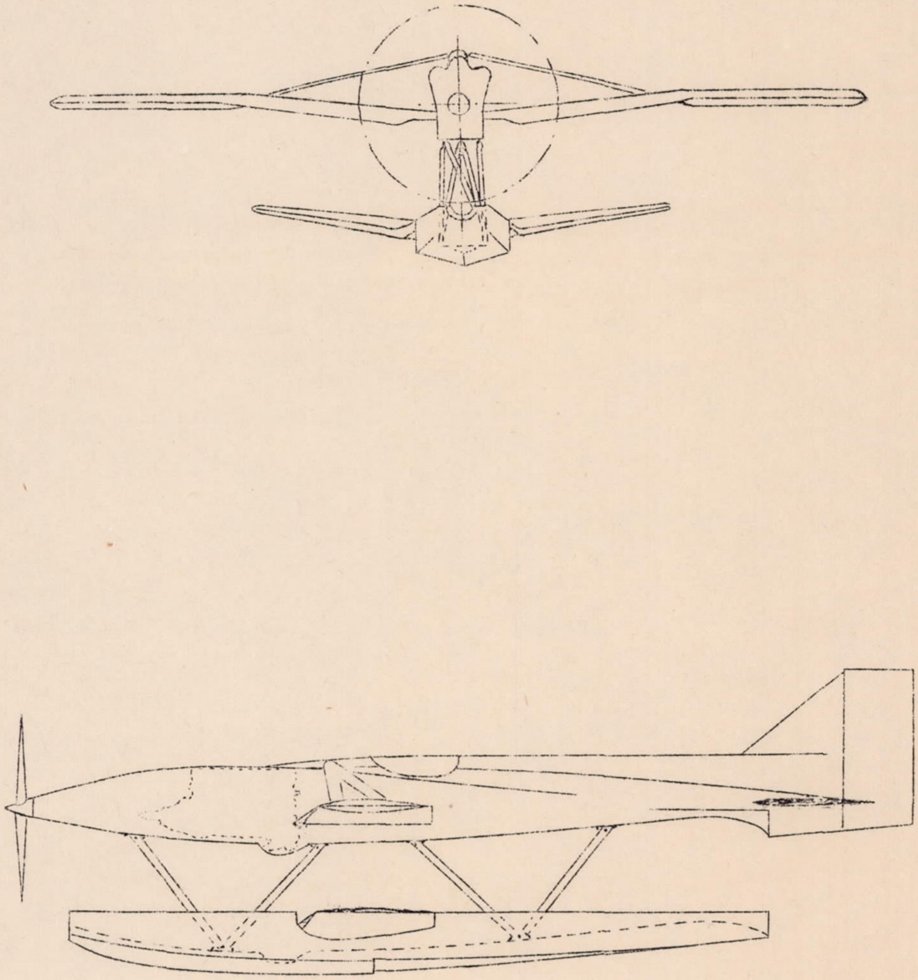


Fig. 21

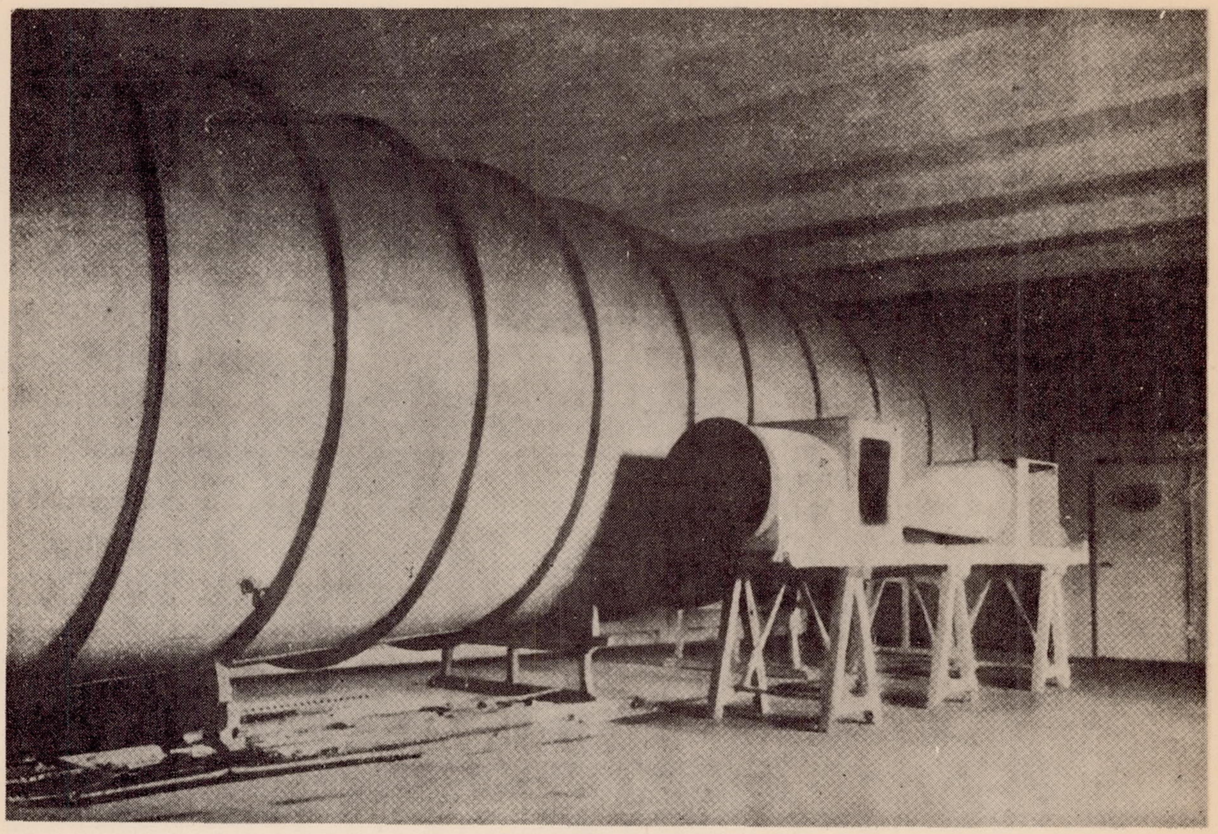


Fig.22

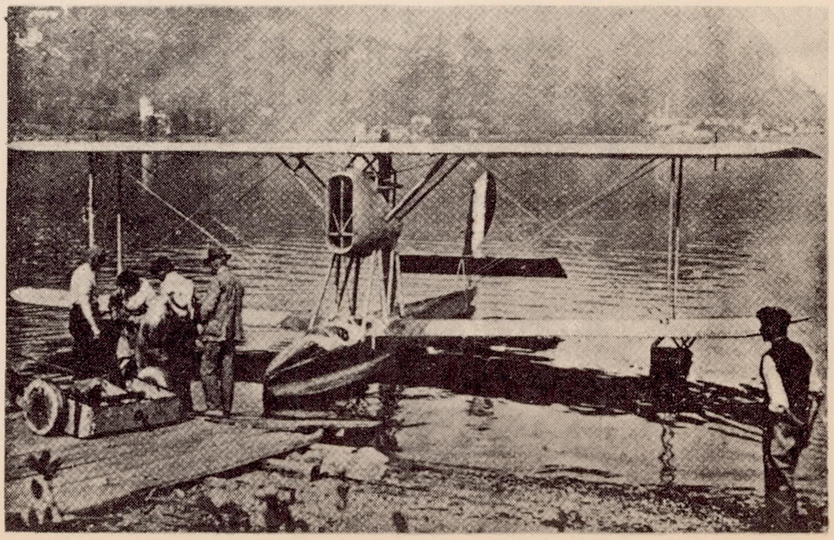


Fig.32

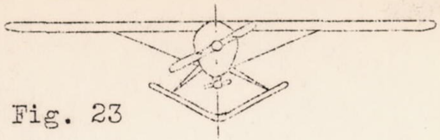


Fig. 23

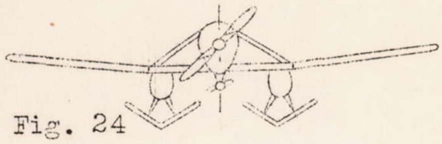


Fig. 24

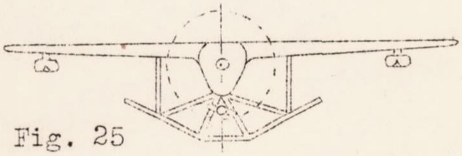


Fig. 25

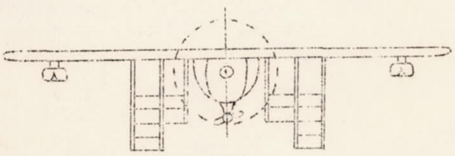


Fig. 26

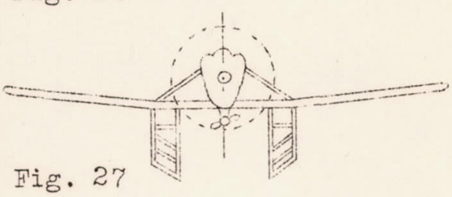


Fig. 27

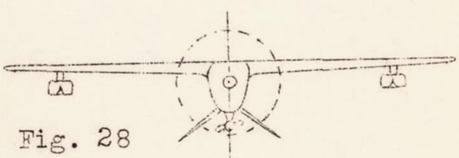


Fig. 28

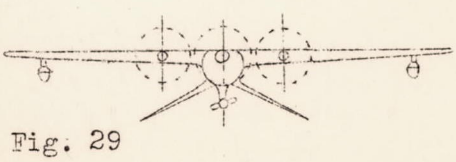


Fig. 29

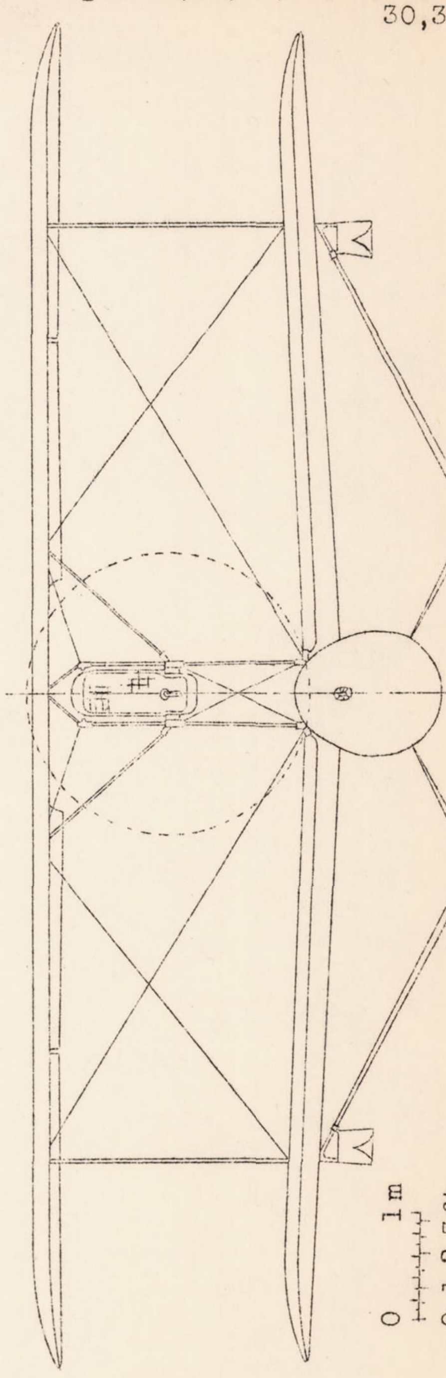


Fig. 31

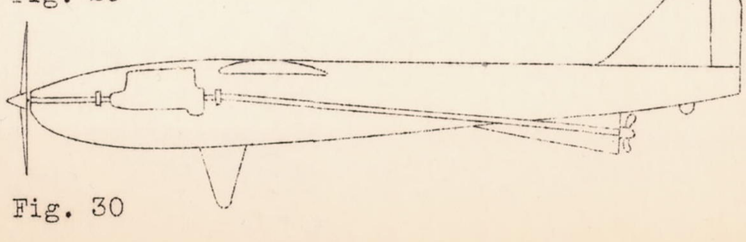


Fig. 30


N.1
N.2
N.3
N.4
N.5
N.6
Fig.33

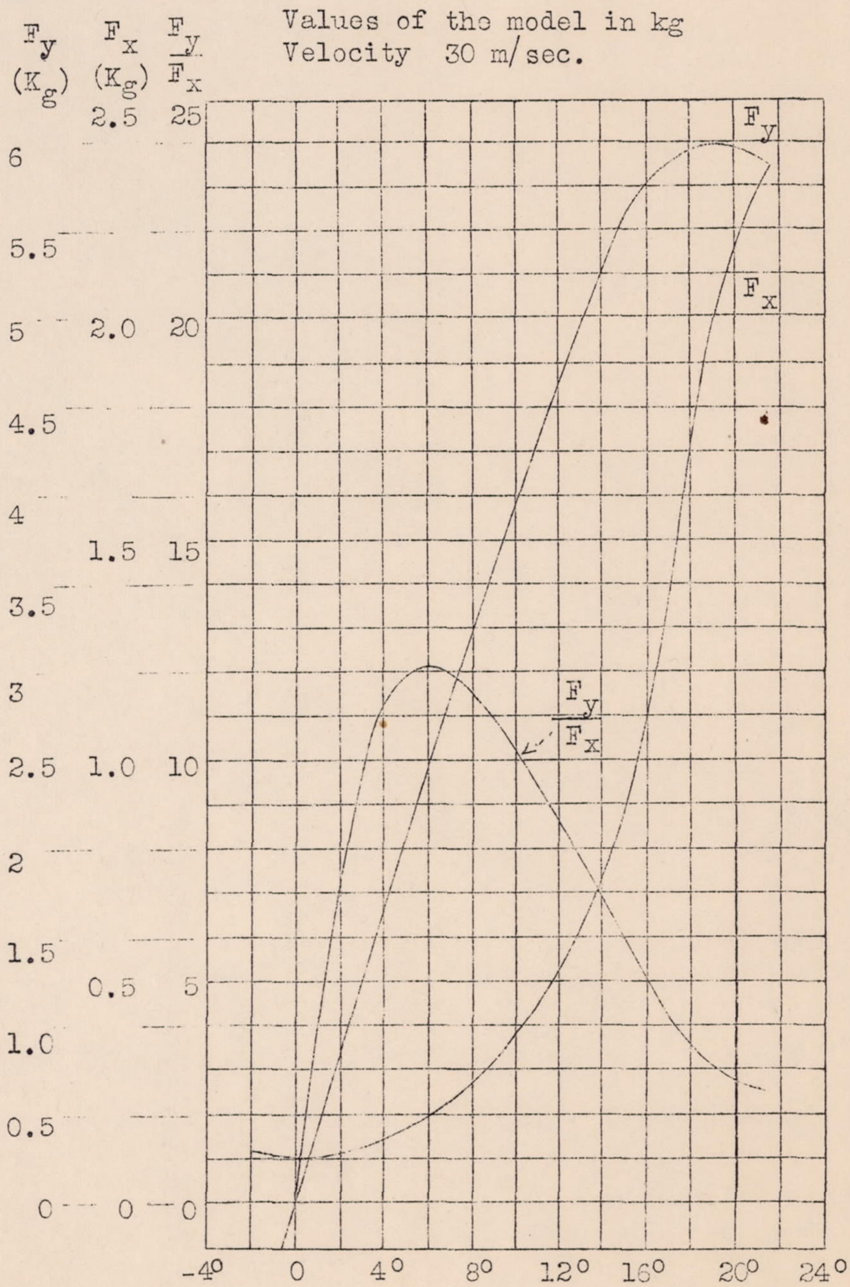


Fig. 34 Monoplane X

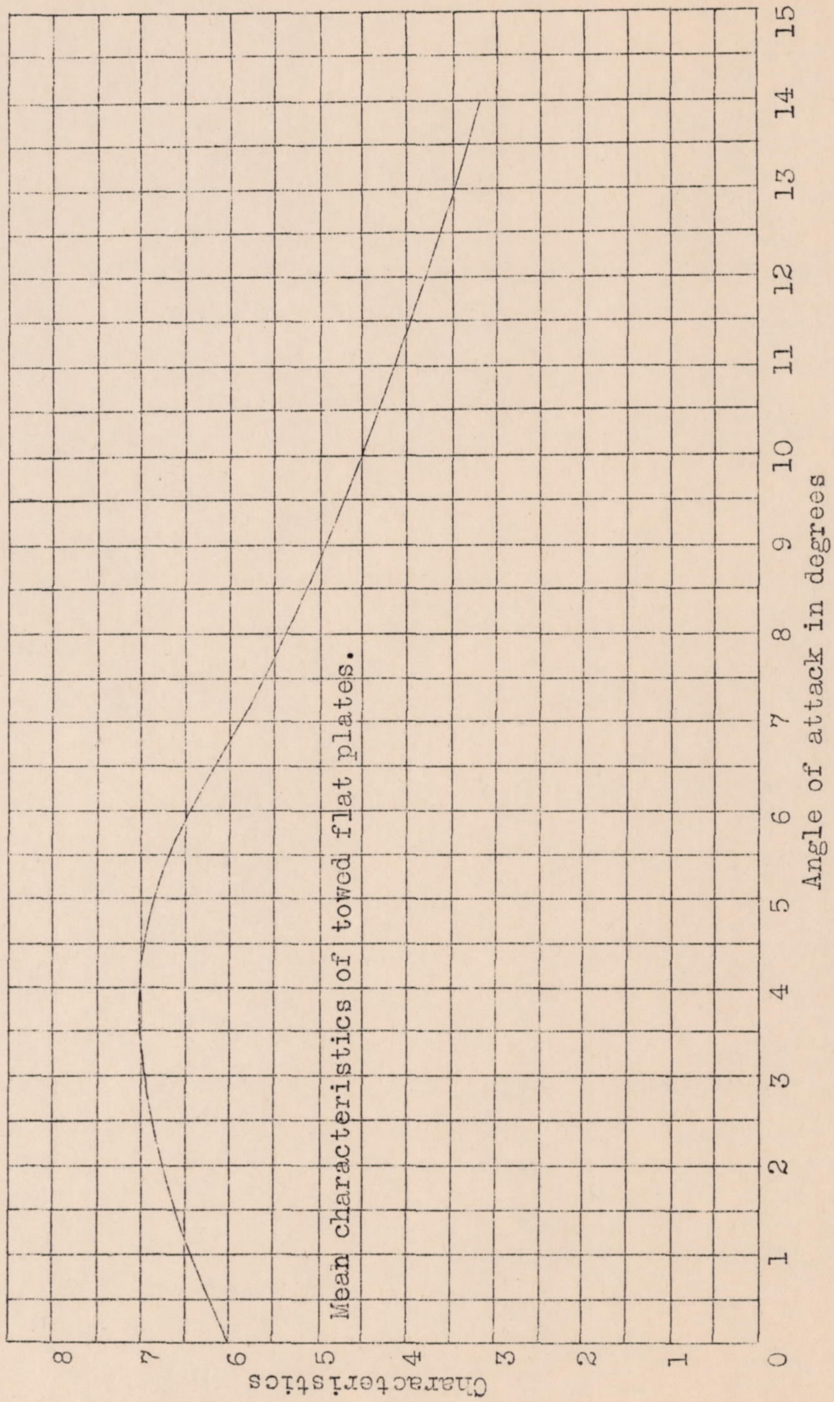

Mean characteristics of towed flat plates.
Characteristics
0
1
2
3
4
5
6
7
8
Angle of attack in degrees
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Fig. 35

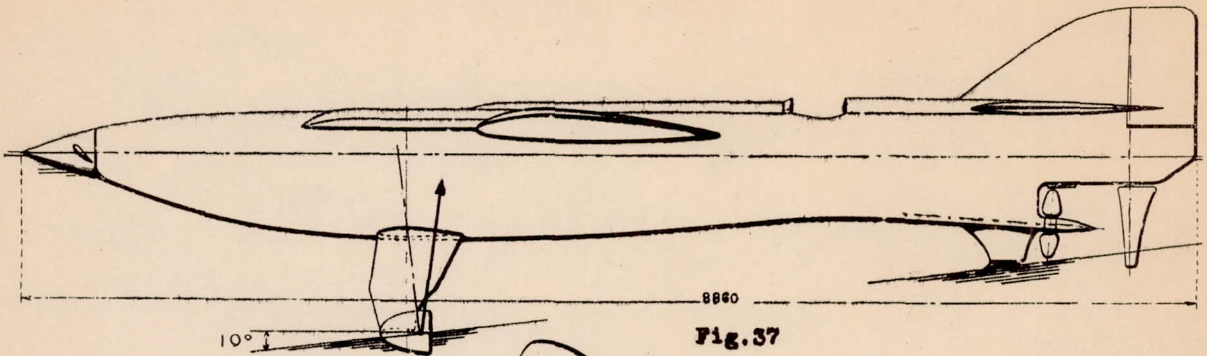
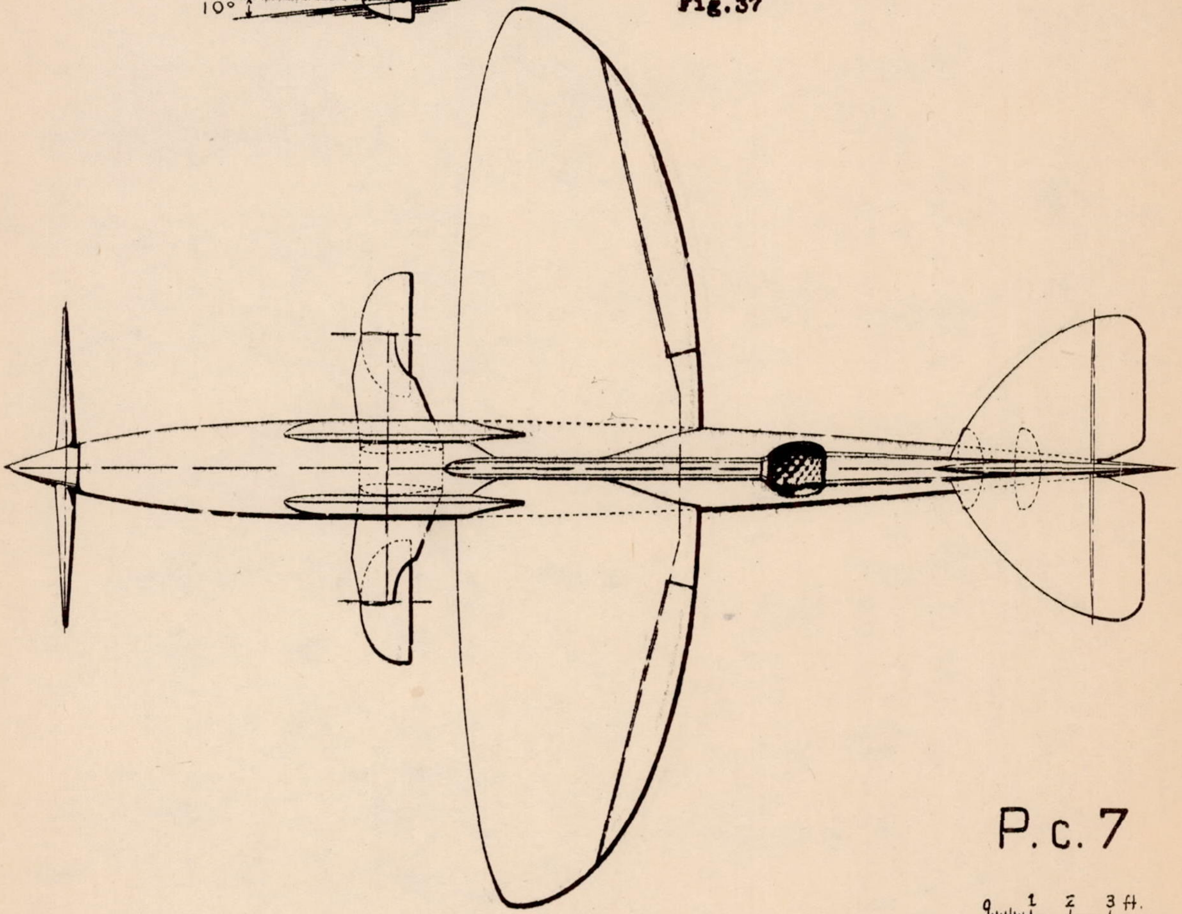


Fig.37



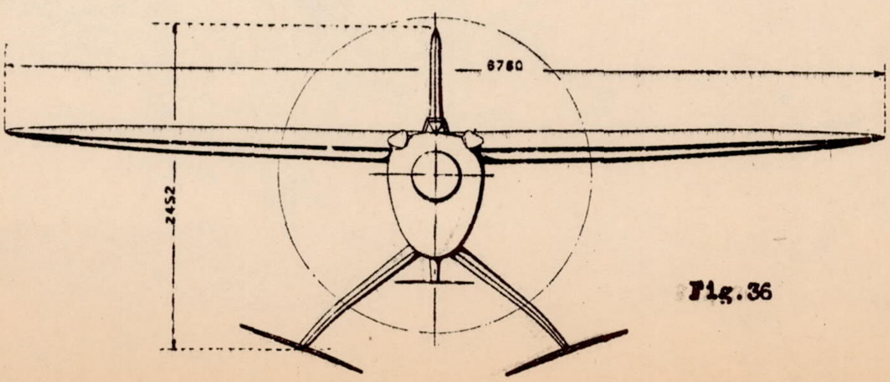
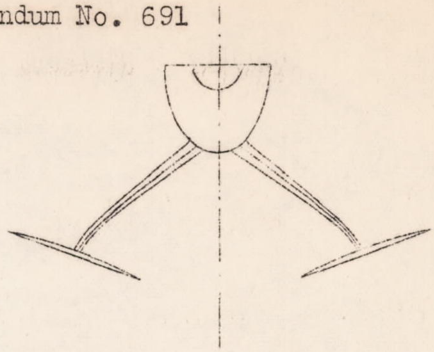


Fig.36



Scale of model 1:10 Weight of model 1.5 kg(3.3 lb)

1 Thrust of air propeller per 1000 hp. reduced to scale of model
2 Thrust of water propeller per 300 hp.reduced to scale of model
3 Towing resistance of complete model

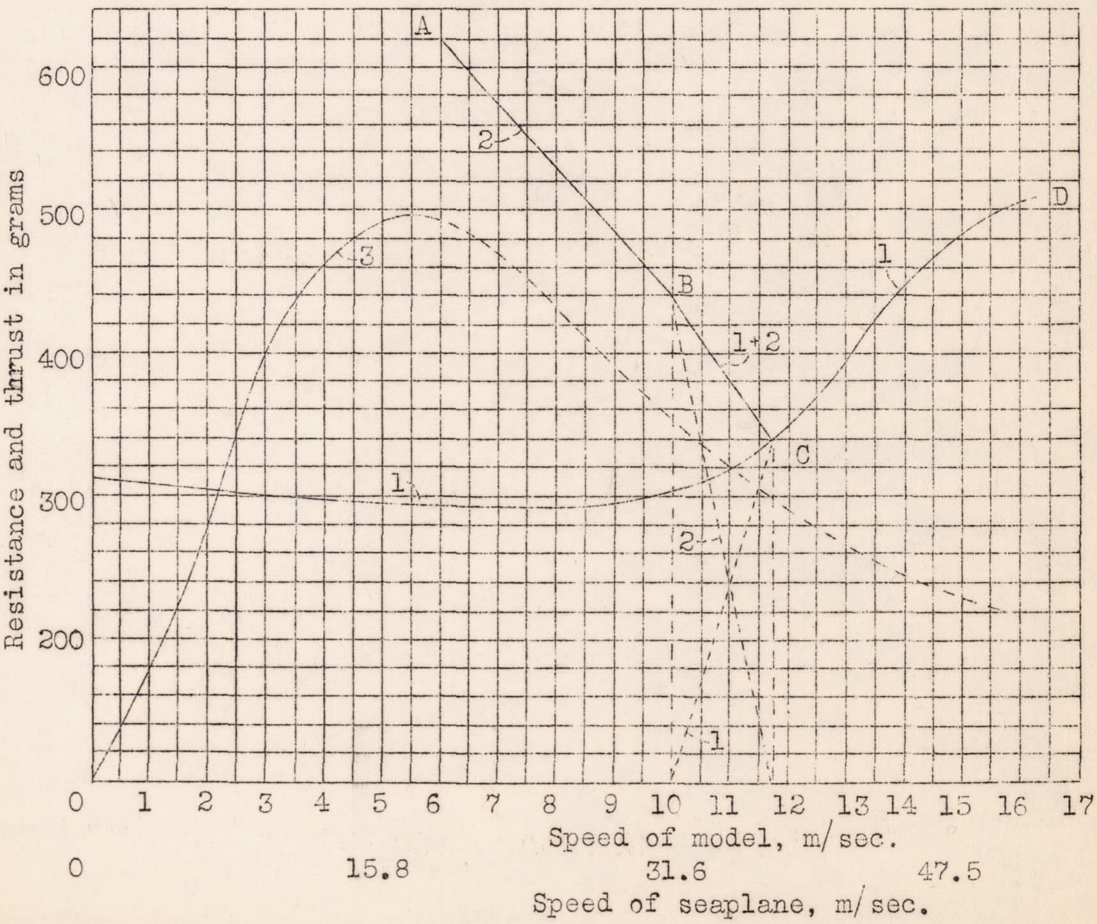
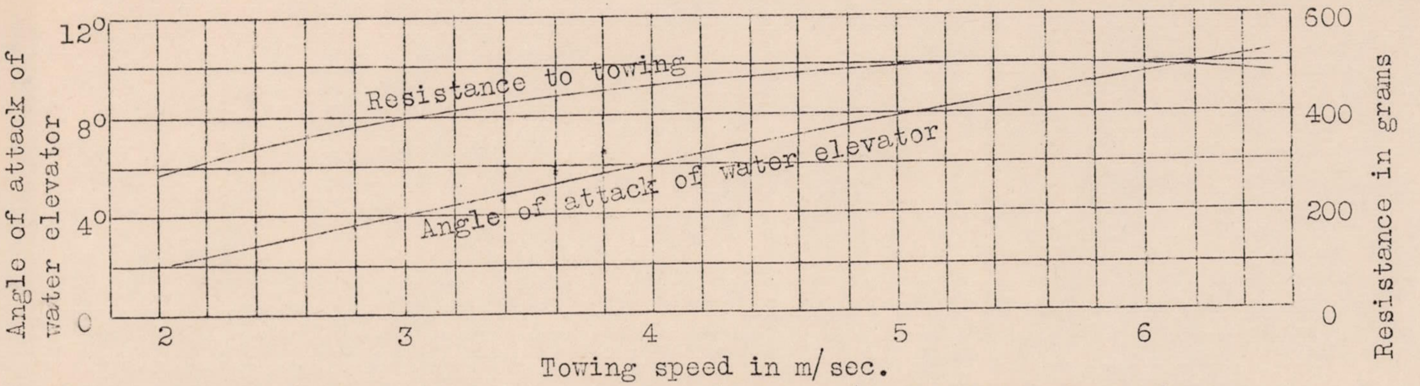
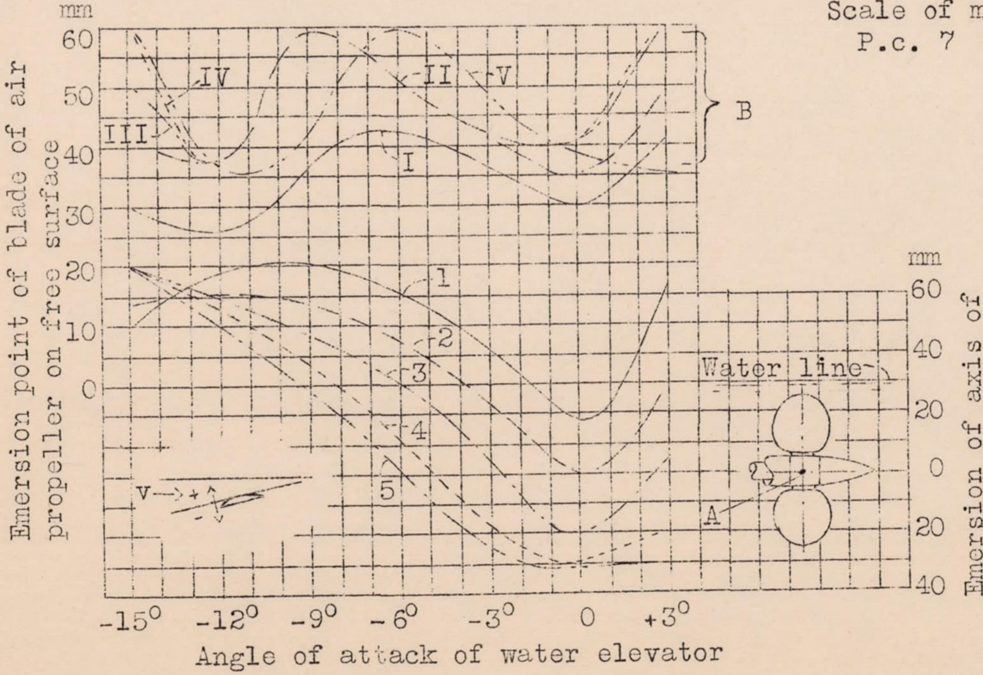


Fig. 38 P.c.7 Take-off diagrams



Water propeller with axis at 30 mm (1.18 in.) of initial immersion
Scale of model 1:10, Weight of model 1.5 kg
P.c. 7 Tank tests of complete model
Fig. 39



Positions of point A of water propeller with water elevator at various angles of attack
1. v = m/sec. 2
2. v = m/sec. 3
3. v = m/sec. 4
4. v = m/sec. 5
5. v = m/sec. 6

Emersion point of blade of air propeller
I. v = m/sec. 2
II. v = m/sec. 3
III. v = m/sec. 4
IV. v = m/sec. 5
V. v = m/sec. 6

Fig. 40 Determination of trim on model of 1:10 scale. Weight of model 1.5 kg

P.c. 7
1. Without horizontal empennage
2. Empennage + 0.25°
3. Empennage + 0.25°
4. Empennage + 4.20°
5. Empennage - 5.10°

N.B.
The moment coefficients are referred to the axis of moments. The zone relative to the fuselage is not considered in values of wing area and span.

Values of $C_m . C_p$ and $C_r . C_p$
Center of gravity coordinates

$$\frac{X_g}{l'_m} = 0.1585$$

$$\frac{Y_g}{l'_m} = 0.2$$

$l'm = 1.45$ m (full size)

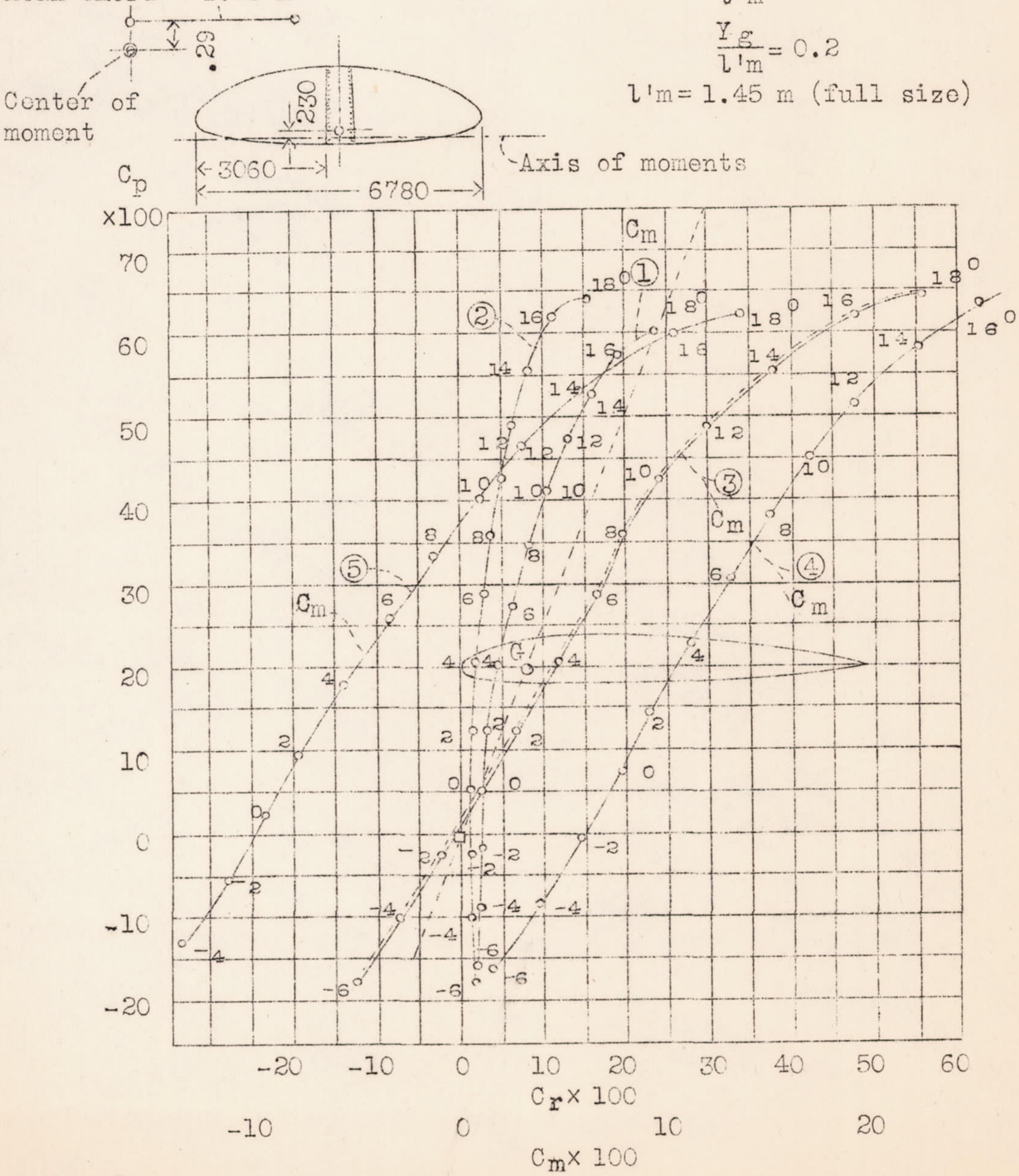


Fig. 41

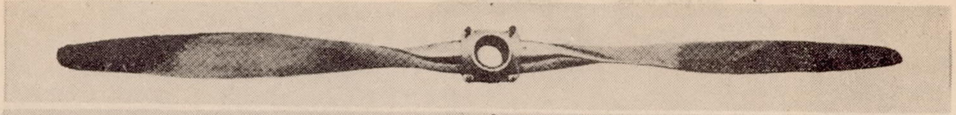


Fig.42

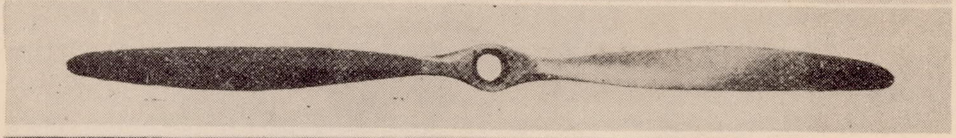


Fig.43

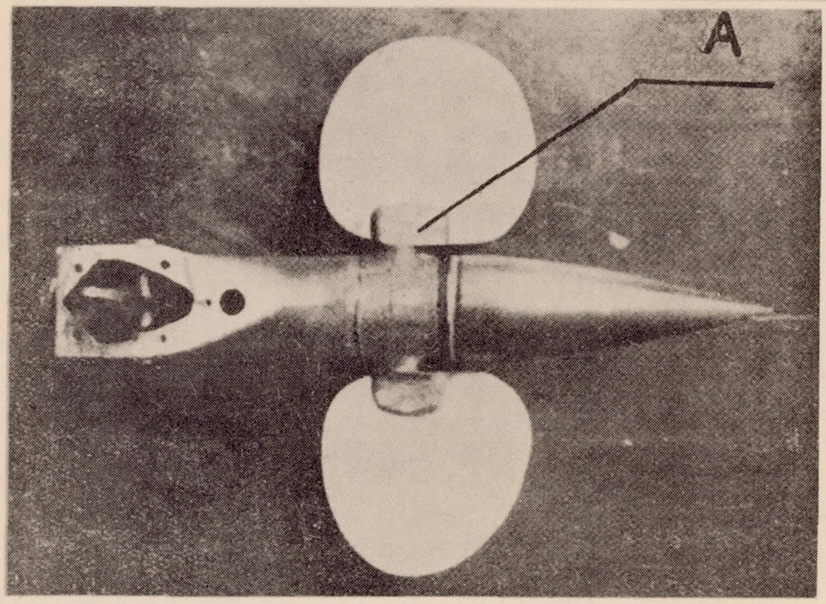


Fig.44

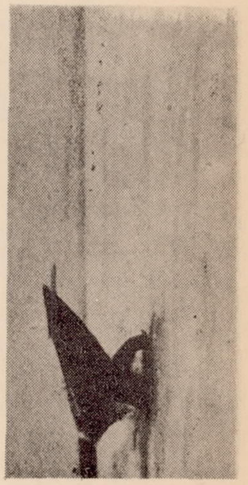


Fig.49

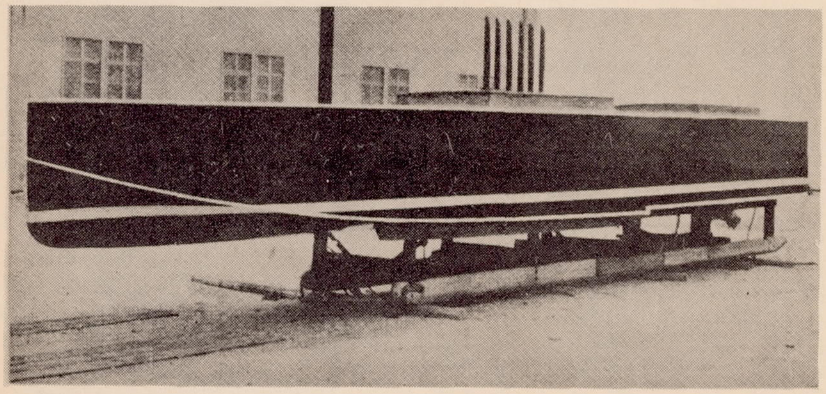


Fig.45

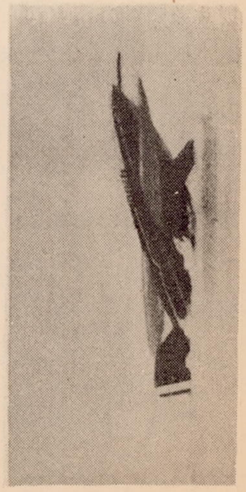
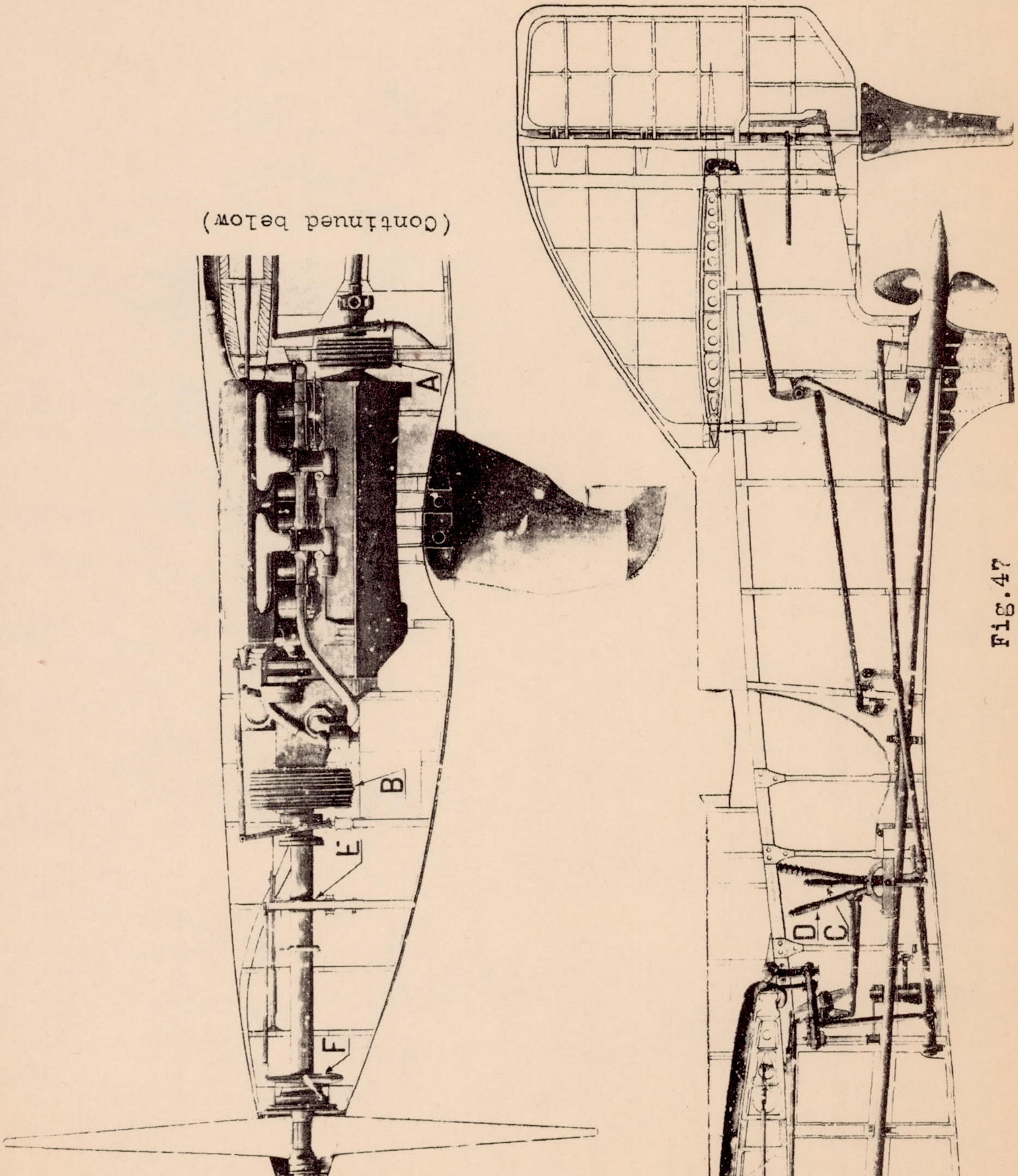


Fig.48


Fig.46


(Continued below)
A
B
E
F
D
C
Fig.47

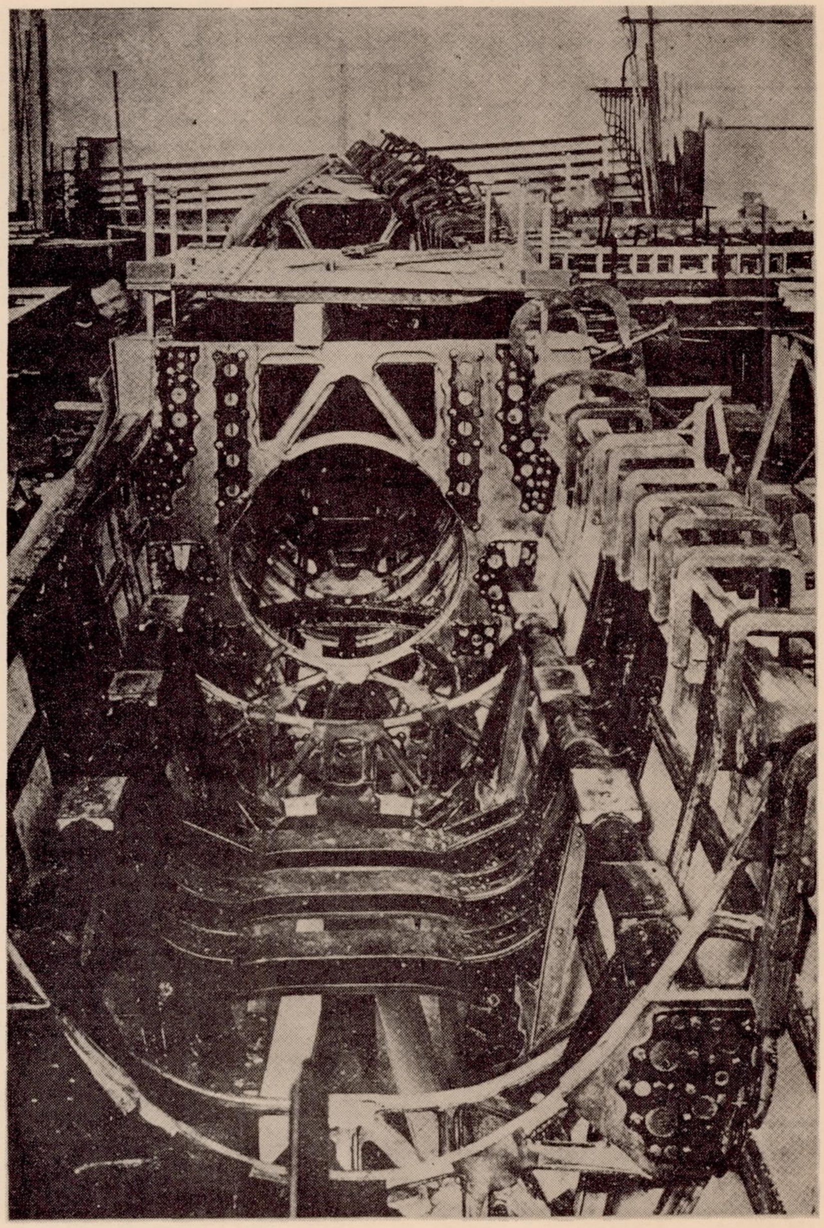


Fig.50

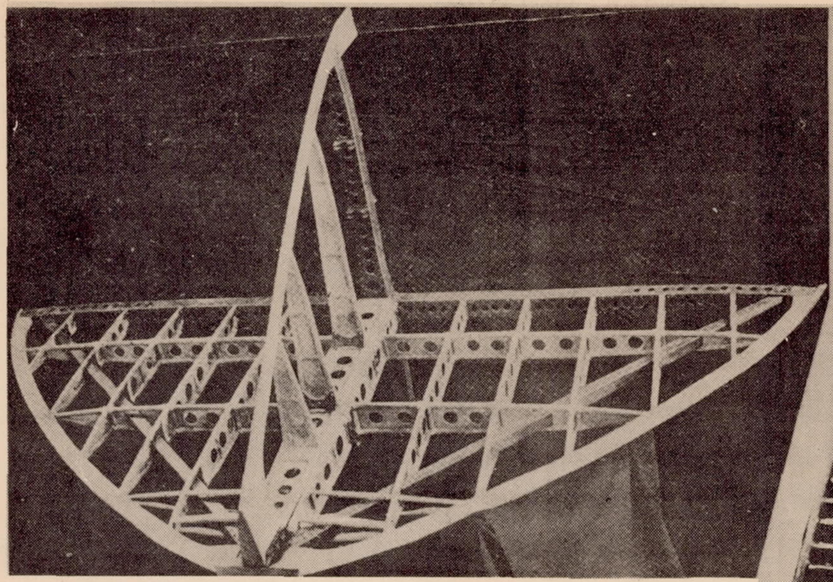


Fig.51

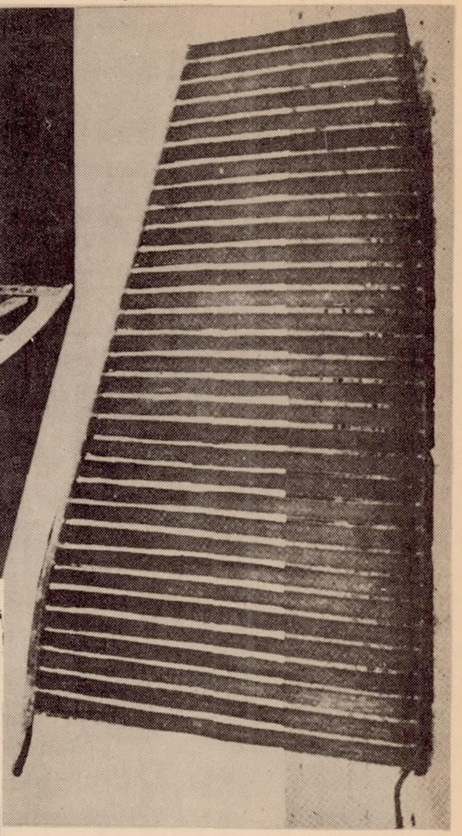


Fig.56

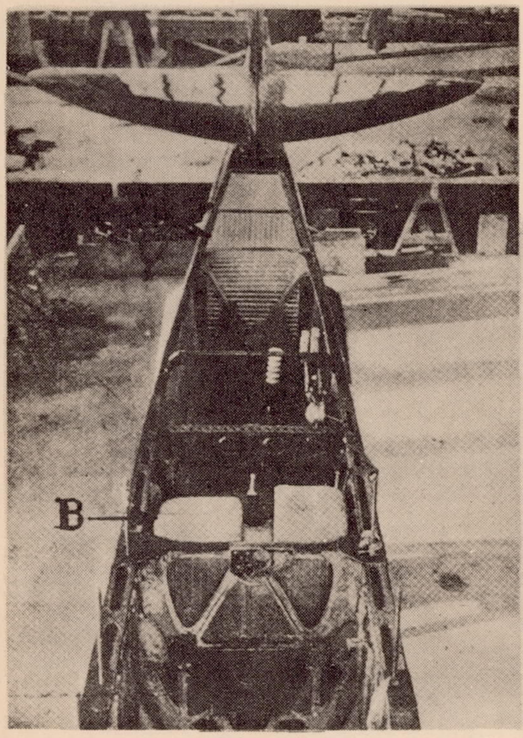


Fig.52

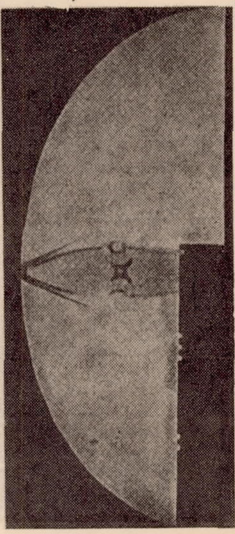


Fig.58

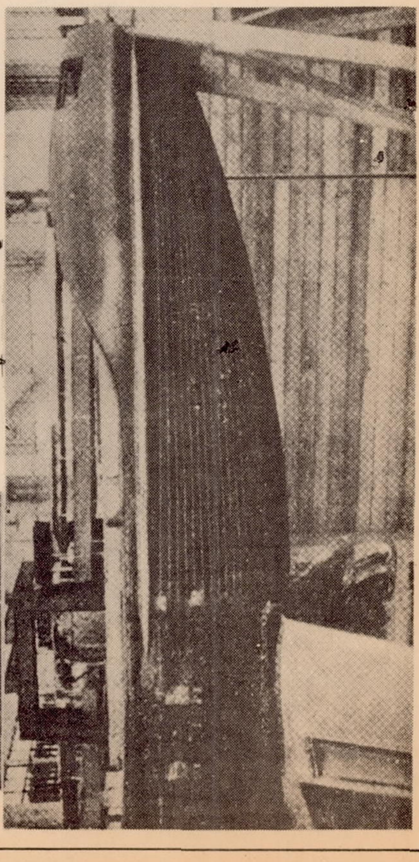


Fig.57

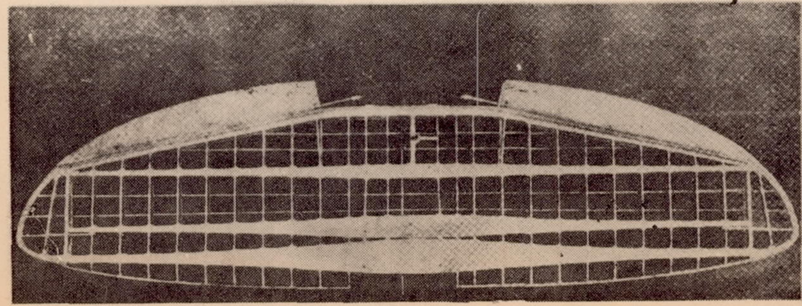
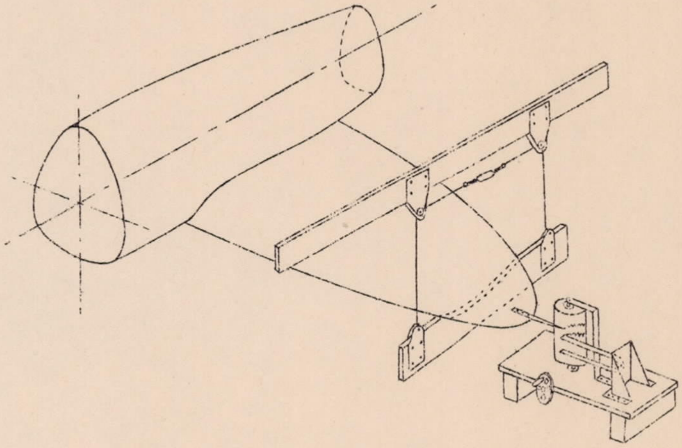


Fig.53



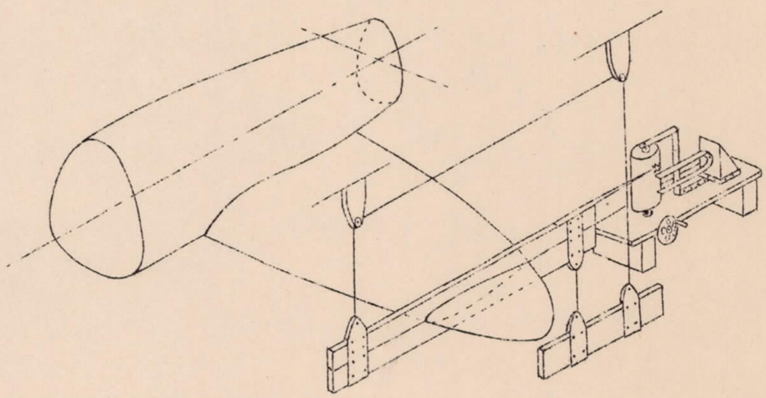
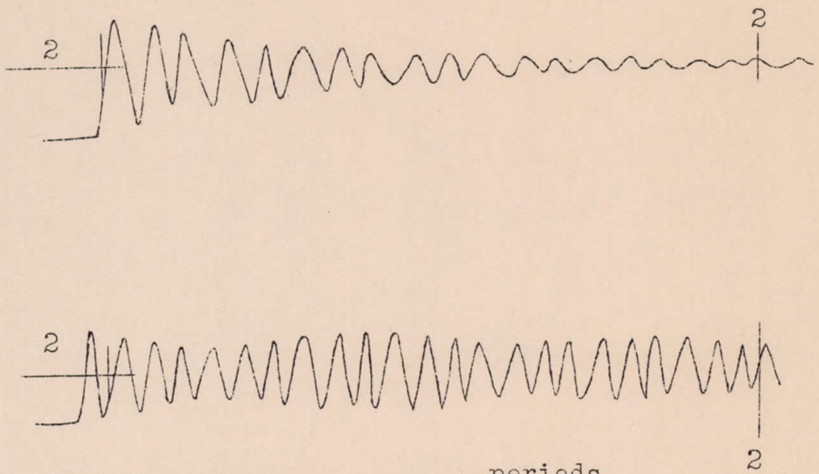
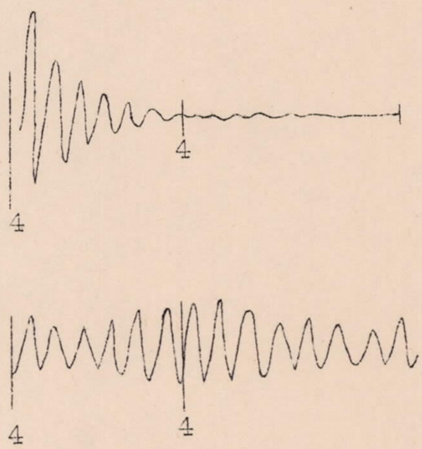


Fig.54



Tuning fork 17.1 $\frac{\text{periods}}{\text{second}}$

Torsional vibrations. Wing frequency 840 $\frac{\text{periods}}{\text{minute}}$.



Flexural vibrations. Wing frequency 1104 $\frac{\text{periods}}{\text{minute}}$.

Fig.55