

A Realistic Aim for Man-powered Flight

By T. NONWEILER, B.Sc., A.F.R.Ae.S., A.F.I.A.S. (Queen's University, Belfast, Northern Ireland)

Presented at the 7th OSTIV Congress, Leszno, Poland, June 1958

The attainment of flight by muscular power has long been one of man's aspirations, and there is no doubt that its realisation has been brought much closer by modern advances in the design of powered aircraft. To take advantage of these advances it would be essential to design the man-propelled aircraft as a fixed-wing propeller-driven monoplane, and there is naturally some question whether this is fundamentally the right way of attempting muscular flight. There are many who feel that the ornithopter is a better basis for design, in so far as it is a reciprocating mechanism and so matches man's muscular activity. This is an idealistic view but, in the author's view, not a sound one: the same philosophy might be applied to the use of the reciprocating engine itself in aircraft design, yet it has never found fruitful expression in practice. This is not to disparage the efforts of those at present working in many countries on ornithopter design. Whether or not man-propelled flight is achieved this way, we know so little about ornithopters, that this pioneering work is extremely valuable for its own sake. But it is merely because we know so little about the mechanical and aerodynamic problems of flapping flight that it seems a mistake not to take advantage of the fifty years' experience of fixed wing machines in attempting to achieve man-powered flight. Moreover, with a fixed-wing design, it is possible to make design and performance predictions on the basis of this experience with a fair amount of certainty. This is a more powerful argument than perhaps it deserves to be, for if we never attempted the unpredictable all the really surprising technical advances would be denied us: but it is none the less cogent, because the construction of a fixed wing aircraft is bound to cost a great deal of money, and the sponsors would naturally need to be persuaded that the expense was reasonably likely to be justified by success.

The man-propelled helicopter is another form of design which deserves attention, and which also may be aided by the recent advances in powered forms of this type of aircraft. Although the author has not seen any serious design studies, there seems every reason to believe that the helicopter may be a better and easier means of achieving flight than the fixed wing machine. It is certain at least that it is fundamentally a more efficient means of achieving height, but a less efficient means of achieving forward locomotion. If we should argue about the comparison of the two machines on these grounds we would need to decide perhaps what we mean by "flight" and what we expect the man-propelled machine to do. The most likely outcome of such an argument would be that such a comparison was unrewarding, and that the two forms of machine could be developed side-by-side to perform quite different and nonconflicting feats of strength. For there is no doubt that in the near future, at least man-powered flight would be more likely a feat of strength than a reasonable form of transport.

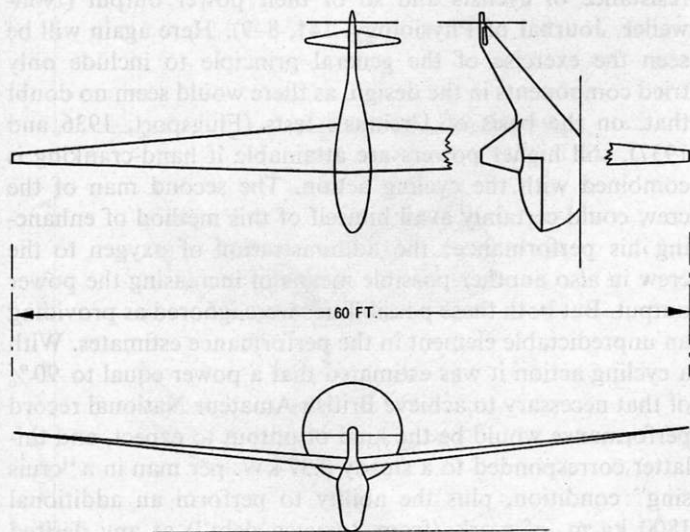
It was with the idea of finding out how energetic an activity flying would be, and predicting what kind of performance might be expected in flight that the author undertook a

detailed design study of a man-powered aircraft, which has recently been published in the *Journal of the Royal Aeronautical Society* (October, 1958). For the reasons already mentioned the aircraft was envisaged as a fixed wing monoplane, and it was designed to carry two men. Perhaps the most important question to be resolved was the power they could be expected to generate, and a cycling action was chosen, not because it was necessarily the best but because wind-tunnel tests have enabled a reliable prediction to be made of the air resistance of cyclists and so of their power output (Nonweiler, *Journal of Physiology*, 141, 8-9). Here again will be seen the exercise of the general principle to include only tried components in the design, as there would seem no doubt that, on the basis of Ursinus's tests (Flugsport, 1936 and 1937), still higher powers are attainable if hand-cranking is combined with the cycling action. The second man of the crew could certainly avail himself of this method of enhancing his performance; the administration of oxygen to the crew in also another possible means of increasing the power output. But both these possibilities were ignored as providing an unpredictable element in the performance estimates. With a cycling action it was estimated that a power equal to 90% of that necessary to achieve British Amateur National record performance would be the kind of output to expect, and this latter corresponded to a steady 0.37 kW. per man in a "cruising" condition, plus the ability to perform an additional 1800 kg. m. of work (from "oxygen debt") at any desired rate, at least up to a maximum of about 0.8 kW. The useful output would of course be reduced by losses in the transmission system and in the propeller—which was envisaged in the design as nearly 2.5 m. in diameter: altogether only about 75% of the above quoted figures was reckoned to be obtainable as useful work.

The overall design used is indicated in the figure, and its only novel feature lies perhaps in the design of the fuselage which was merged into the tail fin, and its horizontal sections given an aerofoil shape. This provided a minimum fairing of very low drag round the men who were mounted in the cycling position. The wing design was optimised to provide minimum power for flight at 10 m. altitude, and of course its features were particularly sensitive to the estimated weight. Various types of wing construction were envisaged at the outset, but in the end a conventional monocoque wing, fabricated with birch ply skin and spruce ribs was considered to be the lightest. It was regarded as essential to avoid the drag of wire braces, and also to maintain a correct surface contour even under load, and had this not been a requirement maybe a lighter method of construction, involving paper or fabric covering, would have sufficed. Whether the maintenance of the true wing contour is really essential (to produce low drag) at the Reynolds Number appropriate to flight—rather under a million—is not known, but this again is an example of the doctrine of safety deliberately introduced into this conservative study. Even with the stable wooden skin, and assuming a load factor of 3, the weight of the 16 sq.m. area of wing was calculated as only 35 kg., and the empty weight of

the aircraft was estimated as about 77 kg. Perhaps the ultimate factor of 3 might safely be reduced to $2\frac{1}{2}$: it is in this of course one is enabled to effect savings over the weight which would normally be needed in constructing a sailplane, because the man-powered machine is—at least at its inception—unlikely to be a fully-aerobatic, all-weather aircraft. Ultimately one might hope to link up with the sailplane, to make gliding a sport independent of take-off assistance, but this day seems some way off.

Maybe this day will be brought closer by the development of wing suction. But this particular facility was not envisaged in the study we are quoting. In this, the form of the wing section, which the construction is meant to preserve, was carefully chosen from the many designs of low-drag aerofoils

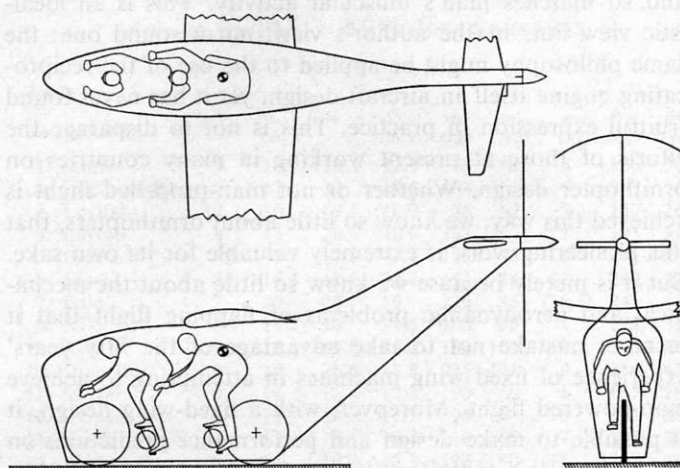


which have been tested, and which show a laminar flow "bucket" in the lift-drag polar by virtue of their "rooftop" pressure distribution. Essentially one is looking for a section with a high/lift drag ratio, with special preference for those which provide this at high C_L . This leads naturally to choice of very highly cambered low-drag wings. There is not a great deal of wind-tunnel information on drag in the range of Reynolds Number of interest in this context, but on the basis of his own experiments the author chose a NACA 65A (10) 12 section, though recent tests by Wortmann (*Z. Flugwiss.*, 5 (1957) Heft 8, 228) give details of other sections which appear superior. Whatever similar section is chosen it would be probably true that the flight lift coefficient would be all the time best kept very high, at values not much less than unity. With the large camber, this is perhaps not too close to the stall, which appeared to be gentle in the tunnel tests. The large negative lift from the tail, needed to trim, is some disadvantage and the proposed design used on all moving tailplane, but stability considerations ultimately dictate its size rather than trim.

In fact, the actual tail size shown in the drawing appeared subsequently to be inadequate; the high propeller is bound to produce some rather unusual flying qualities and does not improve the plugoid motion which needs plenty of damping in pitch to be stabilised in stick-fixed conditions. The lateral stability is also a little unusual as it transpires that one needs little or no damping in sideslip: indeed the fin size shown,

which may indeed look, by ordinary standards, inadequate in view of the large side area of the fuselage, is in fact too large. The subject of control (including the interesting question of the pilot's control movements) received little attention in the study, and certainly deserves more. The lack of any need for extreme manoeuvrability, and the severe drag penalty of conventional control surfaces, would point to the virtues of wing warping in place of ailerons.

Such questions and many others are dealt with more fully in the reference work, and it does not seem appropriate to re-iterate them in detail here. The particular aspect to which it is wished to draw attention here, concerns the performance estimates, which were founded on what was hoped to be a realistic assessment of the drag. However, ground effect on



induced drag has an overriding importance and it cannot be pretended that the theoretical assessment of this which was used is really very reliable in relation to this particular form of wing: this again deserves further attention. The method of take-off was envisaged as without the assistance of power storage in any form. The aircraft was imagined to commence its ground run by the action of the pedal crank driving to the two bicycle-type wheels of the undercarriage. The gearing between wheels and fixed pitch airscrew was imagined to be chosen so that the two men—developing what we have earlier termed their "cruise" level of power output (which they could sustain more or less indefinitely)—gradually accelerated the machine to a ground speed of about 48 km./h., when the propeller would be about to absorb all the useful power output. This idea certainly demands use of a free wheel, but this would anyway be needed for landing, and the alternative of a variable pitch propeller is perhaps more complicated and a good deal less efficient. Some relief from ground friction would be available from the wing lift in the fixed ground attitude of the aircraft in this preliminary run, which would be likely to last over a minute and cover some 800 m. in still air. At the critical stage mentioned, the men were imagined suddenly to increase power (by increasing the propeller r.p.m.—the driving wheels having freed) by calling on the reserves of their "oxygen debt". Take-off speed would be quickly reached, as the wing loading is less than 15 kg./sq.m., and the men could continue to provide the in-

creased level of power output (taken as 1 kW.) for about another 15 seconds in flight, before fatigue set in as the "oxygen debt" became exhausted, and they were forced to relax to the more gentle "cruise" level of output.

There are of course many other possible means of varying power during flight and take-off, but this seemed the most effective of any—involving a sudden burst of power as in a sprint. Even with this fixed programme of power output there are of course a variety of possible flight paths. But, in a straight line ground track, it was found that the greatest height that could be reached is not much more than 8 m., and the total flight duration from take-off to touch-down no more than about 90 seconds, over distances in still air of up to 1500 m.

These then seem to indicate the limits of man-powered flight without recourse to stored power. We might say that they sound ambitious compared with the pioneer flights of the man-powered aircraft designed by Haessler and Villinger in Germany way back in 1935. In their initial tests, the greatest flight duration of the (one-man) craft was reported as 24 seconds, covering 235 m., and the greatest altitude achieved only some 4 or 5 m. Reports of later tests state that a distance of 400 m. was covered, but this is still far short of the predicted performance of the present design study, and moreover was made with the help of power storage in the form of a bungee take-off catapult (withdrawing into the aircraft to conform with the regulation that all storage equipment be carried, as laid down in the terms of the competition in which they were competing, which was organised in 1933 by the Frankfurter Polytechnische Gesellschaft). However it must be remembered that the German machine was a single-seater—and, in general terms, the more men carried the easier their individual task to provide collective flight—that the pilot, Karl Duennebeil, was not a trained cyclist, and that over twenty years of aircraft development might be expected to produce improvement. The real point, in any case, is that they achieved their results in practice, and not on paper.

The use of stored power for flight raises entirely new possibilities for the attainment of man-powered flight, and there is no doubt that devices of coiled rubber could be capable of absorbing a great deal of work prior to take-off and returning it with high efficiency in flight. Their weight is more than compensated by their power potential. But yet such devices inevitably detract from the impact of an *initial* achievement. There is for example still some doubt about the genuineness of the flights of Haessler and Villinger's machine. It is of little purpose to re-examine these objections: enough to mention that they are made. At the same time, there is no doubt that theirs was a none-the-less remarkable achievement. There is even of course nowadays most unhappily some controversy about the Wright Brothers' first flight in Kitty Hawk, and other such pioneer efforts, on the grounds that they were more ballistic than aerodynamic! In truth of course all flight is partly performed by virtue of inertia previously acquired and to try to separate its contribution is meaningless.

It suffices to set up an arbitrary definition and apparently it would not be making the task of an initial man-powered flight too difficult, by stipulating that it should be the attainment of a ground-track of, say, 1000 m. at a height above 2 m. To preclude power storage raises awkward issues, as even the initial take-off run we have mentioned earlier is a form

of power-storage prior to flight. It would seem therefore that it must be allowed, but its limitation by time (to say 100 seconds) would prevent abuse. The Frankfurt competition allowed up to half-an-hour, and certainly within such a time a huge rubber spring could be wound up! The only problem would be its installation in the aircraft.

The Frankfurt competition regulations also laid down that the flight track should be on a *closed* circuit, without intermediate landing, around pylons 500 m. apart. There is no doubt that this would be a much more persuasive achievement than the straight-line path we have mentioned, as after all a man hanging on a balloon on a windy day can go immense distances in a straight line at the cost of no effort! And it would be impossible to prohibit the use of aerostatic lift as it is inevitably present, however small it may be. Yet flight in a turn can only be achieved at some expense in performance, and moreover at a considerable risk, as it is no easy matter to make a banked turn in an aircraft of perhaps 20 m. span when only a few metres above the ground; necessarily it might have to be a flat-turn and this manoeuvre is very costly in drag. In a correctly banked turn at 2 m. height the 1000 m. straight-line flight of the aircraft described would become a circular path only some 20 m. shorter in circumference (and so of over 300 m. diameter), but it would require a sustained bank of 10° which would be very hazardous at only 2 m. height on an aircraft of 18 m. span like the one projected! To turn at all safely, the manoeuvre would have to be undertaken much higher, when indeed it would of course also have to be a much tighter circuit, because of the decreased endurance of the men, resulting from their efforts in reaching the height needed. The greatest ground clearance at the tip, in a complete correctly banked 360° turn, is in fact calculated as attainable on this aircraft in a 130 m. diameter circle at about 6 m. height, when—banked over at 20°—there would be nearly 2½ m. of air space between the ground and the lower wing tip.

The performances in flat turns are more difficult to predict as it is necessary to calculate the drag of the yawed aircraft, making due allowance for the drag produced by control deflections. However, it is evident that in considering flight round two pylons, they might still provide an impossible challenge if placed 500 m. apart, according to the terms of the Frankfurt competition: in fact, if they were placed 100 m. apart they would provide a stern enough challenge. An alternative formula might envisage a landing in the *opposite* direction to that of take-off: the pylons would then be the boundaries of a 180° turn. This of course is much easier to perform, and it has the required effect of ruling out of order the man who hangs on a balloon; it preserves the elementary test of controlled flight, and moreover it would be a strong dissuasion to anyone to attempt to fly on a very windy day. Certainly on so slow an aircraft, some phenomenal straight-line flights could be made if use was made of a high wind; this however would be a hazardous adventure, as the aircraft is likely to be too fragile to survive gusty conditions.

One might then take the idea to the extreme, and demand merely a flight of a given duration (say a minute) with a landing in the opposite direction to that of take-off. There would be no pylons, and with no mention of distance, the helicopter could compete with the fixed wing aircraft on very favourable terms, especially as its landing direction is more or less arbitrary. This, at any rate, brings our discussion full circle to where we began!