California Institute of Technology
Pasadena, California

Class of 1924

Department of Aeronautics

SAIL-PLANE

Thesis of

Louis Kiesling

1924

On outside cover in gold.

The

California Institute of Technology.

Aerodynamical Laboratory

Sail-plane.

Built and designed by

Gerard F. Vultee.
Louis Kiesling.

Supervised by
Prof. A.A. Merrill.

Assisted by

Mr. A.W. Cloverie.

Pilot:
Mr. A.W. Cloverie.

Thesis Work of

Louis Kiesling.
Feb. 25 192

In the years 1920 to September 1922 a great stir of interest was caused by the unheard of successes of certain German soaring machines. For two years, because of the prohibiting by the Allies of large machines, their efforts had been directed to the design and perfection of light weight motorless ships. They held gliding meets in the Rhon Hills and established soaring and gliding records that by far surpassed anything that had ever been done before. These events incited interest in France and England and provoked certain students of one school in the United States, the Massachusetts Institute of Technology, of Boston, Mass., to build a glider which they subsequently entered in the French meet. At the same time this new spirit could not have failed to come west to California, and so we find two students of the California Institute of Technology endeavoring to put into practice some of the engineering principles and theory that they had acquired in the previous three years.

Our practical engineering experience was very meagre, and we had to rely greatly on common sense and the helpful suggestions of our competent advisers. Realising the great success of certain gliders in Germany, we naturally took these for models and in particular the ideas of the foremost German glider, the Hanover Vampyr, of that time. In doing this we were favored by having access to the published theory of the designer of this last machine. Our ship is not an imitation or replica of the Hanover, far from it, but it does embody the general aerodynamic features of this plane. In construction the two are entirely different and we can consider our constructional work as completely distinct, the design following the regular prescribed engineering processes and formulae. We were aided also by the fact that each part of the design must be a compromise or have the approval of all four of us, all different in temperament. Furthermore we all desired, and for financial reasons were forced to embrace, simplicity of design and constructional cheapness. We used standard aeroplane parts such as pulleys, horns, etc. wherever possible. Our small fund of practical building knowledge made it imperative, for safety reasons, to use simple straightforward designs. We were also limited in the way of wood and metal tools. We have friends in the Pasadena High School, Barnhardt Aircraft Company of Pasadena, Douglas Aircraft Company of Santa Monica, and our school authorities to thank for their unlimited advice and material aid. Above all are we grateful to Mr. Merrill and Mr. Claverie in their unceasing enthusiasm and aid in the consummation of this work. Mr. Merrill helped us with our engineering difficulties and made the financing of our project possibbe. Mr. Claverie, with his long experience and deep knowledge, did all of the metal work, a not inconsiderable amount, and has piloted the final result of our efforts.

When judging or condemning this plane, bear in mind the relative lack of experience, age, shop facilities and above all the size of the project. We assert ourselves in saying that we would never have attempted the job if we had realized only in part the time, trouble, and effort required, but we are now sincerely glad that we stuck to it and put it over, good or bad.

Most of our work and all assembling and model research was done in the Aero Laboratory of the California Institute of Technology.

Photo. #1.

It has been mentioned that we were greatly governed by the precedence set by the German gliders and by imperative low cost, and by the lack of facilities. It must not be thought that safety of construction was endangered. Weight considerations were relegated to those of secondary importance. On the whole we were extremely conservative in everything, a very wise thing for our first attempt. Our materials were of class A, in fact, they conformed to government requirements. We used basswood plywood instead some of the more expensive kinds, but not at the expense of safety.

Our considerations lead us to first adopt the cantilever monoplane type of wing because of our own private penchants, and because of the general adoption of this type in foreign practice in gliders. We chose cantilever construction to eliminate all the parasitic drag we possibly could. The wing in relation to the fuselage is of parasol type with the cockpit in front of the leading edge of the wing. This affords excellent visibility to the pilot. The monoplane or biplane polemic has arguments for and against each, and no absolute basis of decision has yet been evolved, hence our choice.

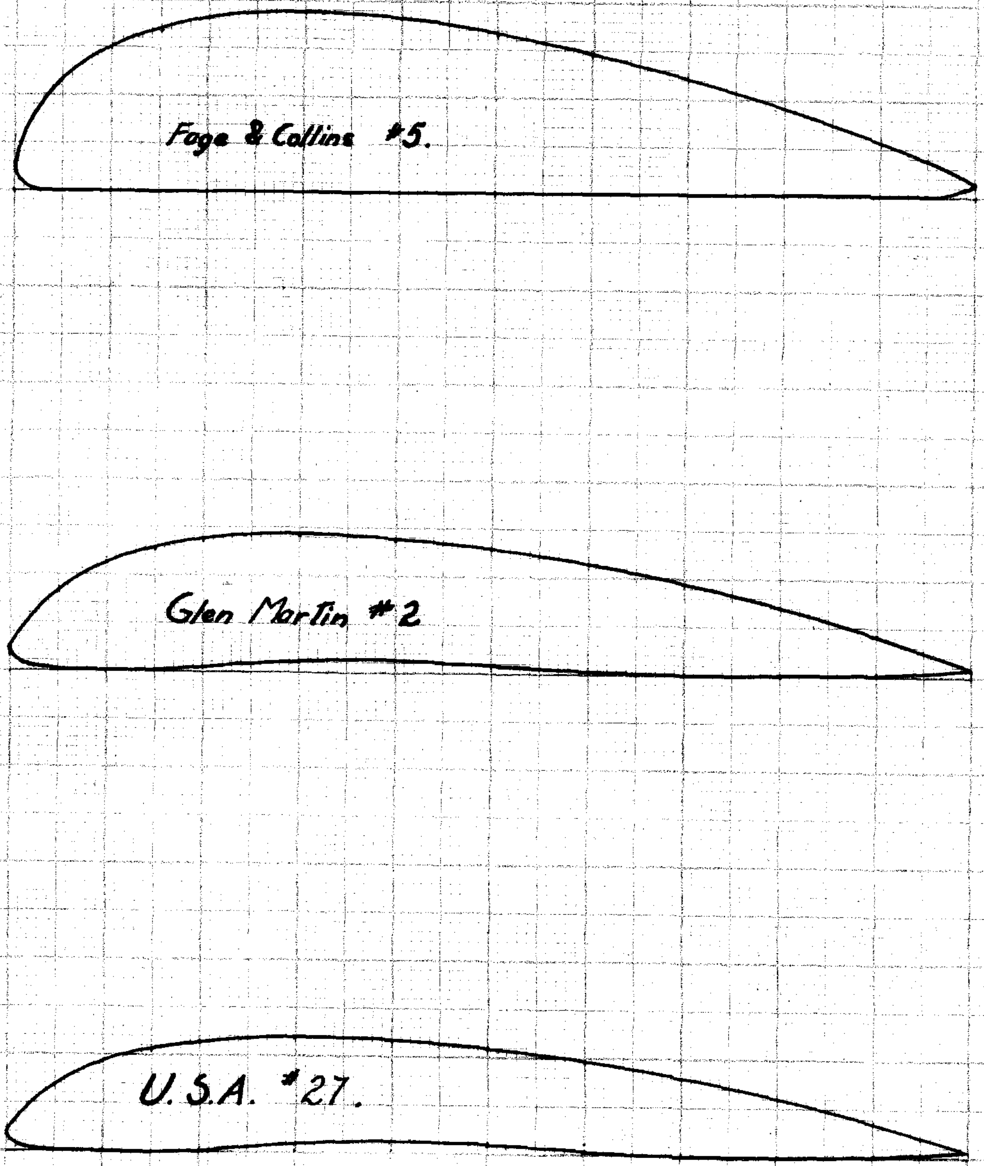
The landing gear of the Hanover was unique but had several disadvantages. We first decided to have skids, made out of hickory. This would have lifted the fuselage away from the ground and thus avoided contact with stones and brush. It would have been of easier construction than that of the Hanover. We ended by designing a wheel landing gear without a cross axle. This eliminated to a degree the chance of nosing over when landing in brush country. Again, the ship would be easier to launch and transport with wheels than with skids. We arranged to have our rubber shock absorber inside the fuselage, thus eliminating some parasitic drag. The skids were designed and made but we found it so hard to bend them into the double curve necessary that this difficulty precipitated us happily to a choice of wheels which we now think are very much better.

The salient feature that all soaring machines must have is quick maneuverability. This is obtained by having large control surfaces and small moments of inertia of the parts about the center of gravity. We followed the Hanover in having a short tail. We decided to have a small horizontal stabilizer and to have our elevator of twice its area. This combination was preferred to that of just the elevator alone as it would give a small inherently stable force and also the desirable effect of a large elevator. We made our fin and rudder after the design of the Hanover. The large fin would tend to nose the machine into the gusts of wind. Our rudder was slightly larger than that of the Hanover.

The new interest in gliders and small horsepower machines is the result of a desire to free the aeroplane industry from the inefficient methods of war machines. Small motorcycle engines could now be made use of. The lack of excess power would tend to lead to improvement along lines which were being neglected. Increased aerodynamical efficiency was the goal. Experiments by the Germans sought to the development of more efficient wings and lead in part to the cognizance of the thick high lift wing and it's improvement. The designer of the Hanover was first to emphasize the sinking velocity or rate of descent and to develope formulae concerning this. To soar means to sink more slowly than the wind rises, hence the great importance of a small minimum sinking velocity. Good gliding angle was of secondary importance in soaring. The new donditions of soaring make it imperative to teach pilots the necessary facts in relation to making use of gusts, rising currents of air, etc.

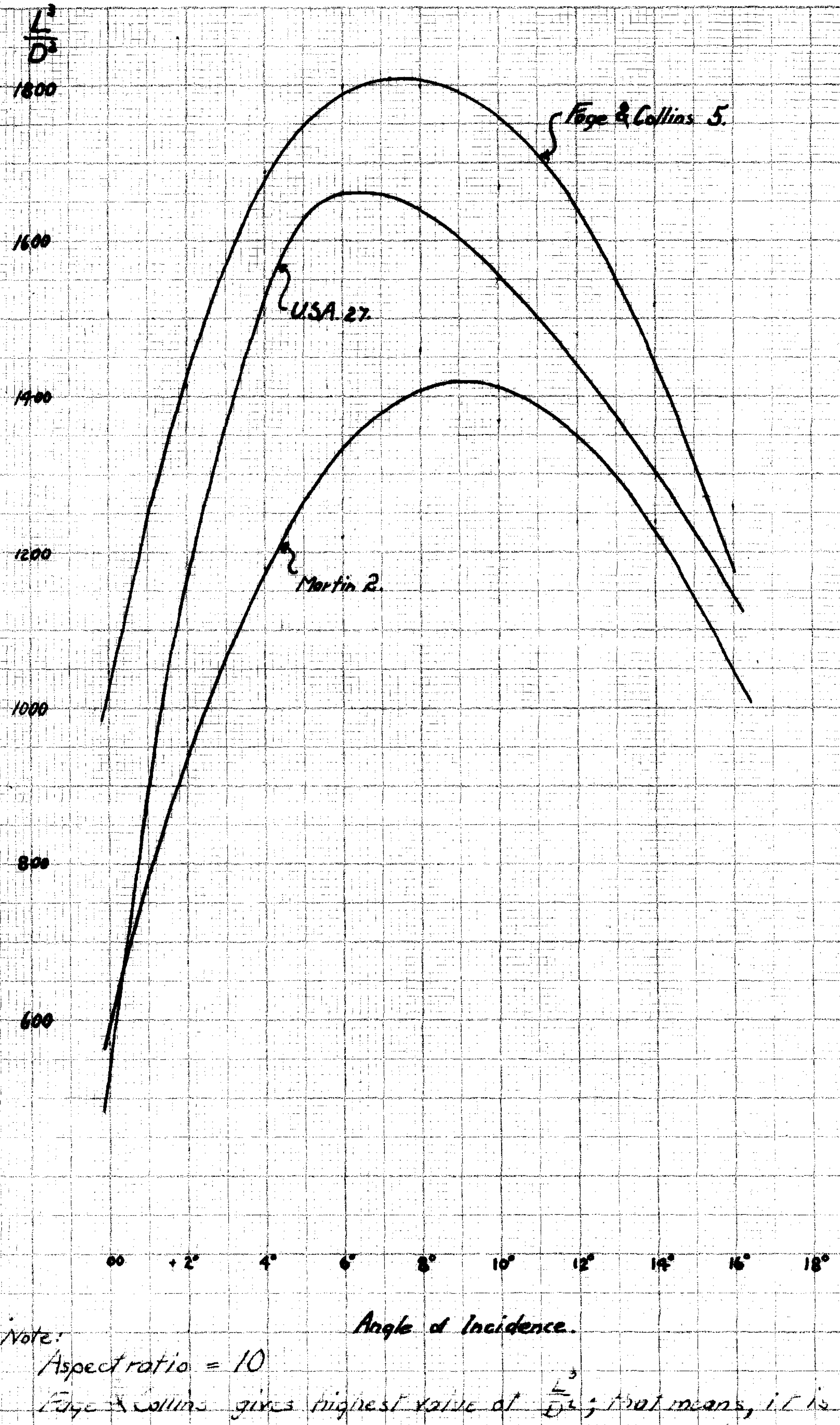
In our problem, which was very similar to that of the Hanover, we must find an aerofoil section which had a very deep camber, deep enough to make cantilever construction possible, and to allow an aspect ratio of at least 10. The section must have a high lift (K_L) coefficient, a good lift over drag $(\frac{L}{D})$ ratio, and primarily a large value for lift, cubed, over drag, squared. $(\frac{L^3}{D^2})$ The latter criterion is embraced in the factors for minimum sinking speed. The wing must have an area and wing loading low enough to permit a low landing speed, around 20-25 miles per hour. This must be attained to render landing and taking off easy. With a speed of 23 miles per hour and a lift coefficient of about .73 we obtained a loading of about 2.

Our weights were the next thing to assume. We calculated from these weights and the loading that an area of about 150 or 160 sq. ft. was necessary. In view of the above facts we then looked about for thick aerofoil sections and narrowed these down to a choice of one of three, namely, the U. S. A. 27, Martin #2, and Fage and Collins #5. We desired to get an aspect ratio of approximately 10, so our first task was to reduce the results of the reports from a basis of 6 to that of 10. The drag of a wing being divided into two parts, namely section and induced drag, with the section drag remaining equal for all aspect ratios, we computed the section drag, found the induced drag for aspect ratios of 10, added these two for total drag at 10, and then found values of $(\frac{L^3}{D^2})$ and $(\frac{L}{D})$ which are plotted on accompanying graphs. The change from 6 to 10 changes the drag enormously,



Fage & Collins is best for internal construction or cantilever design.

Fig. # I.

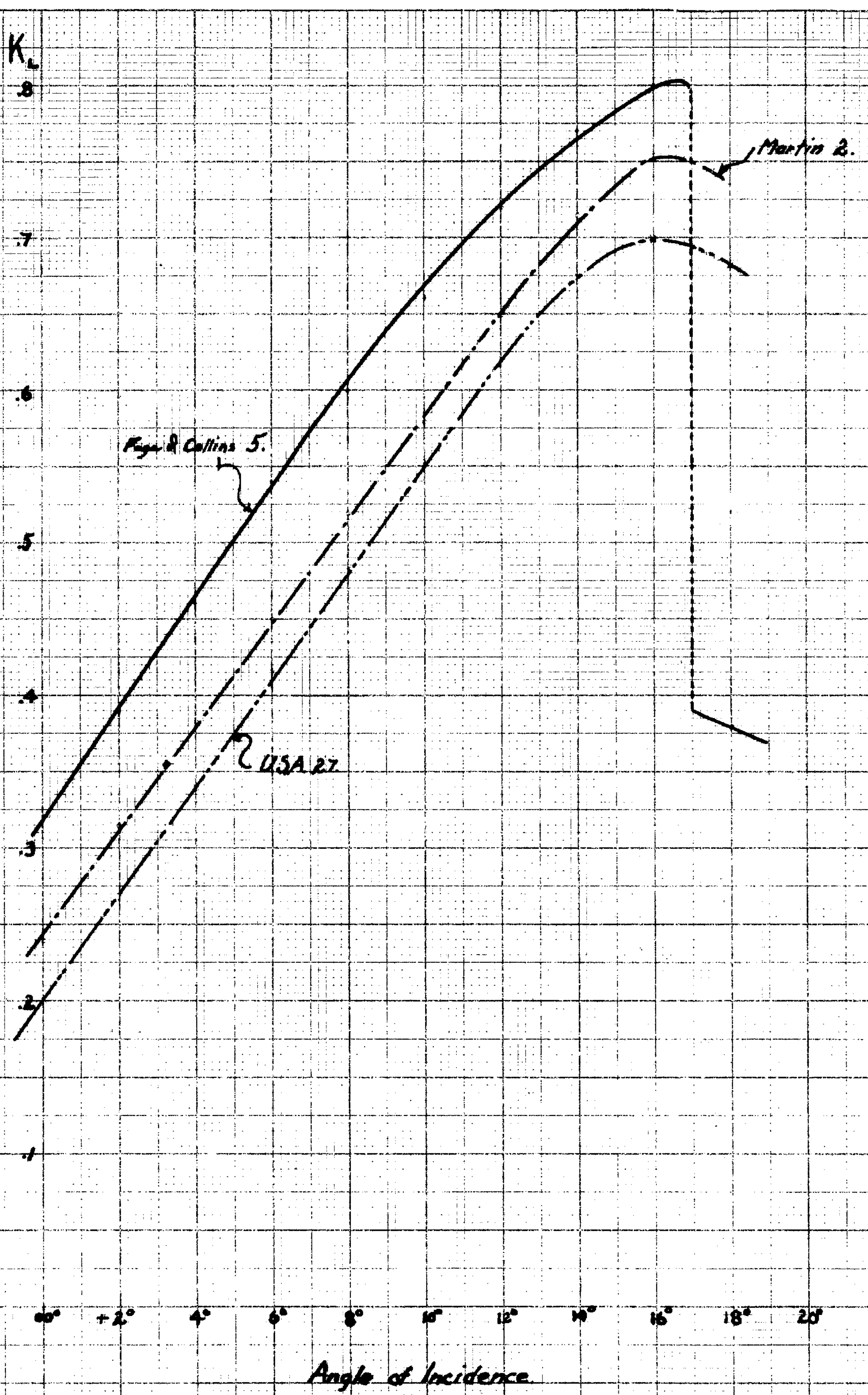


Note:

Aspect ratio = 10

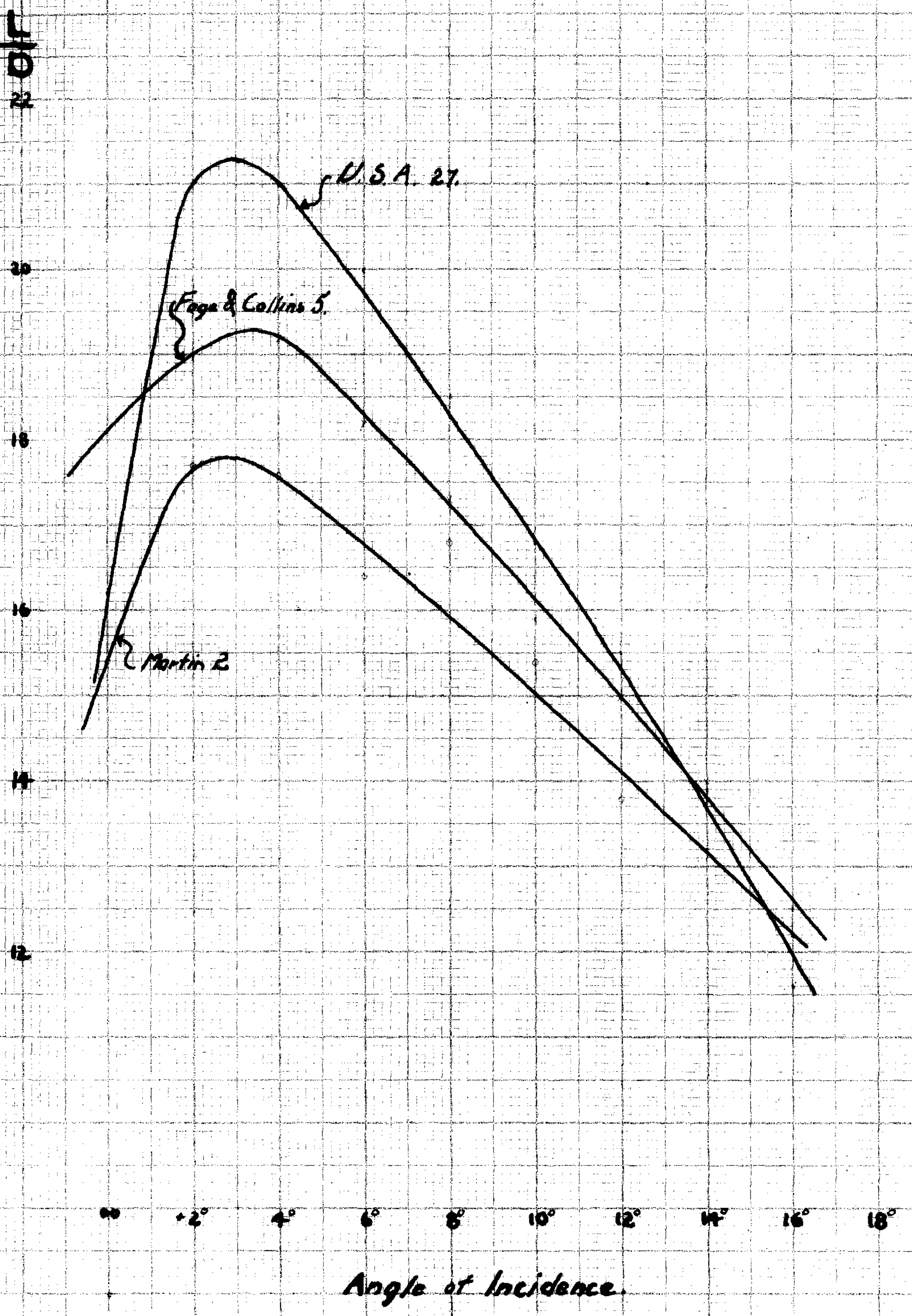
Fage & Collins gives highest value of $\frac{L^3}{D^3}$; that means, it is best for soaring flight.

Fig. # 2



Faye & Collins 5 gives highest lift coefficients

Fig. #3.



Note:

Fage & Collins - second largest value of $\frac{L}{D}$.

Aspect ratio = 10.

Fig. # 4.

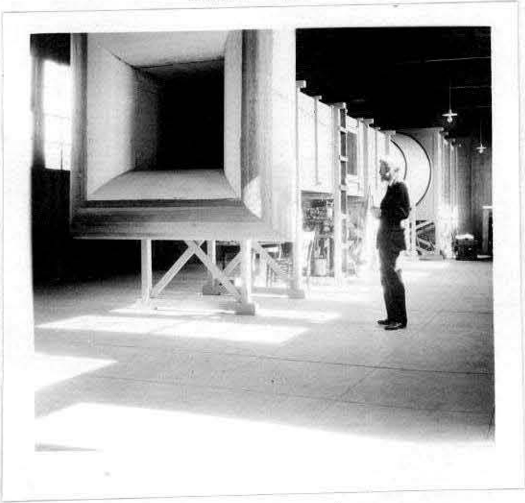
approximately one-third, by virtue of the lowered induced drag. Thus it is seen why we endeavored to get a value of 10 if possible. From the graph it can be seen that Fage and Collins #5 has the best value of $\left(\frac{L^3}{D^2}\right)$ and is second in regard to $\left(\frac{L}{D}\right)$. The outstanding quality is it's camber of almost 19%, permitting lighter and stronger construction. We chose that section. See figures 1, 2, 3, and 4.

We then met a problem which seemed difficult and almost militated against our using this section. We found that the trailing edge was so thick that it might be difficult to construct ailerons and hinges. Again, we thought that even if we could make an air proof hinge, the ailerons would not be very efficient. Next we hit upon the scheme that the Hanover used, a tapering outer section with flaps. This was adopted with flaps giving rolling moment comparable to or larger than that of the Hanover. We did not adopt the sweep back that they used, but we did make our top surface a straight line thus giving us a slight dihedral at the outer tips of about 2.5 degrees. A tapered wing has the advantage, according to recent tests, of higher efficiency and less end loss. From this it can be seen that the flaps will be of triangular plan shape, to give the entire combination a rectangular form. Our efforts to decide the shape of the ends of the wing tips lead us to just chop them off square. This was easy. Exhaustive tests have not lead to the adoption of a standard shape by manufacturers. The tapered wing has another advantage in that it produces a lighter wing loading on the beams at the tips, this effect moving the center of pressure of each half toward the axis of symmetry.

Our fuselage is a modified Hanover having about the same size and shape. This shape, although rectangular in cross section, lends itself to ease of construction. Recent papers of the 1922 and 1923 German gliders show the almost general adoption by other builders of this type. This seems to bear out the contention of the Hanover designers that this type is very efficient in conjunction with monoplane wings. They claimed that the combination of wing and fuselage gave a lift value equal to that of the wing alone and gave in addition a low parasitic drag. Our changes in it's shape consisted in making it adaptable to skids. To our chagrin we later found that we could not make the contemplated skids and so we had to design at the last moment a wheel landing gear. Happily this turned out to be a success, and approval obtained. The tail portion had to be thickened to allow the easy flow of the air around the new position of the fuselage to the wing, which position we obtained from wind tunnel tests. Our pilot must sit in front of the leading edge of the wing. We did this to give him good visibility and to make a favorable location of the center of gravity easy of attainment.

We made extensive model tests in the wind tunnel. This tunnel has an old N.P.L. balance, a 4 ft. sq. channel and gives a maximum air speed~~s~~ of 44 ft. per second.

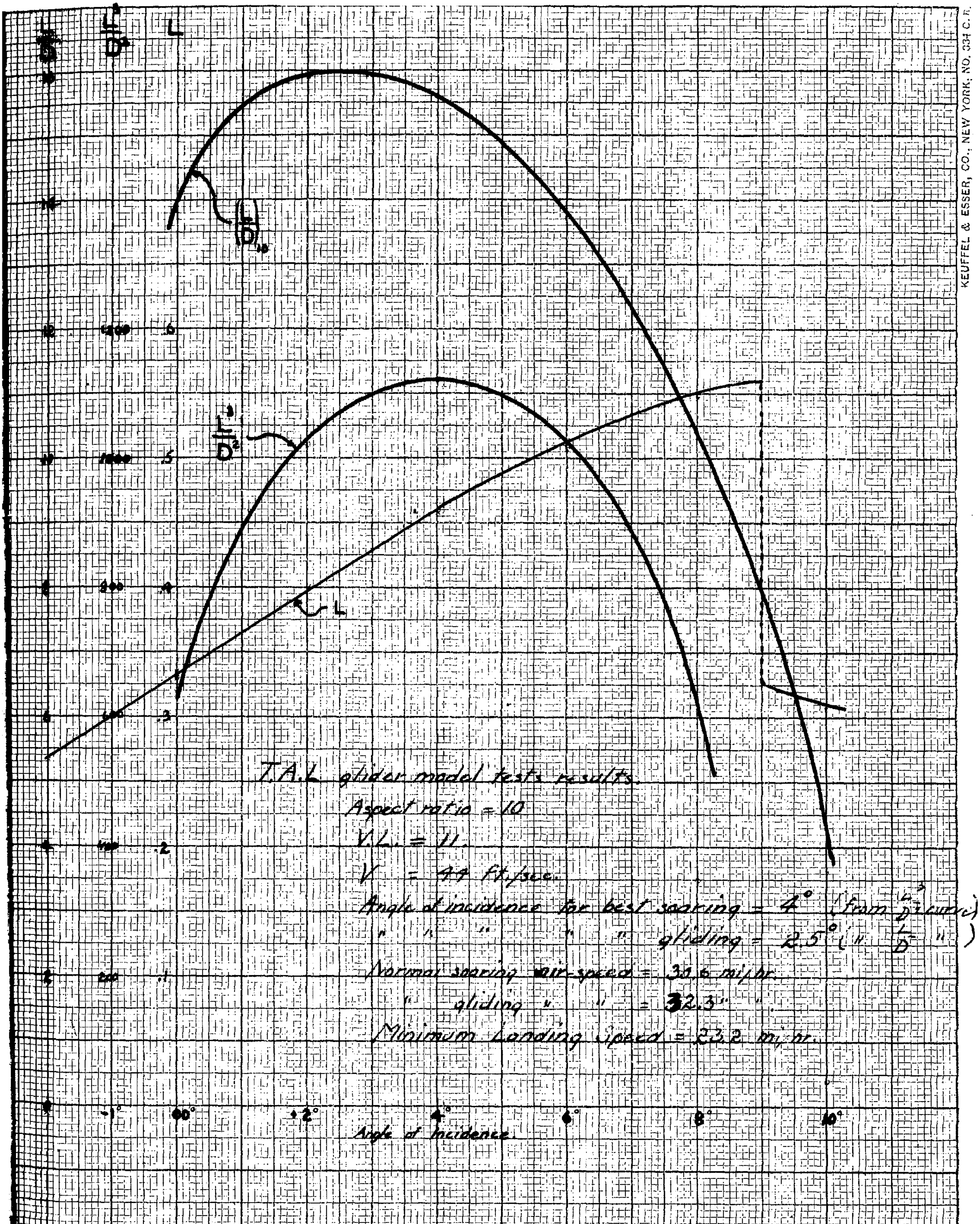
Photo. #2.



Wind Tunnel
C.I.T.

Our models were made to 1/20 scale and our wing had an aspect ratio of 6, to make our tests comparable to tests in other tunnels. We tested the wing alone first and found that the flow of the air broke at 9° incidence instead of the 17° according to the N.P.L. reports. We attributed this to our low speed, which gives a low VL (velocity x chord) of only 11. Mr. Norton of the Washington D. C. laboratory was written to relevant to the safety of our using this wing. He replied that the high value of VL in actual flying conditions would wash out this break in the air flow. Our results below this break were the same as those of the N.P.L. tests, as far as they went. The model was made of wood except for the skids and tail surfaces. We tested this first by varying the position of the fuselage to the wing until we obtained a position which gave us the best $\left(\frac{L}{D}\right)$ ratio. This necessitated our changing the shape of the fuselage slightly. Having done this we put on a horizontal stabilizer of span of 9 ft. and chord of about 2 ft. No elevator was put on because we wanted to determine the smallest stabilizer which would be necessary to just make the ship inherently stable. We assumed a center of gravity, corresponding to current practice, and constructed the model spindle so that the model would rotate as a whole about this assumed center of gravity. By varying the angle of the stabilizer with respect to the wing and by gradually cutting down it's area, we obtained a small surfact which would give a stable couple with no catastrophic instability. That is to say, with this small stabilizer we obtained a normal flying position to which the model would always return of itself, if changed by forces over which the pilot has no control, to another position of larger or smaller incidence. This normal flying position was made to correspond to the position at which the sinking velocity was smallest, or in other words, to the position where the $\left(\frac{L^3}{D^2}\right)$ was maximum. With this stabilizer, then, the ship would come to ground, by itself, if perchange, the pilot took his hands off the control stick. Our stabilizer needed to be only 1 ft. x 9 ft. and at an angle of -1.3° to the wing.

We changed our results from aspect ratio of 6 to that of 10 by use of Prandtl's formula for induced drag, and obtained for the whole ship a best $\left(\frac{L}{D}\right)$ of 16 at 2.5° and a best $\left(\frac{L^3}{D^2}\right)$ at 4°. This means that the best angle of incidence for soaring or staying aloft longest is larger by 1.5° than the best angle for gliding or going farthest. Our computed sinking velocity was 2.7 ft. per second, which is equal to or better than those of several German gliders. This we attribute to the Fage and Collins #5 aerofoil section. See figure (5).



T.A.L glider model tests results.

Aspect ratio = 10

V.L. = 11.

V = 44 ft./sec.

Angle of incidence for best soaring = 4° (from $\frac{L^3}{D^2}$ curve)

" " " " " gliding = 2.5° (" $\frac{L}{D}$ ")

Normal soaring air-speed = 30.6 mi/hr.

" gliding " " = 32.3 " ".

Minimum Landing speed = 23.2 mi/hr.

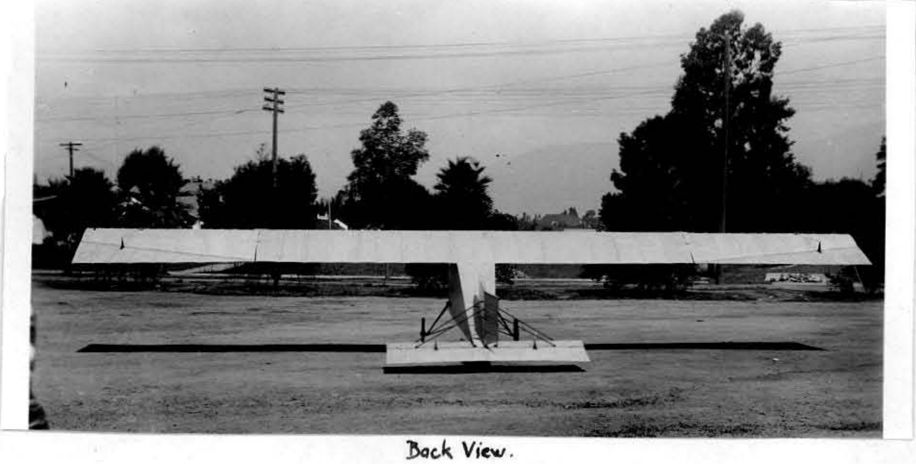
Fig. #5.

Photo. 3.

Front View.

Span –	40'.
Wheel tread	5'.
Width Fuselage	2¼'.
Height above ground	6½'.

Photo. 4.



Back View.

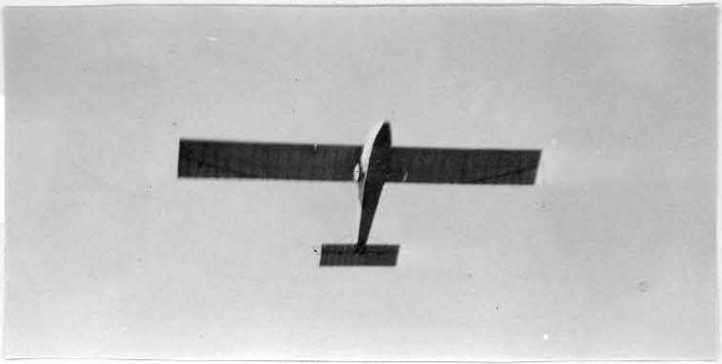
Center Section Wing	22'
Outer " "	9' ea.
Elevator Span	9'

Photo. 5.

Side View.

Length overall	18'.
Depth Fuselage	3'3".
Chord at tip wing	2'3".

Photo. 6.



Plan View.

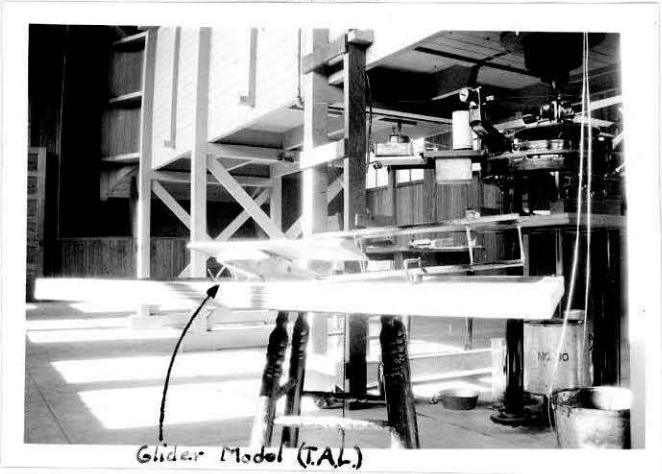
Span Wing	40'
Chord "	4½'
Length overall	18'
Span Tail	9'
Chord "	3'

Photo. 7.

¾ View.

Tech. Aero. Laboratory.
Sailplane.
at
Ross Field.
Arcadia,
Calif.

Photo. 8.



Glider Model (T.A.L.)
Wind Tunnel Balance.
C. I. T.

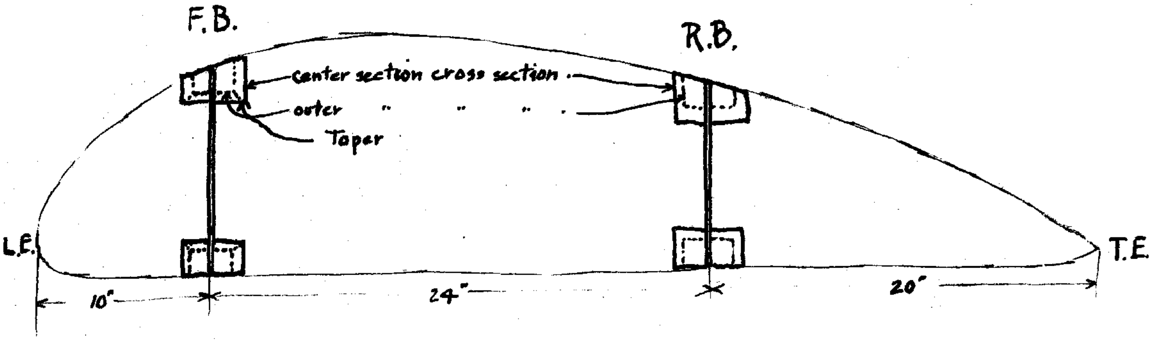
Our work was done for the most part in the wind tunnel, except fof the metal parts which were made at the Barnhardt Aircraft Company. Pasadena High School kindly allowed us to use their wood working machines. We were able for a while to use thw wood shop in our own physics department. The continuity of the work was approximately as follows, with overlappings here and there: (1) The tail portion of the fuselage, (2) the tail surfaces, (3) the center portion of the wing, (4) the front portion of the fuselage, (5) the outer wing sections and ailerons, (6) the controls, (7) the landing gear.

The materials used were grade A spruce, which we tested for checks and spiral grain etc., 5/32" basswood plywood, cold rolled sheet steel, Shelby seamless steel tubing, Roebling aircraft wire, casein glue, etc.

The general specifications for the whole ship are as follows:

Wing Area, including flaps	180.0	sq. ft.
Aileron-net area-each of (2)	10.0	sq. ft.
Horizontal stabilizer area	8.8	sq. ft.
Elevator area	17.6	sq. ft.
Vertical stabilizer area	5.9	" "
Rudder area	3.7	" "
Angle of wing to direction of flight at normal flying attitude	4	degrees
Angle of stabilizer to wing-zero setting	-1.3	degrees
Angle of wing to ground at rest	13.5	degrees
Movement of Ailerons plus-minus	30	degrees
Movement of Elevator plus 24-minus	30	degrees
Movement of Rudder plus-minus	20	degrees
Weight including pilot	410	lbs.
Weight without pilot	270	lbs.
Wing Loading including pilot	2.2	#/sq.ft.

From the advice proffered, we decided to use the two beam type of wing construction, the spacing of the beams also following conventional practice and being in the ratios of about 1/5 and 5/8 from the leading edge. To avoid difficulties, we made the beams of I beam section because this form allowed the placing of spacer blocks at any time after the gluing of thw web and flanges. The web was made of 5/32" basswood 3-ply veneer, and flanges, of which there were two above and two below, were of spruce with the plywood glued between.

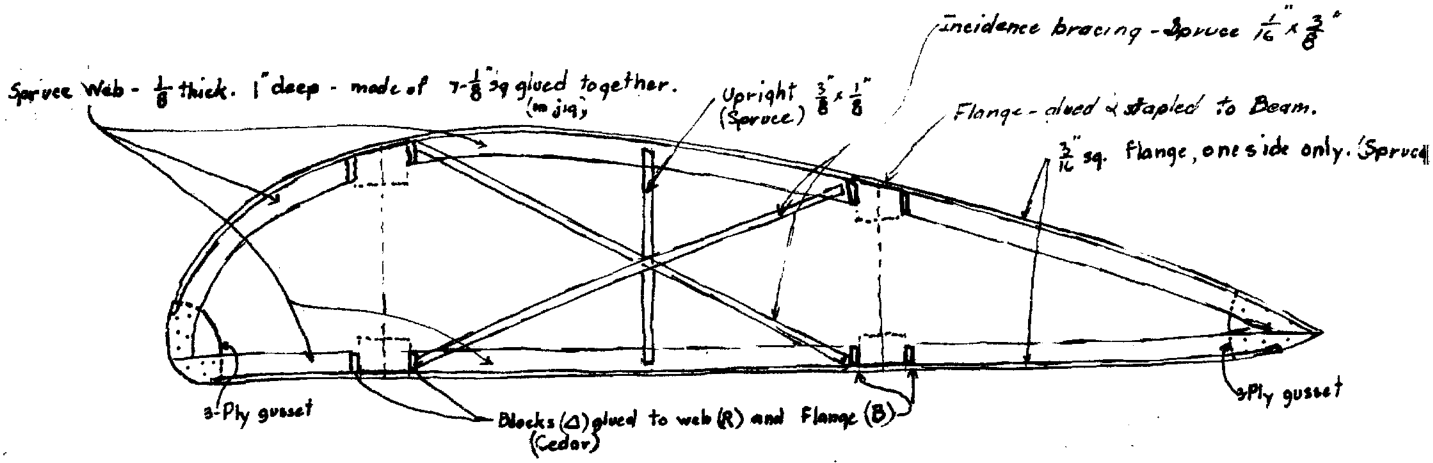


Since our span was 40', we were forced to split up the wing into three sections. Spruce of 22 ft. length was the longest obtainable, and so our center section was 22ft. long and each outer section 9 ft. These sizes allowed ease of handling.

Since we used no external bracing, our bending moments assumed those of a cantilever, the center bay being only 26 in. wide. The loading for normal flying was 2#/sq.ft. We computed on a basis of load factor of five, raising this, therefore, to 10#/sq.ft. From a knowledge of the center of pressure movement and the beam spacing, we assumed, conservatively, that each beam would have to be able to withstand the total load alone. Computations for beam sizes were made simply according to straightforward beam formulae and cantilever moments. In order to cut down on the weight, we tapered the flanges from the center to the outers along a straight line until it became impracticable for them to be made smaller, and so the outer section beams were overstrength. To determine the strength of the web in shear, we subjected a 4ft. length of beam to test and found it had a safety factor of 2 above our load factor and also that it required no stiffeners.

Our standard rib was made as the drawing indicates (page 11) mainly because of it's simplicity and strength. It was heavier than necessary. The strength was computed on empirical formulae prevalent, assuming a total load of about 55# for each rib. The web was unique in that it was made of 7-1/8" square strips glued together to the shape of the section. This was done by gluing 7-1/8" x 3" wide strips in a jig to the aerofoil shape and then ripping these into webs 1/8" thick. The rib had it's flange running over and under the beams and was fastened by gluing and stapling the flange to the beams and placing blocks at the side of the web. The ribs were spaced at 15-16 in. apart.

Standard Rib



Our box ribs took the compression of the drag bracing and were similar to the standard ribs except for the center section having a solid web of plywood. The flanges, of course, were larger according to size of loads.

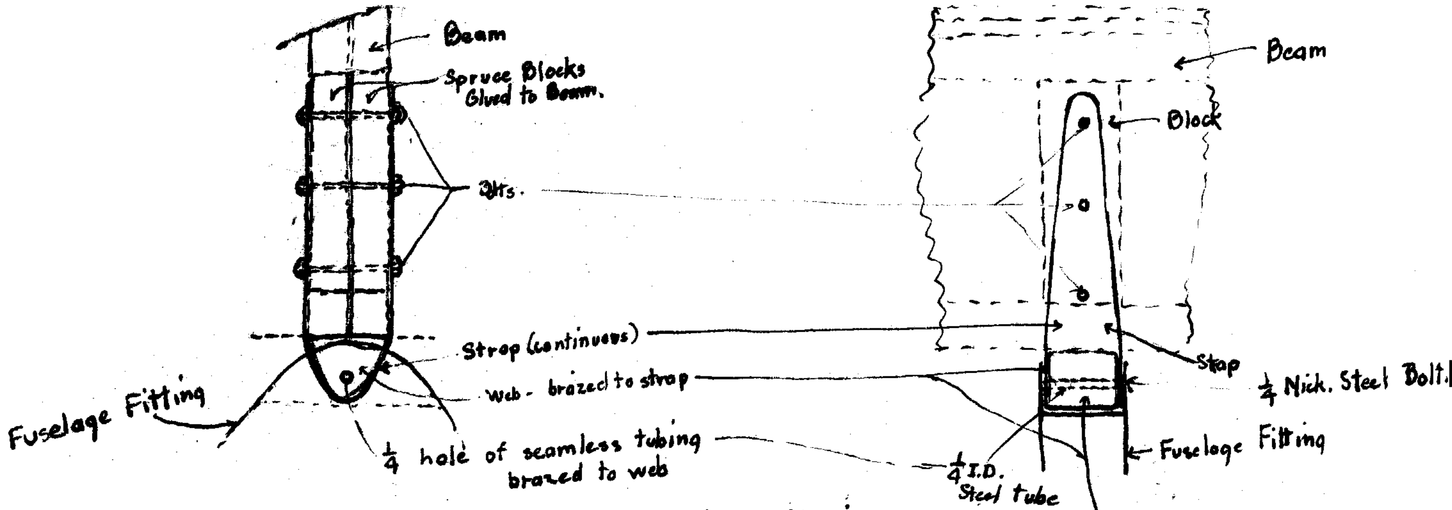
The drag bracing we adopted aroused a bit of skepticism on the part of many. One engineer advised us to use strips of spruce 1/16" thick in place of wires. This plan was very much simpler and easier to make and we followed his advice. I have since changed my opinion as to it's wisdom. Our drag bracing was a double system, one above, and one below, allowable because of the thickness of our wing. Either system was more than strong enough to support the total weight of the ship in a dive at limiting speed and the double system also gave us the advantage of resistance to torque of the whole wing. The strips of spruce were merely glued to the under sides of the beam flanges.

We placed two nose ribs in every standard or box rib division, which gave us a spacing of about 5 in. We had to do this to retain the shape of the nose, a very important condition to be sought for, in order to obtain maximum wing efficiency. The nose ribs were of spruce ply similar to the webs of the standard rib, but only 3/8" deep and with no flange. They were glued and stapled to the beam and leading edge.

The leading edge was made of 1/16 spruce 3" wide, curved around the nose and with grain running longitudinally. This gave optimum stiffness with light weight and something to which the nose ribs could be easily fastened.

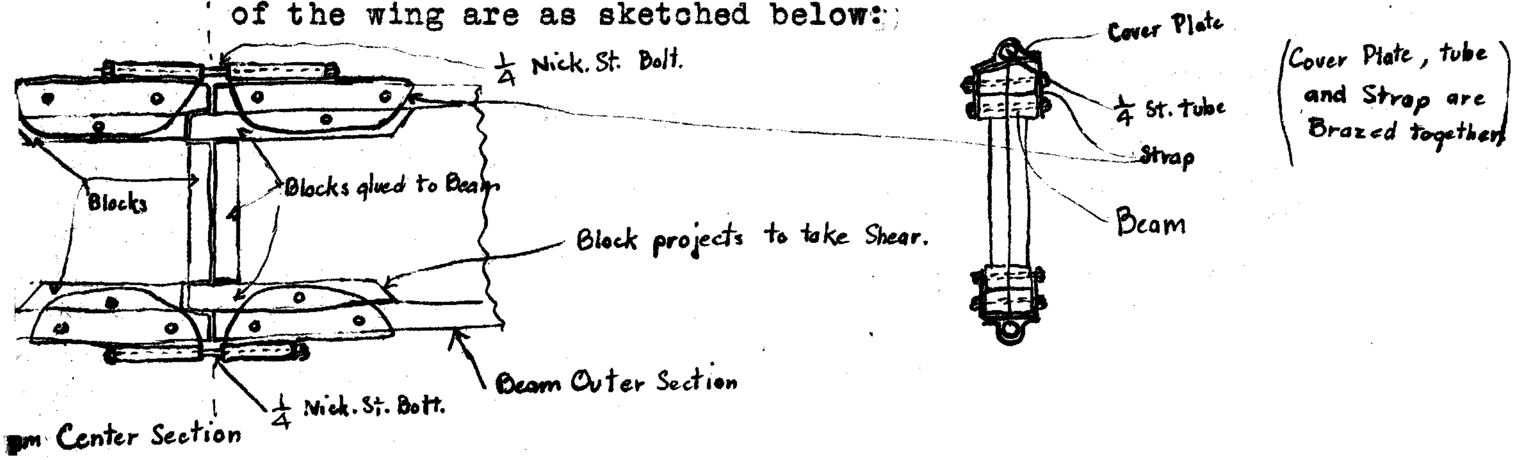
The trailing edge was made of wire that was soldered to copper ferrules at the end of eadh rib. This was easy and also conventional.

The entire wing was attached to the fuselage at four points. The center fittings which did this are as sketched:



Center Wing Fitting. (4 reqd.)

The outer fittings which fasten together the sections of the wing are as sketched below:

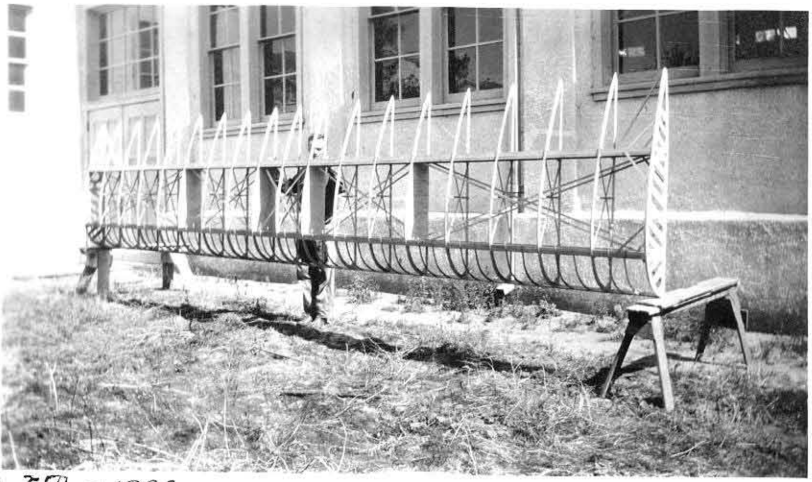


Skids were put on the ends of the wings for the sake of protection and to serve as handles in ground work and launching.

The pulleys for the controls were standard Jn. 4 parts.

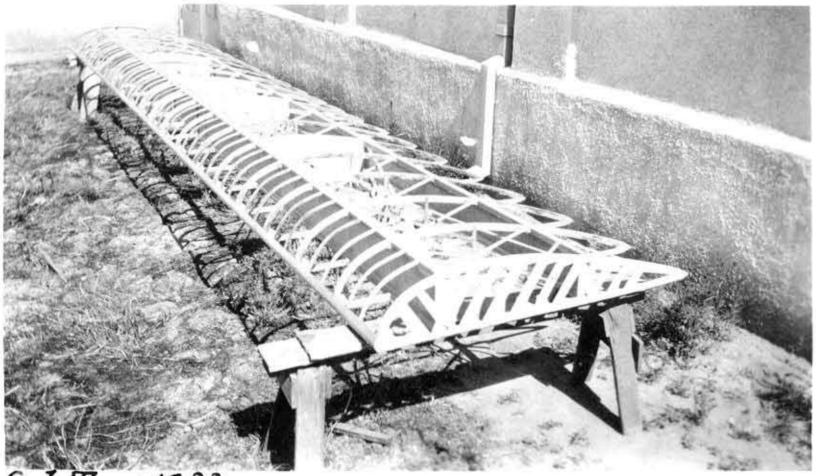
The covering consisted of 90# sheeting. Two thicknesses were put on the nose in order to preserve the section shape. The whole received four or five coats of lacquer and two coats of varnish.

Photo. 9 Center Wing Section.



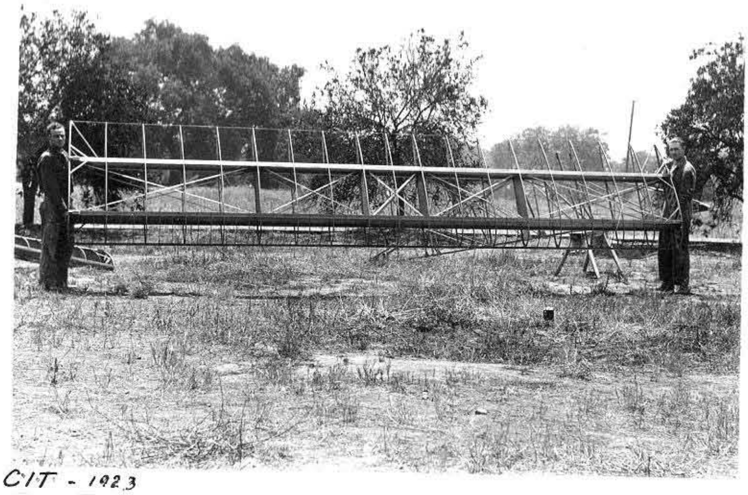
C.I.T. - 1923

Photo. 10 Center Wing Section.

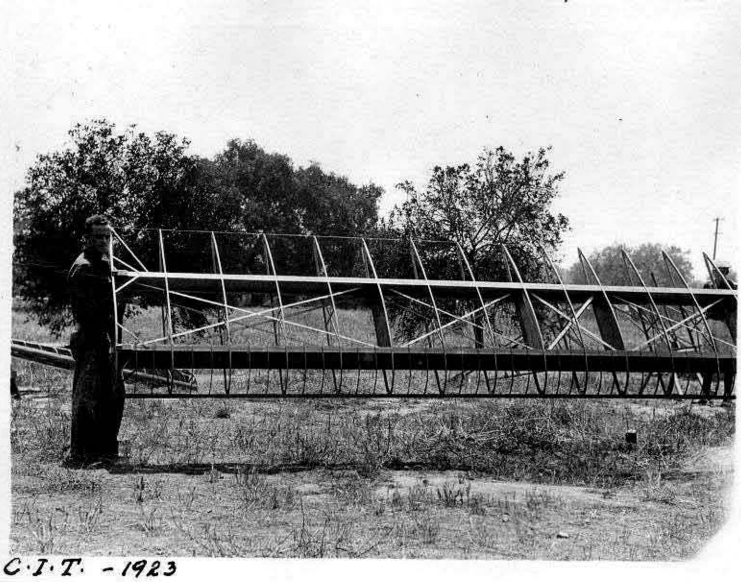


C.I.T. - 1923

Photo. 11 Center Wing Section

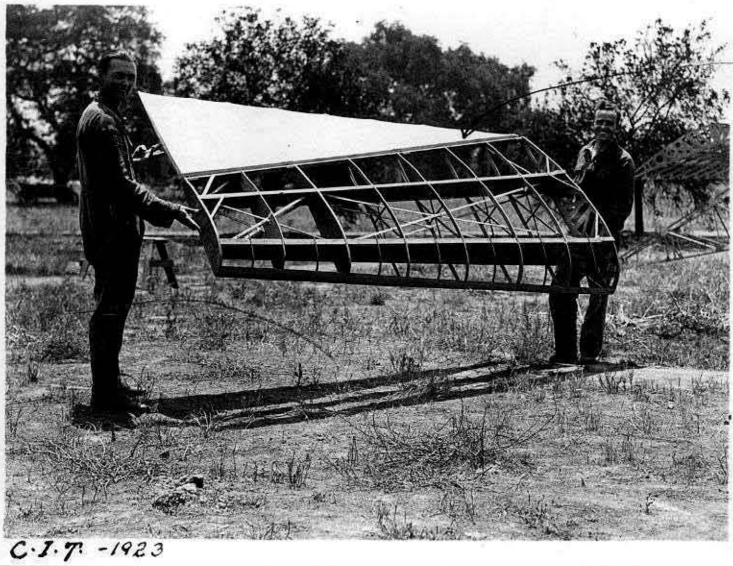


CIT - 1923



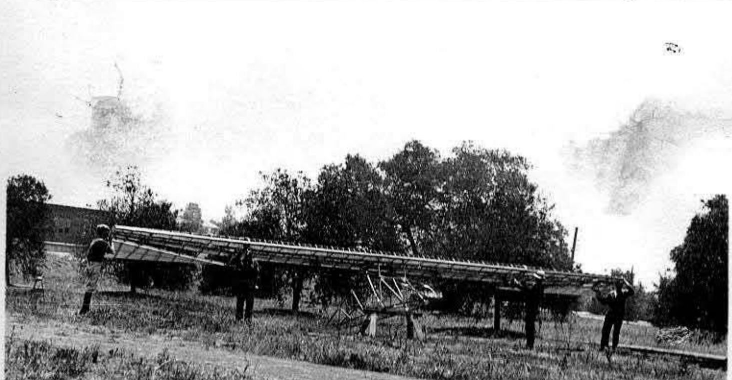
C.I.T. -1923

Photo. 13. Outer Wing Section



C.I.T. -1923

Photo 14. Skeleton Assembly Wingsections & Fuselage.

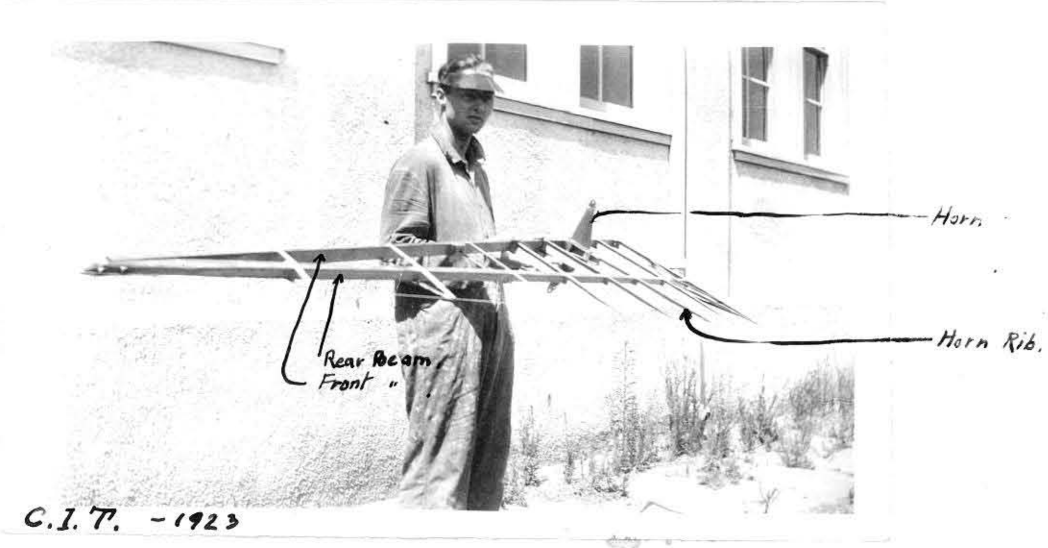


C.I.T. -1923

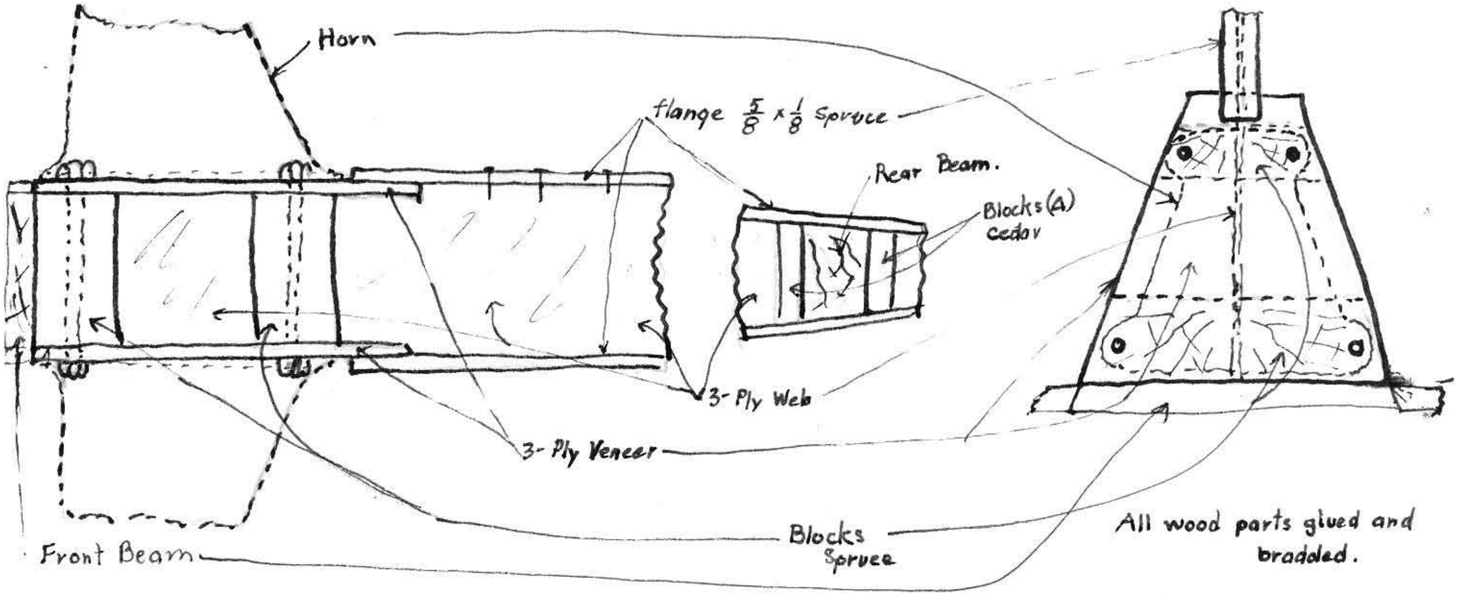
Photo. 15. Putting Wing on Fuselage.

The ailerons can best be shown by the photo accompanying:

Photo. 16 - Aileron.



The horns and horn-ribs were cantilever in design so that there would be no wires to the trailing edge. The horn rib or main rib was as shown below:



The leading edge was covered by aluminum sheet to prevent air leakeage.

Our fuselage was rectangular in cross section with the bottom longerons running in one piece from tail to nose. The upper longerons ran from the tail piece to the rear fittings, which held the wing. We both assumed or computed our loads and then stressed our fuselage members for both symmetrical and torsional loadings. We found that our interstitial bracing carried no load, theoretically, if the load was considered concentrated on the tail piece. The longerons were then in straight tension or compression, and we computed their sizes on the assumption of pin joints between bracing diagonals. We assumed reasonable sizes for the diagonal and incidence bracing, and we put these in such a direction that they would be in tension on landing and compression in flight. We did this because we were sure that landing in rough country would produce greater loads than those of ordinary flight. Here should come the explanation of our bracing system. It is seen that we used no wires, but a straight wooden truss with permanent joints. This method we found would be much easier to make and would, after once done, obviate the necessity for continual tuning up of wires and inspection of turnbuckles, joints, etc. Against this, of course, was the greater difficulty of repair in case of smash-up, but we chose the fixed joints for the above reasons.

These joints were accomplished by means of gusset plates made of plywood. We computed the sizes of the gussets upon a glue strength of only 1000#/sq.in. which may actually attain 2500#/sq.in. In addition to this, we put a small screw at the end of the plywood along each member of the truss to prevent the glue joint fracture, in case there were one, from spreading, which would be aggravated by infinitesimal flexures in the whole system. This method of construction demanded great accuracy of setting up. We succeeded fairly well, the fuselage warping only an almost inconsiderable amount. The tail portion ended in a box like construction of plywood. This produced rigidity to torsion and gave us a desirable foundation for the assembling of the tail group.

It will be noticed that on the fuselage the sides are cut in under the wing. We did this to allow the air unobstructed passage after it passed the pilot's head. The struts, then, were exposed a short length and the incidence diagonal on that bay could not run to the wing fitting. This demanded that we put in some bracing between this point and the wing to make the system complete. We worked out a bracing of small tubing which satisfied both the external fuselage shape and strength requirements. The exposed struts were streamlined with aluminum.

The wing fittings are shown on the photos.


C.I.T. - 1923

Photo. 18. Fuselage.

Photo. 20 - Showing Fuselage under wing.


C.I.T. - 1923

Photo. 19. Skeleton Fuselage + Center Wing Section.

Photo. 21. Skeleton Fuselage & Center Wing Section.


C. I. T. - 1923


C.I.T. - 1923

The tail group was made so that it could all be taken off with a minimum of effort. The fin could be slipped off, and of course, with it the rudder. The stabilizer and elevator were more difficult and will be taken up in the discussion of that group.

The landing gear was ultimately designed for wheels. We were obliged to use Smith Motor wheels and tires (20x2) because of the doubt as to the strength of bicycle wheels. The smallest airplane wheels that we could get were much too heavy and large. We wanted to encase our shock absorber inside the fuselage in order to eliminate parasitic drag. We also wished to avoid a cross-axle, which might cause spills in brushy or rocky country. Last but not lease was the fact to be contended with that we had to adopt our design to the already fixed fuselage trussing instead of doing the reverse as would be normal. All in all, the design, as arrived at, was one with which we were all pleased. It was all constructed of seamless tubing, without any special heat treatment and the joints and ends of the members were all of brazed construction. The two large side struts were computed for size on a basis of both bending and compression and the entire structure was designed to take an impact load of 3, which corresponds to a pancake drop of 18 inches. It is interesting to note that in flight the plane was stalled and pancaked purposely to test the landing gear and that one axle point, on one side only, was bent but slightly. This was bent back and the whole is still as it was originally. The shock absorber was made with 3 wrappings of 1/2" dia. rubber cord on each side. These will deflect about 4 in. displacement under full load. We also put a check in the shape of a web strap in case of overtravel or breakage of the rubber. The rubber is wrapped around a cross tube at the bottom of the fuselage and the corss tube of the landing gear, the latter being higher. This cross tube of the landing gear is allowed to play up and down in the groove formed by the fuselage struts. Excessive side play is prevented by the rubber itself. We do not need to fear breakage of struts in case of a side swipe, because the wheels would collapse first, being only 3" across the hub. The wheels were streamlined with cloth to make less drag, the cloth being clinched by the tire and doped and varnished to tightness. The whole gear was made adjustable, fore and aft, by having the braces running to the front, of two parts, telescoping into each other. Two pins were put through them to fix their positions.

Photo. 22. Landing Gear.

The top of the fuselage in front of and in back of the wing was made open to inspection by means of two detachable turtle backs.

Photo 23 Turtle back

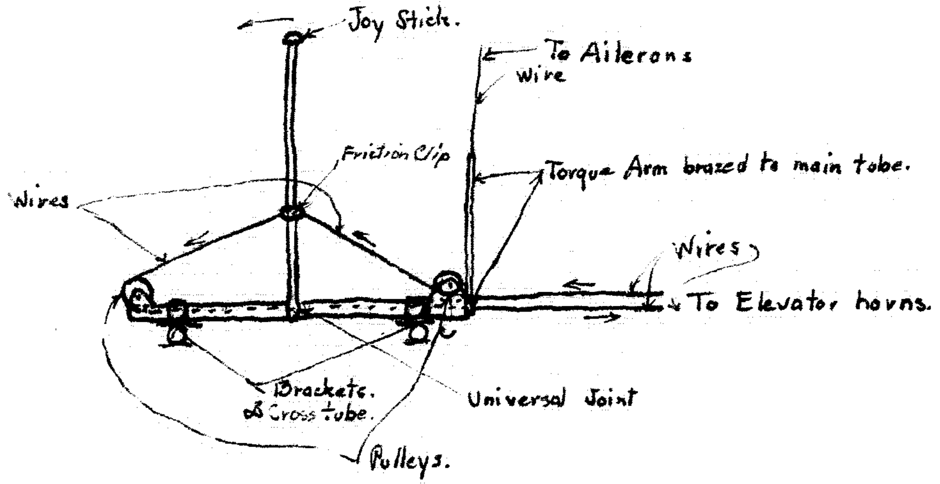
Photo 24 Showing Landing Gear - Turtleback and Fuselage under wing.

Rear Turtleba

The tail skid was a conventional hickroy one with a shock absorber unit. The skid support was designed so that the skid would turn automatically in taxying. Glimpses of this feature may be obtained from other photographs.

The seat was a standard one, equipped with life straps and arranged so as to not give the pilot undue discomfort. It was made adjustable with the controls able to be moved through a distance, fore and aft, of 8".

The control system was of the joy-stick-rudder bar type and can be easily sketched as follows:



Note: When stick is moved perpendicular to paper Torque Arm moves with it to produce movement of Ailerons.

The launching device is one of which we are pleased. The plane is launched, that is, for it's preliminary trials, by means of a 300 ft. cable attached to an automobile. The pilot is able to free the ship from the cable at will, by merely pulling a string inside the cockpit. The device on the nose is such that when the pilot pulls this string the tension of the cable opens the jaws of the device, which hold the end of the bable, affording an absolutely sure release, impossible of catching.

The fuselage and turtle backs were covered, doped and varnished similar to the wing.

The fin was built to be easily removable and the rudder was attached to it by means of three hinges. The group was of cantilever construction. The horn-rib of the rudder was similar to that of the ailerons. The section was a symmetrically streamline one we devised ourselves and we conformed the rudder section to certain new principles. It was found, from governmental tests, of that if the rudder was a continuation of the fin section or/even smaller thickness, there was a certain dead area between whose limits the rudder, when moved, was ineffective. This could be eliminated by making the maximum thickness of the rudder larger by 1/4 than the trailing edge of the fin. They were built to stand 24#/sq.ft. of load.

To eliminate dead area make max. thickness of rudder greater than thickness of Fin at hinge.

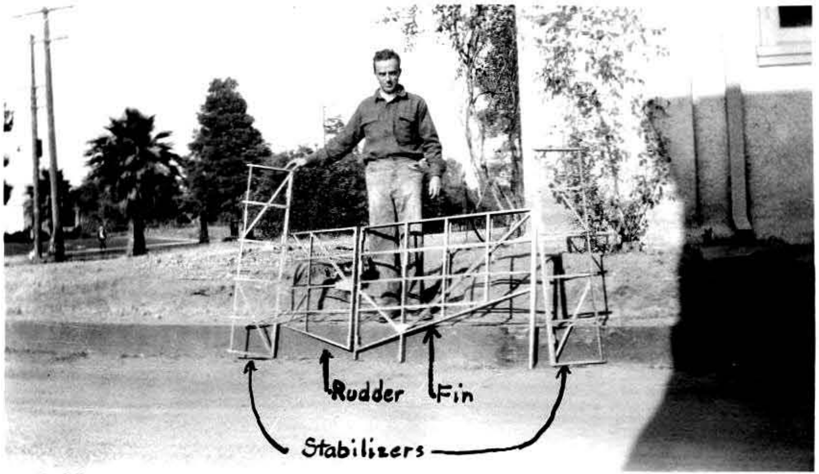


Photo 25 showing Fin, rudder & stabilizers.

C.I.T. -1923

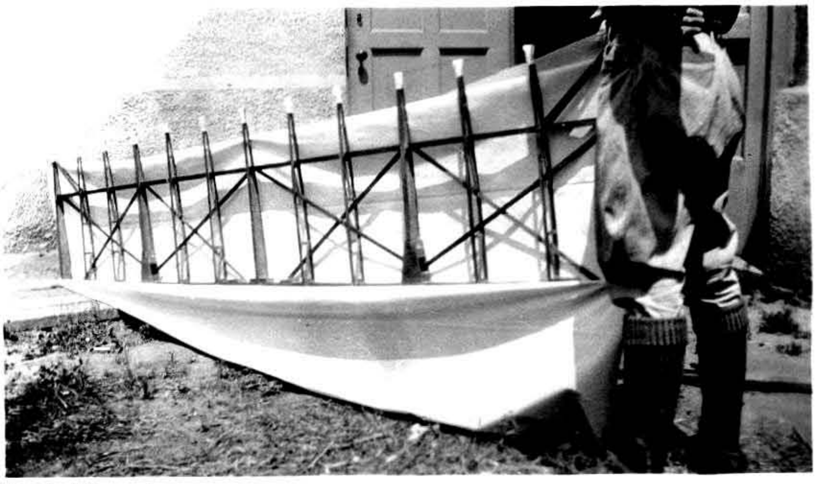
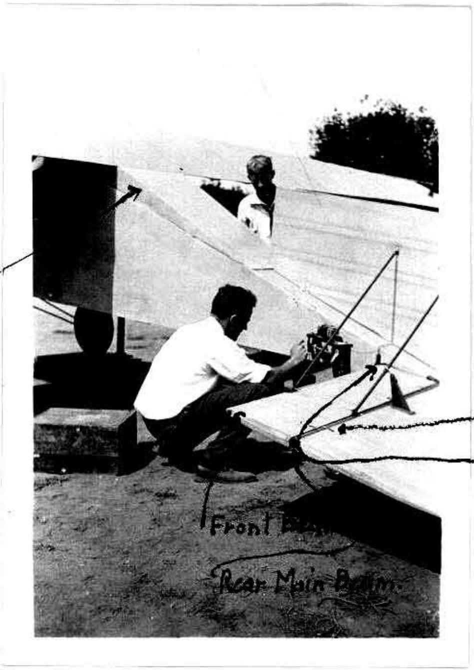


Photo 26 showing Elevator.

C.I.T. -1923

Photo 27.



Locating c. of g. (see p20.)
by weighing in two positions.

(Showing Assembly of Elevator & stabiliz
(See p. 19.)

Photo. 28. Locating Center of Gravity. (See Page 20)

The stabilizers and elevator were of unusual construction. We wished to make the stabilizer adjustable, so that the general attitude of the ship could be changed when desired. The section chosen, mainly so that we could get the required thickness to suit the 1½" beam, was that of a wing (Sloane #1) and we inverted it so that it would be most efficient when a down pressure was to be developed. A ship rarely flies with an up load on the tail. The total load necessary in a dive at limiting velocity was figured from center of pressure movements to be 300# downward. We doubled this to 600# to give a factor of safety of 2, thus giving a loading of 23#/sq.ft. We could not make this cantilever in construction and so we had two tubes as braces on each side, one running from the front beam of the stabilizer to the middle post of the fin and the other running from the main beam to the rear post of the fin. The main beam of the combination was to act (1) as the trailing edge of the stabilizer, (2) as the leading edge of the elevator, and (3) as the hinge rod or center. It was a large tube, 1½" dia. x 22 ga., with fittings brazed to it, at the center, to make it attachable to the tail piece of the fuselage. The stabilizers and elevator were attached by means of strap hinges. A method of trial computations was the only way possible to compute the size of the beams because they were subjected to both bending and compression. This was done by two ways, the Berry and the Perry methods, each of which checked the other.

The front beam which was a tube ½" x 20 ga. was a hard problem to solve. The only method we could see, to accomodate it to the limitations of detachability and adjustability, was to make it so that it could be pulled right out from through the fuselage. The side bracing tubes were each made with a turnbuckle in them to vary their effective length. The fittings which held this beam at the sides of the fuselage, were attached to arms,one on each side, which could be adjusted up or down to any position desired. These arms, in conjunction with the tubes having turnbuckles, made the whole stabilizer adjustable. The horn-ribs of the elevator were cantilever just as the rudder and aileron horn-ribs.

When we had completed the whole plane it was then necessary to balance it and to fix it's flying attitude. It will be remembered that we had three adjustable features, namely, the seat, the stabilizer, and the landing gear. The center of gravity, according to practice, must be at about .28 or .30 of the chord from the leading edge when the plane is in normal flying position. We had, at the beginning of our computations, assumed weights and dimensions, the resultant of which would approximate this locus of the center of gravity. To determine it's exact position, we fixed the seat and wheels temporarily, and weighed the whole ship, including the pilot, in two positions, one, tail low, the other, tail high, by means of three scales, one under each wheel and the third under a point of the tail skid support. The day was comparatively free from wind and the weighings checked in totals, missing only by 1/3 of one percent. By computing the resultant of the weight for each weighing, we obtained the existing center of gravity and found that it was off from the desired by 1 3/4". To obtain this desired locus required that we move our seat as far forward as it was possible. This shows that we reckoned wisely in making the seat adjustable.

After we had found the center of gravity, as it now exists, we were then able to definitely locate our wheels. We fixed them in such a position, that the line through the point of ground contact and the center of gravity would make an angle of 18 degrees with the vertical when resting on the ground level. This angle has been found to be the desirable one for the making of an easy three point landing.

The final adjustment to make was that of the stabilizer. From our wind tunnel tests we found that the setting of the tail stabilizer should be at -1.3 degrees to the wing to give a normal flying attitude for best soaring at 4 degrees incidence. This we did. Having made our adjustments and finished wiring the controls, we were all ready to fly.

The ship was taken to Ross Field, Arcadia, where there is a field with a length of one-half mile. The method adopted to test the ship was to hitch her to an automobile with a 300 ft. cable. The first trial consisted in merely taxying over the ground, Mr. Merrill wisely limiting the speed of the automobile to 25 mi./hr. This gave the pilot a chance to test the tail surfaces and to prove the strength of the landing gear. Without much ado, the next trial found the plane in the air and thereafter many flights were made, with a view to testing the maneuverability of the ship as a whole. Newspaper and motion picture photographers took advantage of these flights to ply their trade.

A few views of the first flights.

The general consensus of opinion is that the plane is successful, inasmuch as it is the first work of two engineering neophytes. The pilot gave as his opinion, (he having never done any gliding before without motive power) that the controls were slower than for a power machine. The pitching and rolling controls were safe, although slow. The real difficulty occurred in yawing. The rudder was totally inadequate. It is a coincident fact, that the rudders of all gliders subsequent to the Hanover Vampyr, in Germany, have been made greatly larger. One cause of our difficulty may have been due to the fact that the inertia of the wing tended to keep swinging the plane around notwithstanding the force of the small rudder to bring it back to norm. The two students are well satisfied with their work as a whole, but can see that the need for large efficient control surfaces is paramount in any glider design. The reason for this is that the absence of propellor slip stream reduces greatly the (according to the ratio of the squares of the velocities) forces on the rudder and elevator. The ailerons are not affected in this regard but in another, equally potent. The wing of a glider is one of the large, perhaps the largest, weights of a ship and the span is concomitantly large.

The centroid of each side of the wing is moved outward according to the above facts and hence the wing requires greater rolling moment to produce accelerations in rolling equal to those in power flight. Therefore, it is seen that all control surfaces should be considerably larger for sailplanes in general than for power machines.

A new scheme for control in yaw has since been devised by Mr. Merrill, and consists of rudders placed at the tips of the wing, the old fin and rudder being removed altogether. The same effect is accomplished with these by turning the rudder on the side of the ship in the direction it is wished to turn. In other words, a drag is introduced on one side only, thus slowing down that side, to produce the yaw. This also helps the aileron action in that it drops the side whose rudder is turned. This method of control in yaw is very effective and has, I think, advantages over the conventional type. This has been tried on our glider and the pilot reports 300% better yaw control.

The monoplane has, in our opinion, proved itself to be the most efficient type in soaring practice. The elements to be strived for to produce efficiency are (1) good wing sections, (2) light weight construction and extreme refinements in streamlining and aerodynamic improvements to reduce, to the lowest possible, the parasitic drag.

The argument is specious, (I think it can be proved so) that is sometimes heard, that because of the slow speeds encountered in soaring, the parasitic drag is non-important. It must be remembered that <u>all</u> the forces, including lift, vary according to the same law e.of velocity squared. Hence, since relatively, the drag depreciates with the velocity and the lift depreciates in the same proportion, it is seen that any diminution of the parasitic drag coefficient will raise the L/D and L^3/D^2 ratios. We have now built one machine successfully, and I fully believe that if we were to build another one now that we would build the new one better and more efficient than the first, although we have gained a lot of satisfaction from the success of our first attempt. It is to be hoped that we may see this glider attempt soaring flight over a suitable terrain some day. But at the present time the pilot and Mr. Merrill have many research problems they wish to solve first. A gliding meet in Oakland, California is contemplated for next summer, and if it actually occurs, it is our wish that we may enter this plane.