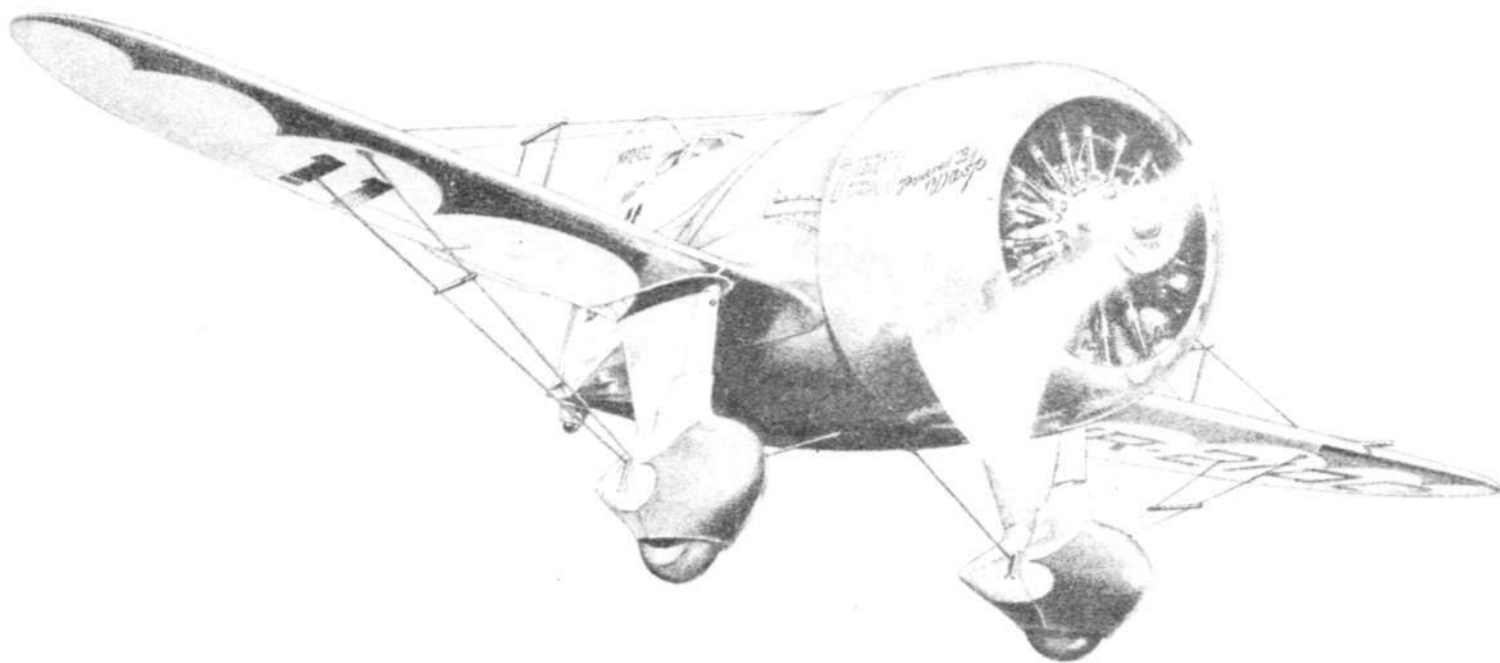




GEE-BEE Racer

Design and Development

Submitted, by Erwin J. Bulban

A paper authored by Howell W. Miller and Z.D. Granville, of Granville Brothers Aircraft, Inc., and presented before the Metropolitan section, Society of Automotive Engineers, at the Hotel New Yorker on 18 May 1933.

The development and construction of the 1932 Gee Bee "Super Sportster" which Major James H. Doolittle piloted to win the Thompson Trophy Race and establish the present World's land plane speed record of 294.38 mph, at the Cleveland National Air Races was a result of considerable experience, aerodynamic research and wind-tunnel testing. Granville Brothers Aircraft, Inc., the builders, have continued their habit of building along new and somewhat radically different lines, incorporating ideas and features that provoked storms of criticism from the flying fraternity. The best combination of features for low parasite drag were determined first from experience and then proven by comparative drag tests in the wind-tunnel. The popular conception of an ideal racing craft has always been the long slender fuselage with as little frontal area as possible, but contrary to the generally accepted idea on this subject, we firmly believe that a radial engine can be made to go as fast as any in-line engine of equivalent horse power, provided the cowling and fuselage were properly built.

Working on this idea, we conducted a few experiments and the 1931 Gee Bee "Super Sportster" was a step in the direction of building a bulky fuselage behind an engine of this type. This job brought a hail of criticism and many authorities on the subject predicted that the ship would never fly, or if it did fly, would have neither speed nor controllability sufficient to win any races.

The 1932 Gee Bee "Super Sportster" was designed principally for racing purposes and to establish a new land-plane speed record for America, but much information has been gained from its construction and general lines, useful to the designers for future aircraft development. The appearance of the airplane when first exhibited evoked much criticism from the aeronautical fraternity in spite of the fact that we had proven our point the year before on the 1931 ship.

The new job has considerable more frontal area due to the use of the larger engine. The huge fuselage, 61 inches in diameter at its thickest point and with only a twenty-five foot wing span, presents an appearance that is absolutely ridiculous to the eyes of the adherent to the old idea of a needle-like fuselage. To be absolutely sure that our ideas and calculations were correct we built a wind tunnel model which we tested in the New York University wind tunnel. This test proved our theory entirely correct and the actual ship was built on the same lines as **first** intended and incorporated in the wind-tunnel model.

It is the purpose of this paper to review the aerodynamic features and to present the reasons underlying the design and construction. Further, the certain results of wind-tunnel tests on a scale model of the Super Sportster will be quoted. Relative values of drag

will appear in the pages of this paper in terms of percent. This paper will treat each group of the airplane separately. Under each head will be found the reasons why each component part was selected.

TEE ENGINE

The engine selected was the Pratt and Whitney "Wasp", Model T3D1, supercharged to 730 horse power at 2300 rpms. The ability of this motor to develop a tremendous overload of horse power over an extended period, together with its horse power/weight ratio, gives this engine a great many advantages over every other engine available in the United States. Last year's experience taught us that a propeller efficient at high speed was extremely poor on the get-away and take-off which counted seriously in a race from a standing start. With this difficulty in view we selected the Smith Controllable Pitch propeller as the ideal installation which would give us the desired take-off, and still hold the motor down to the proper rpms, at full speed.

THE FUSELAGE

It has long been known that, for minimum profile drag coefficient, a streamline body of revolutions should have a fineness ratio between 2 and 4. Also the maximum diameter should be located at about one-third of the length of the body. With these points in mind the Super Sportster fuselage was laid-out. The fineness ratio was set at 3.2 and the maximum body diameter was located at 34% of the fuselage length. The fuselage, of course, was not a body of revolution but approached this. The sections to about 30% of the length were true circles. From this point aft, the sections became ellipses, with the major axis vertical. The disposition of the cockpit near the tail necessitated this. The drag coefficient D_c (lbs/sq. ft./mph.), reaches a minimum value at a fineness ratio of nearly 2, when a curve or drag coefficient vs. fineness ratio of streamline bodies of revolution was plotted, and increases above and below this fineness ratio. With a low drag coefficient, the fuselage cross-section area could be increased greatly over the other type fuselages before the fuselage drags were equal. This allows a large, comfortable cabin for the pilot, and with an eye towards commercial aircraft, permits the use of a roomy interior for airplanes in use on airlines without sacrifice of aerodynamic efficiency. Therefore passengers can now travel in greater personal comfort without increased cost to them or the airline operator;

THE WING

For the selection of an airfoil for the wing, it was of course desirable to use one with a low minimum-drag coefficient and suitable moment characteristics with a small total center of pressure travel. A high value of maximum-lift coefficient was necessary to obtain a reasonably safe landing speed. Since the airplane was a low-wing type, ground effect entered the problem and the actual landing speed was somewhat lower than the calculated value.

As far as minimum-drag was concerned, the M-series of airfoils recommended themselves. On certain of these sections the center of pressure travel was small, allowing a minimum of tail surface area for ample control. The fuselage length being small, the overcoming tail moment was small at the best, hence a low center of pressure travel was desirable for several reasons.

The drag of several of the M-series of airfoils at a constant value of life coefficient was plotted against thickness in percent chord at 30% chord. For this comparison, a value of lift coefficient equivalent to a speed of 300 mph. of the full-scale airplane was selected.

The M-series airfoils (M4 through M-9) may be classified as the "stable series" of M-type airfoils. The center of pressure travels towards the trailing-edge as the angle of attack is increased from low to high angle of attack. It was observed that the M-6 section has the smallest total center of pressure travel, namely 9%. For the Super Sportster wing, sufficient spar depth was possible with the ordinates of M-6 reduced to 65%. It is believed that the center of pressure travel is not altered by this change, but the minimum profile drag of the wing is reduced. In flight, the center of pressure travel is small, for the adjustable stabilizer as installed on the Super Sportster is not entirely necessary. The elevators were found to be sufficient to maintain trim alone, throughout the entire speed range and with power on or off. It is therefore believed that a small center of pressure travel is a necessary characteristic in racing airplanes.

The Stewart-Hartshorn flying and landing wires are attached to the wing by specially designed ball-and-socket fitting which allow the wire ends containing the threads and the round section, as well as the fitting, to be entirely concealed within the wing, even though the maximum wing thickness is only 4-5/16 inches. In order not to disturb the streamlining, special fittings were also designed for the other end of the wires, allowing

AUTHOR'S NOTE:

This copy of a paper originally authored by Howell W. Miller & Z.D. Granville for presentation before an engineering society some 30 years ago was submitted to AAHS JOURNAL for three reasons: to provide members in general and air racing buffs in particular with one or more pieces that may be missing in the vast unfinished jigsaw history of this vanished era that they are collecting; to reproduce in close to its original form, in its original language and style, a document which may have been unknown to exist, or remains in such few numbers that only through a publication such as our JOURNAL can it readily be made available to any who are interested and thus prolong its life and possible value; and thirdly, to illustrate to all members a simple and easy way that they can contribute to the JOURNAL if they are not otherwise inclined, because of lack of time or fear of lack of ability, by unearthing from their files, as in this case, some yellowing document and re-typing it. This paper also illustrates the cache of aviation history that lies in the thousands of papers presented before numerous engineering societies in years past by the

designers and test pilots, involved in all manner of aircraft projects. Erwin J. Bulban.

GEE BEE RACER ILLUSTRATION

Member Bob Cunningham submitted the Gee Bee Racer drawing in late November, coincidentally with the beginning of makeup of the design story submitted by Erwin Bulban.. Bob is an illustrator, in fact, Illustrations Editor in Advance Design group at General Dynamics, Ft. Worth. His work appears in many of the company brochures and advertising releases and has been used on the cover of RAF Flying Review. Currently in the works is a painting of Bell Helicopter Corp.'s H V-1 which will be reproduced in color.

Possibly because his first ride in an airplane at an early age was with Clarence Chamberlin in a Curtiss "Condor", second with Reg Robbins, Bob Cunningham, now 33, has never lost interest in aviation. He majored in art at T.C.U., joined Convair in 1955. As spare time hobby he paints airplanes - what else - of the "grand decade" the 1930's and is working on a book of air racing.

micrometer adjustments on the wires without rotating them about their points of intersection with the wing. This also allows a very quick, easily accessible and accurate rigging adjustment.

Solid spruce spars, reinforced at highly stressed point by dural side plates are used. The ribs are plywood web with spruce capstrips, with rib spacing of five inches. Covering is Haskelite plywood covered with flightex balloon cloth doped on and finished to a glassy surface with fourteen coats of dope. Ailerons are also plywood, covered and finished in the same manner. The ailerons have an area of 5.55 sq ft. and afford excellent lateral control. The aileron control is a typical Gee Bee angular ball-and socket, using ball bearings on all torque tubes. As a precautionary measure, the ailerons are also statically balanced, using a weight forward of the hinge line, concealed, and working within the formed aluminum fillets at the wing butts.

WING FILLETS

The fillets at the junction of the wing and fuselage are worthy of considerable experimentation. This fillet serves a two-fold purpose. One is to reduce the mutual interference drag which is present at this point and the second is to secure a smooth flow of air over the tail surfaces. It is believed that the wing fillets, as fitted to the Super Sportster, are ideal for this particular airplane because the elevator and rudder control are perfect in all flight attitudes. Two types of fillets were tested on the wind-tunnel model for comparison. One type consisted of a small radius at the leading edge of the wing and increase in radius towards the trailing-edge where it was maximum. This fillet proved to be poor on this particular fuselage and wing combination as far as low drag and longitudinal stability was concerned. The second type tested was a fillet of constant radius from leading-to trailing-edges of the wing. Of this latter class, three complete tests were made, exclusive of no-fillet test run. These model fillets corresponded to full-scale fillets with radii of 6 in., 8 in., and 12 in. Each radius was constant. A full-scale radius of 8 inches was found to give the best results for the Super Sportster. Check runs on longitudinal stability showed that the flow over the tail was satisfactory throughout the range of angles and there was no break in the complete model lift curve.

TAIL SURFACES

The tail surfaces of a racing airplane should be of sufficient area to permit all necessary control at stalling speed and also not be larger than necessary because of parasite drag. Furthermore, large surfaces are apt to be over-sensitive at high speeds.

The tail surfaces are of cantilever type, all wood construction, similar to the wing. They are designed for 75 lbs. to the square foot, with margins of over 100%, which, together with the method of attachment on the fuselage at widely separated points, gives tremendous rigidity. This construction was much heavier than was necessary but we wished to be absolutely sure that there was no possibility of any vibration being set up due to flexibility.

The stabilizer area is 7.5 square feet. A fillet of 2 inch constant radius is fastened to the stabilizer and held against the side of the fuselage by spring tension and travels up and down with the stabilizer against the fuselage during adjustment.

The stabilizer control is screw-type, operated by a wheel directly in front of and at right angles to the seat, within easy reach of the pilot, with his eyes on the course. The stabilizer has 15 degrees of travel, being hinged about the front spar. In actual practice, we found that no adjustment was necessary for landing, takeoff or flying after the proper adjustment was once

made. The elevators are controlled by cables from the stick to a ball-crank mounted directly below the stabilizer front spar, thence to the elevators by a push-pull tube with ball-bearing joints.

The control stick was unusually long and geared down in such a way as to make a very small movement of the control surfaces with a large movement of the stick. The control proved to be very light and very sensitive.

THE RUDDER

The rudder is somewhat different from the usual in rudder construction and design. It is merely a movable end of the streamlined fuselage. The reason for this thick rudder is two-fold. From previous experience it was found that a thin rudder acting between the converging streams of air on each side of the fuselage was entirely too sensitive at high speeds if of sufficient size for control of stalling speed. The rudder is nearly 12 inches thick at the hinge-line and the sides of the rudder are therefore nearly parallel to the flow of the airstream on each side. This makes the rudder action soft at high speeds while of sufficient area for complete control at stalling speeds. This peculiar rudder excited a great deal of comment, the general consensus of opinion being that the rudder would be entirely ineffective, especially at low speeds. As a matter of fact, the actual operation proved exactly the opposite, sensitivity at stalling speeds being more noticeable than at high speeds.

ENGINE COWLING

The engine cowling, regardless of type or characteristics, should permit sufficient cooling of the engine cylinder heads and barrels. It should also be so constructed as to allow smooth air flow around the fuselage and have as large an anti-drag component as possible. At this point, it might be said that a large number of tests to determine the best chord length, angle to the thrust line, and fore-and-aft position could be made for the best combination for this particular model. Time, however, was the limiting factor and experience dictated the general lines to be followed for the design of the engine cowling. However three types were tested on the wind-tunnel model and drag values were obtained for each type.

The results of these tests showed the single-camber cowl to be better than the other two types as far as drag is concerned. It was believed that cooling would be sufficient under all conditions in which the airplane was to be flown. This cowl was adopted and, it might be added, the cooling was found adequate and the flow of air behind the cowl and along the fuselage was excellent. This fact is attested to by the exhaust smudge on the fuselage after a trial run with a rich mixture.

The second cowling, with a double-camber surface, showed a higher drag in the tunnel than the single-camber type. The drag of the complete model with this cowl was 6.5% greater than the single-camber cowling.

The third type of cowling was the poorest of all from the drag standpoint. As tested, this cowling showed 15.7% more drag than the model with the single-camber cowl. From these tests, the conclusion was reached that the anti-drag characteristics obtained from the "airfoil action" of a cowl is of prime importance in the design.

From past experience we expected considerable trouble from the N.A.C.A. cowling, and governed the design accordingly, but in spite of our precaution the cowling persisted in sliding forward. It was held by its leading edge, supposedly the strongest part of the cowling, by turnbuckles. This leading edge was reinforced by a half-inch tubing rolled into the cowling. In spite of the extra strength of this arrangement, the tendency of the cowling to move forward was so great as to roll the

entire leading edge inward, tending to turn the entire cowling wrong side out. We found it necessary to reinforce nine points of attachment as well as to build up ribs inside the cowling at this point, to hold them from falling back.

THE LAUDING GEAR

The landing gear is, more or less, a conventional Gee Bee type of fork and shock absorber, having an Aerol strut with five inches of travel, working on air and oil.

The chassis structure of the Super Sportster consists of a "V-type" brace, the ends of which are fastened to the fittings along the line of the wing spars. At the apex of the "V" is a horizontal fork to the wheel axle. The shock-strut leads to the front spar and the lower end combines with a fork to straddle the wheel. The chassis "V" structures also serve as members of the flying structure. The front and rear flying wires from the wing panels are merged at the apex of the "V" and the loads are transferred from this point through the "V" structure and through a heavy, single, streamline wire to the fuselage centerline. This feature permits a lighter structural weight as the landing gear "V" plays a double role. The maximum loads in the "V" (from landing) and the loads from the flying wires, as wing restraining members, occur at different times. That is, when a landing is being made, the loads in the flying wires and hence the loads induced into the chassis structure from the wires is at a low value and conversely, when flying, the chassis structure was performing as part of the flying structure.

Warner Aircraft wheels and brakes are actuated by the conventional Gee Bee system of "full back on the stick" with directional control by the rudder pedals. The 6.50-10 Goodrich tires are enclosed in boots which are attached to the wheel forks in such a way that they travel straight up and down with the wheel, keeping in line of flight and keeping the wheel and tire covered to a maximum in all positions. The Goodrich sponge rubber tail wheel is used with a three-inch, oleo-type shock absorber, the whole unit being contained within the rudder, which, it will be remembered, is 12 inches thick at its hinge line. The tail wheel is thus controlled by the rudder, giving positive ground control when taxiing or landing. The wheel is held in line of the rudder by a cam action which is releasable, allowing the wheel to swivel 360 degrees on its vertical axis. This makes the ship easy to handle in the hangar and eliminates the use of a "dolly."

THE COCKPIT

The cockpit is situated just ahead of the stabilizer. The main reason for this is visibility, inasmuch as the fuselage at this point has changed from the huge circle, 61 inches in diameter at the wing butts, to an ellipse 56 inches deep and slightly wider than the pilot's shoulders at the top longeron. This allows the use of a small cabin which streamlines well into the fin, and at the same time allows the pilot to look down at the side and around the fuselage at the best possible angle. The windshield is three piece "shatterproof glass" The covering from the windshield back to the head rest is Fibroid, secured through specially designed catches, making this cover removable by the movement of a small lever on the left side. This allows the pilot to release the cover in an emergency and exit through the top, or in case of oiling up the windshield, allows him to release this cover, and with the windshield fixed in place, fly the ship like an ordinary open-cockpit job.

Access to and from the cockpit is by means of a door in the side of the fuselage. By means of a lever just ahead of the door, the hinge pins can be withdrawn, and the door itself instantly released. By this means, the pilot, in case of emergency, could put his head be-

tween his knees, release the belt, and roll over, instantly being clear of everything with the exception of the stabilizer, which having no bracing of any kind, and being right at the door, can not possibly catch or injure the pilot. This gives the pilot two means of exit in case of emergency.

The pilot's seat is adjustable, by means of a wheel on the left hand side, allowing the pilot to adjust himself to the most comfortable position for visibility.

The instrument board is fully equipped with navigation' and flight instruments. A Lewis Engineering Co. thermacouple, with selector switch is installed, with the Fahrenheit gauge as new as possible in line with the pilot's vision during a flight, where he can note the cylinder head temperatures without taking his eyes off the course. A small hand-operated counter is provided for recording laps.

Ventilation of the cockpit is provided by a three inch flexible tube, bringing fresh air from a scoop just forward of the cylinders on the engine. This stream of perfectly fresh air at rather high velocity is controlled by a knob on the instrument board which forces a deflector plate against the tube outlet, closing off or on, and deflects the air at will. The ventilator behind the pilot's head allows exit of the air and brings circulation of fresh air to the pilot's face without unpleasant draught. The air exhausts through the joint of the fuselage and rudder.

Two gasoline tanks of eighty-gallon capacity each are provided, with a shut-off valve at the extreme lower left of the instrument board, allowing either or both tanks, or the twenty-five gallon reserve to be used. Oil is carried in a twenty-gallon, flat, corrugated tank installed in the engine compartment, forward of the firewall.

A specially designed throttle, spark, and altitude control, having large rigid knobs and individual friction adjustments, is used. This control unit consists of a lever controlling the Hamilton Standard controllable pitch propeller and also the control for the Smith controllable propeller. Thus, engine controls are in one strong, neat-appearing and accessible unit, requiring the use of the left hand only and not requiring the shift of hands on the stick for any operation.

The throttle is of such rigid construction as to allow the pilot to use it as a hand to steady himself while flying along at high speed in rough air. From the gas tank section back, the fuselage turtle deck is of plywood construction, the sides being built up of fairing and covered with fabric.

Disappearing handles are provided for use in lifting the tail for any purpose, as is also a rest contained within the fuselage, under which a "horse" can be placed without damaging the fairing. As the tail wheel is full swivelling, it is not necessary to place the tail wheel on a "Dolly" for maneuvering about the hangar.

Two hand holes with spring covers opening inward are provided on the right and left sides of the windshield allowing the pilot to clean the windshield in flight. These holes are ordinarily kept covered to exclude any exhaust gases.

GENERAL

Exhaust gases are deflected to the proper points within the N.A.C.A. cowling by special stacks and allowed to mix with the air passing through the engine and out the rear edge, thus eliminating the possibility of disturbing the air flow around the outside of the cowl.

The signs of smoke from the exhaust, evenly distributed along the fuselage is visible proof of the soundness of design as far as air flow is concerned.

Owing to the bulkiness of the fuselage, the first impression gives one the idea that the ship is tremendously short coupled, as well as having extremely small tail surfaces, which however is an optical

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GEE **BEE** (Continued from Page 277)
Illusion, as actually the tail area and the distance
from the leading edge of the wing to the elevator
hinge is greater than in the 1931 ship. The tail sur-
(See next Page)

face area in relation to the wing area is greater than standard practice, being 20.75%. The entire ship is designed with a load factor of 12 at angle of attack, with the exception of the tail surfaces, whose load factors were even higher. This resulted, in a weight of 1,850 lbs., light.

GENERAL SPECIFICATIONS

Dimensions and Weights

Span	25 ft. 0 ins.
Length	17 ft. 8 ins.
Height	8 ft. 2 ins.
Net wing area	75 sq. ft.
Root chord	53 ins.
Wheel tread	76 ins.
Max. fuselage diameter	61 ins.
Aspect ratio	6 : 1
Incidence	2.5 degrees

Dihedral	4.5	degrees
Weight empty		1,840 lbs.
Racing gross weight (50 gals. fuel)		2,415 lbs.
Max. gross weight (160 gals. fuel)		3,075 lbs.
Total gas capacity		160 gals.

Performance

High speed		294.38 mph.
Cruising speed		260 mph.
Landing speed (est.)		90 mph.
Rate of climb		
Fixed pitch propeller (est.)		3,550 ft./min.
Variable pitch propeller (est.)		6,100 ft./min.
Endurance		
Full throttle (160 gals.)	2.14	hrs.
Cruising speed (160 gals.)		3.56 hrs.
Range		
Full throttle (160 gals.)		630 miles.
Cruising speed (160 gals.)		925 miles.