

Propulsion for self-launching sailplanes

NORMAN E. GOWIN

Presented at the 8th OSTIV Congress, Cologne, Germany, June 1960

Abstract

The capability of the self-launching sailplane for expanding the scope of soaring activity is discussed. After enumerating the requirements for sailplane propulsive means, current types of powerplant and their possible applications to sailplane propulsion are considered. Status of development and limitations of the various propulsive schemes are discussed and conclusions drawn as to the most promising direction in which effort can be applied to further the development of propulsion for self-launching sailplanes.

Growth of soaring activity has been limited to a great extent by lack of means for launching sailplanes. Glider operations have been welcomed at only a limited number of commercial airfields, where airplane towing is available at any time by a fixed-base operator. On the other hand most operations have been sparked by one or two enthusiasts who have formed club organizations which operate their own launching equipment at their own field, or else there is a close tie-in with a fixed base operator at an out-of-the-way airport who provides aero-tows on the week-end. These latter operations are usually from grass strips which results in the curtailment of soaring activity during winter and early spring because of snow and wet ground. As a consequence many good soaring days are forfeited, for it has been demonstrated that thermals of at least 10 ft./sec. develop in the Elmira, New York area during January and February, even with the ground snow-covered. Besides the limitations on soaring activity in areas where operations have been established, there are many areas where potential soaring conditions have never been explored, or have been tried only to a limited extent. An example of the launching problems attendant upon exploratory flights was contained in the account by Mancuso [1, 2] of his wave flights over the Tehachapi Mountains in California. Before a permanent base of operations was established about 35 miles from the release area, one aero-tow of about 120 miles had been attempted and a 50-mile tow was made for the flight which took him to 37,500 ft.

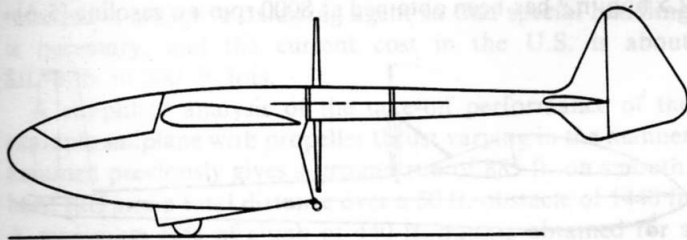


Fig. 1

FIG. 1 C 10

A further draw-back to the expansion of soaring activity has been the need for a launching crew. The direct means of alleviating the need for launching crew and at the same time extending soaring to a year around activity, wherever and whenever soaring conditions exist, is the self-launching sailplane.

The need for the self-launching sailplane has been recognized and attempts have been made at installing auxiliary powerplants on existing designs. But more promising results have been obtained with sailplanes designed with propulsive means in mind. The number of different designs which have been constructed, however, are limited. An early example was the German C 10, a single-place design built in 1942. A pod and boom configuration, it incorporated a two-cylinder engine of 18 horsepower driving a folding propeller mounted concentric with the tail boom (fig. 1). More recently Nelson in the United States produced the all-metal "Hummingbird", which evolved from two previous self-launching sailplane designs [3]. The two-place "Hummingbird" (fig. 2) features a retractable four-cylinder engine of Nelson design, with direct drive to a propeller. A two-place design was chosen since the larger engine required over that for a single-place gave a higher power to weight ratio. Also, the larger physical dimensions provided more space for powerplant stowage.

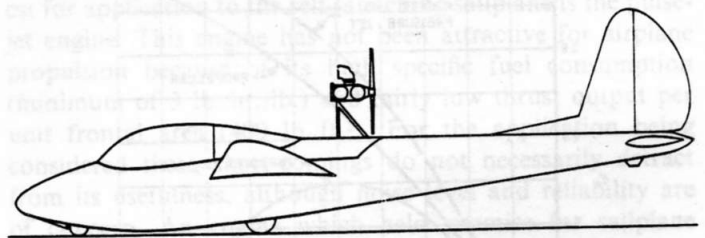


FIG. 2 NELSON "HUMMINGBIRD"

Fig. 2

A number of requirements affect the selection of an auxiliary powerplant for sailplane propulsion. Emphasis in this paper is placed on providing power for launching only. Ease of restarting while airborne, endurance and range are not important factors for consideration. Thus, the primary requirement is to provide adequate take-off performance for grass strip operation. Once airborne sufficient excess power must be available to maintain a rate of climb of at least 300 ft./min. in still air so that areas of down air may be traversed with minimum loss of altitude. Experience with biplane trainers towing two-place training gliders shows that this climb performance would be adequate for launching in thermal conditions. Also, the same operating experience shows that a fuel load sufficient for twelve minutes of operation is adequate for obtaining a launch into a strong thermal at 2000 ft. above the launching site. A further requirement is that the propulsive device have a low residual weight after launch so that the turning performance of the sailplane is not unduly compromised by a high wing loading. Of equal importance is the requirement that the aerodynamic configuration of the sailplane not be compromised to accommodate the propulsive device. Reliability is an important factor for sailplane propulsion, as it is for any aircraft propulsive means.

The factor of cost is tied in with the other requirements, but it has an important bearing on the selection of a powerplant. For instance, a solid propellant rocket engine may have a low residual weight, but is unacceptable on the basis of the

high fuel cost. One criterion for cost is that the total of first-cost, up-keep and fuel for the operating life of the propulsive device should compare favorably with the cost of aero-tows for the same number of flights. However, cost can be weighted less as a particular propulsive device increases the flexibility of operation of a self-launching sailplane.

The powerplant weight requirement needs further discussion. Residual weight is related to propulsive efficiency; for a given thrust horsepower required the higher the propulsive efficiency, the lower the power output required of the engine, hence the lower the powerplant weight. On a kinetic energy basis, the propulsive efficiencies of applicable devices for propulsion by reaction may be shown to vary with velocity ratio as indicated on fig. 3. Velocity ratio, V/V_j , is defined as the ratio of the flight velocity to the jet or slip-stream velocity. Since sailplane flight velocities are low, the direct thrust powerplants, i.e., rocket and turbojet engines, give very low velocity ratios with correspondingly low propulsive efficiencies. On the other hand propulsive efficiencies approaching 85% are obtained with well-designed propellers. Consequently, the weight advantage should rest with a propulsive scheme utilizing a propeller.

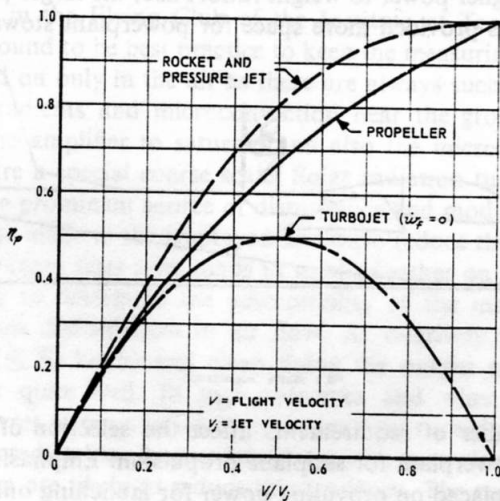


Fig. 3 PROPULSIVE EFFICIENCY VS. VELOCITY RATIO

In order to make a comparison of the various propulsive devices applicable to the self-launching sailplane a frame of reference must be established. Since the main concern is with take-off and climb performance, the most direct way of making a comparison is to consider a hypothetical sailplane. The assumed characteristics of the design are as follows:

- Single-place
- Wing loading, W/S = 7 lb./ft.² at take-off
- Wing area, S = 140 ft.²
- Weight, W = 980 lb., from above
- Max. lift coefficient, CL_{max} = 1.4 with flaps in take-off position

A rough weight breakdown for the above is:

- Basic sailplane empty weight 500 lb.
- Pilot and parachute weight 200 lb.
- Installed powerplant and fuel weight 280 lb.

The take-off thrust required is based on experience with aero-tow operations which have shown that a static thrust to weight ratio of at least 0.20 is necessary for satisfactory take-off performance [4]. Thus, for the example sailplane utilizing

a propeller, a static thrust of 196 lb. is required. Determination of brake horsepower requires assumptions as to the propeller characteristics. For a fixed pitch propeller designed for take-off and climb, the thrust output may be represented as decreasing linearly with velocity from the static value to 0.6 of the static value at take-off velocity. With the take-off velocity, V_{TO} , defined as $1.2 V_{STALL}$ for the take-off configuration, a value of 77.6 ft./sec. is obtained for a wing loading of 7 lb./ft.² and a CL_{max} of 1.4 at standard sea level conditions. Thus, the thrust horsepower developed at take-off would be 16.6 horsepower. The propulsive efficiency of a propeller used for the self-launching sailplane will be of the order of 70% by reason that it be kept to a relatively small diameter and turn at a relatively high rate of speed in comparison to the usual light-airplane practice. The required output of the powerplant is then 23.7 horsepower. This is the minimum power necessary for the assumed conditions and would apply for a direct drive to the propeller. (See Appendix for specifications of aircraft powerplants currently available which are satisfactory from a power and weight standpoint.)

When consideration is given to maintaining a good aerodynamic configuration for the sailplane and the fuselage volume available for powerplant stowage, it appears that a power transmission must be provided between the powerplant and the propeller, with the powerplant in a fixed position. The power losses associated with a transmission scheme mean that a more powerful, and hence larger, powerplant must be used than would be required for a direct drive arrangement, but the weight penalty is offset by the increased soaring performance of a clean design. A proposed single-place fuselage design which maintains a good aerodynamic shape is shown in fig. 4. The thrust line is kept low by using a small diameter propeller, thus minimizing the nose-down pitching moment with thrust applied. At the same time the stowage space required is kept to a minimum. For the arrangement shown, power transmission is accomplished by exhausting compressed air at the propeller blade tips. The source of compressed air is a centrifugal blower driven by an internal combustion engine. Direct drive between the engine and compressor may be used since an engine with high specific output, obtained at high rpm, is desirable from a weight standpoint. An engine currently under development which holds promise for this application is the NSU-Wankel rotary engine. A bare engine power to weight ratio of 2 bhp/lb. is possible with this design and a specific output of over 2.5 bhp/in.³ has been obtained at 8000 rpm on gasoline [5.6].

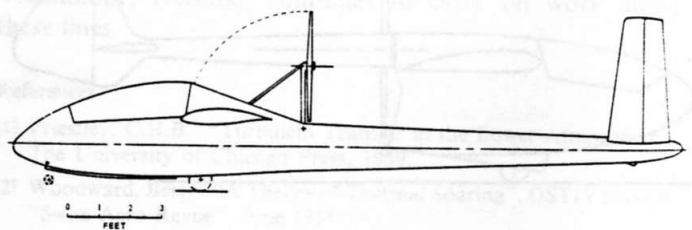


Fig. 4 PROPOSED DESIGN

One possible drawback to the compressed air drive is that the thrust horsepower at take-off velocity is of the order of 40% of the brake horsepower output of the engine, mainly because of the losses at the propeller and the compressor. The propulsive efficiency of the pressure jets for driving the propeller may be kept fairly high, of the order of 90%, since

the propeller tip speeds approach the jet velocity (see fig. 3). For an overall efficiency of 40%, the example sailplane would require an engine with an output of 41.5 horsepower—almost twice that required for a direct drive. Final choice between the two arrangements would be affected by the weight and cost of gear reduction and retraction problems encountered with the direct drive arrangement. It may develop that the same engine would be used in both cases, with a de-rated turning at lower rpm without gear reduction being utilized for the direct drive. An idea of the space required for mounting the NSU-Wankel engine is obtained from fig. 5, which shows a compressed-air drive arrangement. The engine layout, based on the dimensions of an experimental model, includes provision for water cooling with a radiator mounted ahead of the propeller. By having the engine mounted in a fixed position, center of gravity travel between propulsive means operating and retracted is minimized.

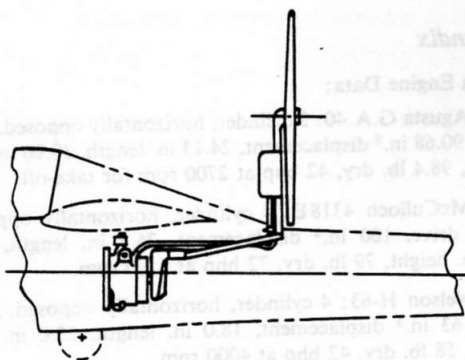


FIG. 5 COMPRESSED - AIR DRIVE ARRANGEMENT

Another propulsive means considered utilizes the propeller with hydrogen peroxide rockets at the blade tips. The same propeller mounting arrangement as shown previously on fig. 4 could be used. A pump is required to deliver the hydrogen peroxide to the propeller hub; centrifugal force would then carry it to the tip thrust chambers where a catalyst decomposes it to steam and oxygen to produce thrust. For the example sailplane about 90 lb. of hydrogen peroxide would be required for 12 min. of operation. This fuel load is well within the load carrying capability allowed for the reference sailplane. However, this propulsive scheme has two severe limitations: hydrogen peroxide of the concentration required is an active oxidizing agent so that special handling is necessary, and the current cost in the U.S. is about \$0.70/lb. in 300 lb. lots.

A simplified analysis of the take-off performance of the example sailplane with propeller thrust varying in the manner assumed previously gives a ground run of 885 ft. on smooth, hard turf and a total distance over a 50 ft. obstacle of 1440 ft. A maximum rate of climb of 440 ft./min. is obtained for a full gross weight of 980 lb. as compared to the requirement of 300 ft./min. previously specified. The take-off and climb performance thus appear to be more than adequate.

A turbojet with the same static thrust as that for the propeller would yield different performance, since the thrust output may be considered constant for the flight velocity range of the sailplane. The ground run for the example sailplane with a constant thrust of 196 lb. is reduced to 600 ft., while the maximum rate of climb is increased to 920 ft./min. It is

evident that a lower thrust engine may be used to obtain performance comparable with that for the propeller-driven design. A take-off ground run of 885 ft. could be achieved with a constant thrust of about 140 lb. This amount of thrust would yield a rate of climb of 620 ft./min. Considering that a thrust to weight ratio of at least 1.5 may be obtained for a small turbojet engine, it cannot be eliminated on the basis of having high residual weight. For a specific sailplane design it is likely that the gross weight would be less than that assumed for this study. As a result, the thrust required for take-off could be reduced further with an additional saving in power-plant weight. However, such a small turbojet engine is not likely to ever be developed because of the limited demand. Small gas turbines are being developed for use as auxiliary power units in military applications and for one-man helicopters. These are designed for shaft power output and would appear attractive for powering the self-launching sailplane, since the power to weight ratio is around one horsepower per pound. However, further gear reduction would be required for a propeller drive and sound muffling would be required to reduce the noise to a tolerable level. But without further consideration, both the turbojet and shaft-turbine engine are eliminated on the basis of cost, which now runs in U.S. dollars to five figures.

Another direct-thrust propulsive device which holds interest for application to the self-launching sailplane is the pulse-jet engine. This engine has not been attractive for airplane propulsion because of its high specific fuel consumption (minimum of 3 lb./hr./lb.) and fairly low thrust output per unit frontal area (400 lb./ft.²). For the application being considered these short-comings do not necessarily detract from its usefulness, although noise level and reliability are of concern. An engine which held promise for sailplane application was being developed for a one-man helicopter in 1953 [7]. A thrust output of 105 lb. was reported for a unit 5 in. in diameter, 32 in. long and weighing 17.5 lb. Two of these engines would provide adequate thrust for the reference sailplane and could be mounted side-by-side so as to be readily retractable into the fuselage (fig. 6). Nothing further has been heard of this engine, although at the time, it was reported, the designer quoted a price of \$85/engine for the first lot of fifty.

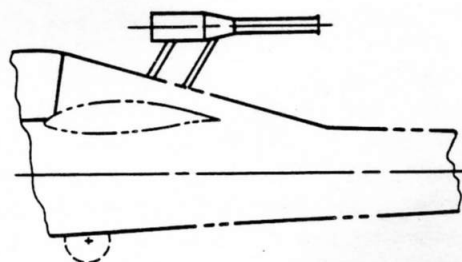


FIG. 6 PULSE - JET ARRANGEMENT

The solid propellant rocket was previously excluded from consideration on the basis of high fuel cost. Another form of rocket which appeared to hold possibilities for sailplane application utilizes water as a propulsive medium. A pressure head is provided by liquid carbon dioxide or compressed air to exhaust the water through a convergent nozzle. A study of take-off performance with a rocket pressurized to 500 psi with carbon dioxide and producing 300 lb. thrust showed

that for the reference sailplane fully loaded to 980 lb. (i.e., 224 lb. of water for a rocket mass ratio of 0.8), the amount of water would be sufficient to accelerate only to take-off velocity. Increasing the pressure head will not significantly improve the performance since the mass flow varies inversely as the square root of pressure ratio for constant thrust output. By adding an additional 276 lb. of water which would be exhausted by the time take-off velocity is reached and increasing thrust to 1000 lb., an altitude of the order of 150 ft. could be reached. The exact altitude depends on the flight technique used—whether full thrust is maintained to obtain excess kinetic energy followed by a zoom climb, or whether thrust is reduced by throttling after take-off to maintain a steady climb. In any event the propulsive scheme yields unacceptable altitudes for the amount of water which can be utilized.

Of the propulsive schemes which have been considered, only the direct-drive propeller, compressed-air drive propeller and the pulse-jet are now acceptable for application to the self-launching sailplane. Since each of these propulsive devices plus fuel will weigh much less than the 280 lb. allowed in the weight breakdown for the reference sailplane, application of a particular device with thrust output assumed for this study would result in increased performance for the same size sailplane because of reduced wing loading. Alternatively, the same performance as shown for the reference sailplane could be obtained with a smaller powerplant. In any event the most desirable results would be obtained from a sailplane designed with a particular powerplant in mind. On the basis of specific output and specific weight, the NSU-Wankel rotary engine could well find use in the self-launching sailplane. Considering that this engine should reach volume production with attendant reduction in unit cost, its desirability is further increased.

References

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- [2] Mancuso, Dewey, J.: "High Flight—Part II", Soaring, Vol. 23, No. December 1959.
- [3] Perl, Harry, N.: "The Powered Sailplane", Soaring, Vol. 19, No. May-June 1955.
- [4] Kidder, R. C.: "Design Study for the Evolution of an Economic Tow Plane", Paper presented at Twenty-Second Annual Meeting the Institute of the Aeronautical Sciences, New York City, January 25-29, 1954.
- [5] Willoughby, V.: "Low-Down on the NSU-Wankel", The Mot Cycle, Vol. 104, No. 2958, pp. 190-194, 18 February 1960.
- [6] Willoughby, V.: "NSU-Wankel—Progress and Future", The Mot Cycle, Vol. 104, No. 2959, pp. 220-224, 25 February 1960.
- [7] Anon.: "Noise is Cut in New Pulse-Jet Engine", Aviation Week Vol. 59, No. 12, p. 41-42, September 28, 1953.

Appendix

Piston Engine Data:

1. Agusta G.A. 40: 2 cylinder, horizontally opposed, aircooled, direct drive, 90.68 in.³ displacement, 24.13 in. length, 30.90 in. width, 15.35 in. height, 98.4 lb. dry, 42 bhp at 2700 rpm for take-off.
2. McCulloch 4318E: 4 cylinder, horizontally opposed, aircooled direct drive, 100 in.³ displacement, 26.7 in. length, 28.0 in. width, 14.5 in. height, 79 lb. dry, 72 bhp at 4100 rpm.
3. Nelson H-63: 4 cylinder, horizontally opposed, aircooled, direct drive, 63 in.³ displacement, 18.0 in. length, 25.0 in. width, 17.5 in. height, 58 lb. dry, 42 bhp at 4000 rpm.

Gas Turbine Engine Data:

1. Solar YT62 Titan: Shaft turbine with centrifugal compressor. 24.75 in. length, 12.5 in. width, 50 lb. dry, without gear reduction. 55 shaft hp at 56,700 rpm, 12 lb. residual thrust.