GENERAL DESIGN CONCEPTS OF MAN POWERED AIRCRAFT

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Introduction

Design of a man-powered aircraft represents a compromise between aerodynamic, constructional, crew, operational and structural criterion in trying to achieve a required performance. These are all important. The designer cannot concentrate on one aspect to the exclusion of the others, particularly as they are inter-related.

The earlier man-powered aircraft were designed by relating performance to the crew power outputs, a reduction in power ideally ensuring a longer duration. On this basis it was possible to relate the power to the available aerodynamic and structural data in order to predict the aircraft configuration. This was a realistic approach in view of the information available at the time. It is now evident that the more easily quantifiable aerodynamic, structural, weight and power parameters must also be related to the practical constraints of workshop/hangar availability, group size and expertise, pilot availability and aptitude, prevailing weather conditions and runway facilities.

It is necessary to define a realistic performance objective. Although the £50,000 'figure-of-eight' Kremer course remains the ultimate goal, experience indicates that it will be very difficult to achieve. Although it has been hoped that a dramatic improvement in performance would result from either improved aerofoil sections, or some technique for reducing induced drag, in reality it is more likely to result from our gradually improving knowledge of light-weight structures and constructional techniques. Only one area of operation at present provides any hope of a rapid improvement in performance, that being the utilisation of atmospheric lift in order to gain height and thereby extend flight lengths with man-power assisted glides.

At the present time the longest flight recorded is of 1,355 yards, attained by Squadron Leader John Potter in 1972 during the initial Jupiter trials (1).This suggests that the next performance objective of one mile is within reach and could perhaps be achieved by one of the present generation of man-powered aircraft. Thereafter any extension of flight length along a straight course would generally be restricted by airfield size unless the aircraft was specifically designed for short cross-country flights.

Alternatively, man-powered aircraft could be designed with other performance objectives. The M.I.T. canard biplane project B.U.R.D., for example, is designed to have a compact wing span of 62 ft., to investigate turning manoeuvres at low altitudes(2). Designing man-powered aircraft of compact dimensions capable of flying in force 3 winds in order to investigate low altitude atmospheric lift also provides another field of study(3).

Whatever performance objectives are defined for a particular man-powered aircraft the present day designer has several advantages over the pioneers of the late 50's. We know that true man-powered flight is possible! Much of the basic design data is readily accessible in book form(4). Although there are still gaps in our knowledge, experience has been gained regarding changes in aircraft configuration, new aerofoil sections and different forms of construction.

Before designing new aircraft it is important to assess the lessons learnt from past machines. Unfortunately our knowledge is incomplete in this respect due to lack of written communication from some groups on their findings. Nevertheless it is proposed to review some of the man-powered aircraft development in order to indicate design trends for the future.

It is now fourteen years since the first 'true' man-powered flight when the Southampton University machine covered a distance of 50 yards from take-off. Since then some seventeen aircraft of differing configurations with wing spans ranging from 64 to 132 ft., have achieved man-powered flight. Details of some of these are listed in Table 1.

	Span (ft)	Wing Area (ft^2)	Aspect ratio	Empty weight (lbs)	Flying weight (lbs)	Wing loading (lb/ft^2)	Country	First flight
SUMPAC	80	300	21.3	128	269	0.90	U.K.	1961
Puffin I	84	330	21.4	118	267	0.81	U.K.	1961
Puffin II	93	390	22.0	140	290	0.78	U.K.	1965
Linnet I	73	288	18.5	105	230	0.80	Japan	1965
Linnet IV	83	316	21.9	119	237	0.75	Japan	1971
Malliga Aircraft	64	262	15.6	113	239	0.91	Austria	1967
Sato-Meada OX-1	73	290	17.9	122	245	0.85	Japan	1970
Mercury	120	480	30.0	125	276	0.57	U.K.	1971
Jupiter	80	300	20.7	146	297	0.99	U.K.	1972
Wright Aircraft	71	480	10.5	90	240	0.50	U.K.	1972
Liverpuffin	64	305	13.4	140	300	0.99	U.K.	1972
Toucan	123	600	25.0	209	519	0.85	U.K.	1972
Egret I	74.5	307	18.0	126	258	0.84	Japan	1973
Hurel Aviette	132	581	30.0	145	295	0.51	France	1974
B.U.R.D.	62	640	12.0	130	405	0.64	U.S.A.	1974*

*The M.I.T. 'B.U.R.D.' biplane experienced a structural failure of the wing during the initial take-off. It is now being re-built.

All the aircraft listed are single seat machines except for Toucan and B.U.R.D., both of which have two man crews. The Linnet aircraft resulted from postgraduate projects at Nihon University. Altogether five Linnets were built but only I and IV are described in Table 1. The Egret aircraft follows the Linnet range. Best flights of 43 yards and170 yards have been recorded with Egret I and II respectively (5). All aircraft listed in Table 1 were built by groups, except for the Malliga and Wright aircraft, both of which were built by individuals. Both were completed within six month periods and in the case of the Wright aircraft the work was defined as not exceeding 500 man-hours.

Man-Powered Aircraft Development

It is impossible to discuss the design lessons gained from each of the aircraft listed in Table 1, however it is proposed to discuss four aircraft in order to indicate general trends of value to future designs. The four aircraft are S.U.M.P.A.C., Puffin II, Mercury and Jupiter. These have been chosen as they cover the chronological development of man-powered flight and there is well documented information on these machines (6), (7), (8), (9), (10). The first three illustrate the development trend of aiming for improved performance by power reduction with a corresponding increase in wing span whilst Jupiter has actually exhibited an improved performance.

The configurations of the four aircraft are shown in Figure 1. S.U.M.P.A.C. was built by three postgraduate students at Southampton University. Its actual performance potential is considered to equal that of Puffin I. Although recorded best flights were 650 yards for S.U.M.P.A.C. and 993 yards for Puffin I this difference can be mainly attributed to the lack of hangar and runway facilities of the Southampton group.

Construction of S.U.M.P.A.C. was 'conventional' using spruce for the primary structure and balsa strips for the wing ribs. It was covered with nylon which imposed a weight penalty due to the dope needed to keep the covering taut. Original weight of the aircraft was estimated at 122 lb. whilst the actual weight was 128 lb. A reclining position for the pilot was chosen as tests indicated that the same power could be produced for a reclining as for a cycling position. A reclining position allowed a reduction of the fuselage cross-section and the forces from the pilot to be taken by the seat back, leaving his arms free for control. S.U.M.P.A.C. incorporated the N.A.C.A. 65_3 818 aerofoil section with an assumed C_L of 0.85.

Puffin II was the successor to Puffin I, retaining the same fuselage, tail surfaces and drive/propulsion unit, but with an improved wing. The earlier aircraft had a balsa sheet monocoque construction for the wing that was not completely satisfactory in practice. A new wing construction using a spruce spar and balsa ribs spaced every 4 inches along the wing to preserve a true aerodynamic shape was built for Puffin II. The opportunity was taken to increase the span up to 93 ft. and incorporate an improved aerofoil section, the Wortmann FX-63137 section, with a design C_L of 1.15.

Major problems with Puffin II were with regard to control. The original rudder was inadequate for directional control. It was increased in size and eventually wing tip drag rudders were added to overcome this problem. Man powered flights of about 1,000 yards were achieved but performance was not appreciably better than that of Puffin I. This was largely due to the increased difficulty of controlling the aircraft, the reduced flying speed - 23.2 ft/sec. for Puffin II compared to 29 ft/sec. for Puffin I - necessitating a longer duration for a given distance, and the limited opportunities for flight trials. Due to prevailing wind conditions the number of flights averaged about 25 per year.

Work on Mercury started in 1967 by the Weybridge group, two years after Puffin II had flown. Based on the results of S.U.M.P.A.C., Puffin I and II, the group decided that improved performance could only be obtained with a larger wing span. Design studies indicated that a span of 120 ft. was feasible for an aircraft no heavier than Puffin II.

It was considered that with a large lightweight wing the main problems would be aeroelastic in nature, particularly aileron reversal. The solution was to pivot each wing half at the root about a spanwise axis so that the incidence of each wing half could be varied differentially for lateral control.

The wing primary structure was built of thin aluminium tubing joined by the Czerwinski laced joint technique (11). With thin aluminium tubing welding and rivetted joins are unsuitable. The laced joing method binds the tubes together with glass fibre chord, or tape, which is embedded in an epoxy resin matrix. Secondary structure of the wing consisted of 148 ribs constructed from strip balsa. To minimise the weight of the wing secondary structure, rib structures were optimised in order to withstand flight loadings. Unfortunately the Melinex covering materials applied tension to the ribs and some warping occurred, particularly at the trailing edge, resulting in the actual wing sections not conforming accurately to the designed aerofoil. A gradually reducing aerofoil thickness was employed from the root to the tip based upon the use of the Wortmann FX-68180, FX-68160 and FX-68140 aerofoil sections with an assumed working C_L value of 1.

After 10,000 man hours of labour time Mercury was completed in 1970, under the original name of Dumbo. Following modifications to the angle of incidence of the wing and several months repair work after being damaged during a gust, the aircraft was eventually flown in September, 1971. The Weybridge group only made two flights one of 30 yards length and the second of 50 yards at 3 ft. altitude. They found that power requirements were apparently well within the pilots capability but the second flight was terminated due to lack of directional control.

Since then the aircraft has been taken over by a group at R.A.F. Cranwell under the leadership of John Potter, who renamed the aircraft Mercury. They find that although control response is slow the aircraft is tolerably stable in straight flight. Investigations are continuing into both control and extending the performance. However, with such a large aircraft, one of the major problems is that of getting suitable weather conditions to allow flight trials.

Design work on Jupiter started in 1964 before either the Puffin II or Weybridge projects. The configuration is very similar to that of S.U.M.P.A.C. but with the pilot in a cycling position. Constructional materials are also conventional for that stage of man powered flight, the primary structure being of spruce and the secondary structure of balsa. Wing ribs are spaced at every 3 inches to preserve an accurate shape for the aerofoil, which was an early N.A.C.A. 65_3 - 618 laminar section.

With John Potter as pilot the first flight was made on the 13th February, 1972, and was then flown regularly, until by May when an unofficial record flight of 1,355 yards was achieved. This flight was only terminated in order to land within airfield boundary. Shortly afterwards, on the 60th flight, an officially observed flight of 1,171 yards was made. The official flight was shorter as the pilot was not at his peak physical condition and the aircraft was not operating at the angle of incidence for optimum power (9).

In trying to draw general conclusions from Jupiter performance compared to previous aircraft one is limited by lack of numerical evidence. Several points concerning both the aircraft and the flying experience are worthy of note. The wing is the 'cleanest', in the aerodynamic sense, to be used for a man powered aircraft. Jupiter is a fairly heavy machine for its size resulting in a final wing loading of 1 lb/ft^2.Much of the increased weight of machine is in the wing, not only due to the increased number of ribs but also in making the primary structure much stiffer than for equivalent aircraft. One other design innovation, that of incorporating a wide chord propellor. The characteristics of this are unknown but with a working C_L less than for previous man powered propellors it is possible that the efficiency is improved due to a reduction of both induced drag and profile drag.

Although these may have had some influence it is considered that the improved performance of Jupiter can be largely attributed to the choice of pilot and his opportunity to gain consistent flying experience on the aircraft.By the time of the record flight he had accomplished nearly 60 flights in three months which was more concentrated flying experience than had previously been possible.The aircraft was capable of being flown in wind conditions of up to 8 knots and, perhaps more important, with cross-wind components of 1 - 2 knots. No useful feedback is available on ground-effect as in general terms the pilot found that he could operate more comfortably at 20 ft. than at 3 ft. altitude.

In discussing these four aircraft; S.U.M.P.A.C., Puffin II, Mercury and Jupiter, the practical aspects of operating the aircraft have been emphasised. It is considered that man-powered flight cannot progress unless pilots gain the necessary flying experience. This might necessitate a new form of man-powered aircraft of compact dimensions. capable of being flown in wind conditions of say 10 knots, solely to be used for training purposes. The Liverpuffin aircraft has indicated one approach to such a type of machine, particularly the elimination of lateral controls to simplify pilot operation. To date four aircraft, Linnets III and IV, Liverpuffin and the Wright aircraft have been flown without lateral controls.

This aspect of pilot operation must be investigated further. The pilot should not be an after-thought but an integral part of the design as he provides both of power and the control for the machine. As yet there is no clear answer as to whether the reclining or the cycling position are best. The former appears to be most comfortable for controlling but there is some evidence to indicate that power outputs can be maintained for a longer period from a cycling position. Linnet I had a reclining position, whilst the later Linnets had the pilots in a cycling position. The still more recent Egret series of aircraft have reverted to a reclining position indicating some evidence in its favour. If there is a trend to more compact man-powered aircraft the reduction of fuselage drag could become a major design consideration and this would necessitate the use of a reclining position.

Technical Developments

There are several areas of man-powered aircraft design where our knowledge can be improved through basic research programmes. These concern aerodynamic criteria applying to aerofoil sections, wing configurations for minimising induced drag and the ground effect on induced drag. In 1968 Shenstone (12) queried whether part of the available power should be used for boundary layer control which might provide an overall gain in power requirements. The lack of reliable design information regarding aerofoil sections. For example S.U.M.P.A.C., Mercury, Jupiter and Toucan were built using aerofoil sections for which the aerodynamic characteristics could only be estimated. For an activity where the aerodynamic criteria were considered to be of great importance, it does raise doubts as to whether aerofoil section shapes are as critical at low Reynolds numbers as assumed. This is further emphasised by the Malliga aircraft employing a 20% thick aerofoil section created by its designer on the ad-hoc basis of it looking 'right'.

Figure 2 shows four profiles of aerofoil sections especially developed for man powered flight. The Wortmann FX-63137 section used for Puffin II and Liverpuffin, the Wortmann FX-68160 one of the 68140 - 68160 - 68180 series used for Mercury and an estimated shape of the Malliga section, estimated because no record is available of its actual shape. The GU 25-5(11)8 is a high lift aerofoil section designed for man powered aircraft, that has been wind tunnel tested. Figure 3 shows a lift-drag curve at a Reynolds No. of 0.63×10^6.

Also Figure 3 shows a lift-drag curve for the FX-63137 at a Reynolds No. of 0.7×10^6, an estimated curve for the FX-68160 and an estimated operational point for the Malliga section.

If the performance criteria for man powered aircraft is taken as the aircraft weight to power ratio (W/P) it is possible to restate this as a function of the aerofoil section performance coefficients:

$$\frac{W}{P} \propto \frac{L}{D.V.} \propto \frac{1}{\dfrac{C_{D_o}}{C_L^{\frac{3}{2}}} + \dfrac{K\,C_L^{\frac{1}{2}}}{\pi A}}$$

This assumed that for a particular aircraft design the wing configuration parameter constant. For the weight/power ratio to increase, the parameter ($C_{Do}/C_L^{3/2} + KC_L^{1/2}/\pi A$) been shown (3) that if the profile drag coefficient C_D can be maintained at below 0.01 there is very little gain in performance for C_L values above 1.2. Figure 3 indicates that we have aerofoil sections that already provide such a working C_L value, although in the case of the GU 25-5(11)8 the C_D value is greater than 0.01.

Figure 4 provides a comparison of the performance of the FX-63137, FX-68169 and GU 25-5(11)8 sections by plotting the parameter $C_{Do}/C_L^{3/2} + KC_L^{1/2}/\pi A$ against C_L. It has been assumed that $C_{Do} = C_D + 0.005$ in order to allow for the parasite drag and that $^K/\pi A = 0.01$, which is equivalent to a wing aspect ratio of 20 operating within the ground effect region. Figure 4 clearly illustrates the important influence of the profile drag as the FX-63137 aerofoil section exhibits improved performance potential over the other two except where the GU 25-5(11)8 section can operate at C_L values above 1.6.

Comparing Figures 3 and 4 the conclusion to be drawn is that a man powered aircraft should operate as close to the stalling point as possible in order to maximise the $^W/_P$ ratio. This simply results from the decrease in velocity with increasing C_L being greater than the increase in drag.However in practice it is also necessary to fly at the maximum speed, compatable with power, in order to maximise the flight distance/duration ratio, to provide for penetration against the wind and to maximise flying opportunities. It is possible to comply with this requirement by assuming that for any particular aircraft the velocity is constant and that aspect ratio varies inversely with C_L. This gives $^L/_D$ as being the relevant performance parameter and if man-powered aircraft are to extend performance through gliding this would be more appropriate.

Figure 5 shows plots of $^L/_D$ for aircraft employing the three aerofoil sections, FX-63137, FX-68160 and GU 25-5(11)8 again assuming that $C_{Do} = C_D + 0.005$ and $^K/\pi A = 0.01$. It indicates that for optimum $^L/_D$ the C_L values are lower than for optimum $^W/_P$, about 1.0 for the FX-63137 section increasing to about 1.2 for the GU 25-5(11)8 section.

The designer is looking for improved $^L/_D$ ratios at higher C_L values. Although the Liebeck laminar roof top aerofoil gives promise of this improved performance it has not been tested and still remains the result of a theoretical study (13). In practice higher C_L values can only result from thicker aerofoil sections which in turn have higher drag characteristics.

Increasing the operating Reynolds number of an aircraft, either by increasing the chord or the velocity, decreases the aerofoil profile drag and thereby improves the C_L/C_D against Reynolds number for four aerofoil sections, FX-63137, FX-60126, GU 25-5(11)8 and the N.A.C.A. 65_3-618. The FX-60126 is a low drag profile developed for sailplanes by Dr. Wortmann (14). Readily available data on the N.A.C.A. 65_3-618 is for a minimum Reynolds number of 3×10^6. (15).

From Figure 6 it would appear that increasing Reynolds number should significantly improve performance. If maximum $^L/_D$ is plotted against Reynolds number as shown in Figure 7, it will be seen that this trend is less marked for any particular aerofoil section above Re = 0.7×10^6. Although it is difficult to extrapolate from Re = 3×10^6 down to the appropriate Reynolds numbers for man-powered aircraft, Figure 7 does indicate that the N.A.C.A. 65_3-618 used for Jupiter could have an optimum $^L/_D$ ratio similar to that for the FX-63137 section.

Information that would greatly help the designers of man powered aircraft is regarding the behaviour of actual wings, with the inevitable inaccuracies that occur during construction related to the assumed design data based on model aerofoil sections. This comparative information is not available and could well provide a useful research topic.

Some development work has taken place over the past decade regarding structures. Whereas spruce and balsa were used for the early machines, aluminium tubular primary structures and lightweight foam plastic secondary structures have since been investigated. A thin tubular.primary structure was incorporated in Mercury with excellent results but the labour time required for its construction was high. As the aluminium tubes were only 0.010 inches thick their manufacture involved the etching of proprietory tubes down to the required thickness, a facility not available to most man powered aircraft groups.

Expanded polystyrene (E.P.S.) secondary structures have been incorporated in the Liverpuffin and Malliga aircraft. The former employed hollow sections of E.P.S. (4).This is only suitable for constant chord wings in order to minimise the construction time and the number of jigs required. Nevertheless in practice this form of construction has resulted in a robust secondary structure for the Wortmann FX-63137 aerofoil section. The wing on the Malliga aircraft employed 1 inch. thick E.P.S. ribs spaced at one foot intervals with thin E.P.S.sheeting over the leading edge. This form of structure was chosen to minimise the construction time and the hot wire cutting of all the ribs was completed within five man-hours.

The most exciting prospect concerning man powered aircraft structures is the combination of foam plastics and composites. With careful design these could result in long life structures with minimum maintenance, yet structures that can be rapidly constructed, particularly if moulding techniques can be introduced. Carbon fibre reinforced plastics have been used for the Wright aircraft with E.P.S. and balsa members to stabilise the structure. About 7 lb. of carbon fibre was incorporated in this machine that was designed for an empty weight of 60 lb. The fact that the aircraft came out overweight at 90 lb. is largely attributed to the use of readily available steel tubing for the pilot support frame. The combination of an E.P.S. secondary structure with glass fibre carrying members gives promise of a low cost robust structure with a much longer working life than those structures that have previously been based on balsa wood. A combination of E.P.S. with carbon fibre is more costly but more suitable where aircraft weight needs to be minimised.

Before leaving this discussion of technical development it is worth briefly considering propulsive systems. Assuming that flapping wing devices require a considerable amount of research before the necessary design data can be determined, man powered aircraft designers must continue to rely on propellers for propulsion. All the aircraft listed in Table 1, except for the Hurel Aviette, have pusher propellers so that the fuselage is not in the higher velocity airstream leaving the propeller. Unfortunately this means that the airstream entering the propeller is influenced by the preceding sections of the fuselage, but there are no test results as to whether this produces a noticeable drop in efficiency.

Most propellers have been of 9 ft. diameter, although Wright made initial flights with a three bladed 6 ft. diameter propeller but later changed to a two bladed 9 ft. propeller with improved results. A 9 ft. diameter has been generally adopted as combining good efficiency (88% -89%) with low weight and simple construction although the larger 10 ft.propeller of the Hurel Aviette should provide useful information. Design techniques have ranged from an ad-hoc basis used by Malliga, scaling up of aeromodel propellers as used by Wright, to the use of blade element theory for the S.U.M.P.A.C. and Puffin aircraft. One area that is worthy of further investigation concerns wide chord blades as used for Jupiter.

Improvement of Performance

The designer must have specific performance objectives in view for any aircraft. If the object is to improve performance, either in terms of duration or distance, over that achieved by existing man powered aircraft there are very few indications as to how to proceed with certainty. Increasing wing spans reduces power but at the expense of increasing control problems and decreasing the opportunity for flight trials. Increasing the number of crew members of necessity increases the aircraft size, so increasing the constructional and organisational problems.

If we just consider single seat man-powered aircraft, it is possible to extend performance by having an athlete as pilot, but this would require simplification of the controls. This would point to the need for a 'compact' configuration having a wing span of under 70 ft. with controls reduced to rudder and elevator only. Such an aircraft would only be suitable for flights over a straight course.

For more general application it is necessary that aircraft should be designed to allow a reduction in pilot input power. Without resorting to increased wing spans the additional power must be provided by other means. In this respect both power storage devices and atmospheric lift have been suggested. An initial study of the use of power storage in man powered aircraft indicates that a considerable improvement in performance could be expected (16). Unfortunately such a device has not yet been developed and when available. would be prohibited from use within the Kremer Competition.

Of more practical significance is the possible extension of performance through utilising atmospheric lift. Two forms of lift seem to be available at the low altitudes appropriate to man-powered flight. The first is that gained from convection up-currents. These are of uncertain nature at low altitudes and would repay a basic research study without initially risking man-powered aircraft. The second is that gained in the wind gradient near the ground.

Using the wind gradient involves either dynamic soaring, as demonstrated by birds such as the Albatross, or gust soaring. Hendricks (17) has analysed the former and shows that the Albatross oscillates into and out of the wind gradient in a time equal to its phugoid period. He goes on to show that dynamic soaring is only possible for birds, or aircraft, with high wing loadings. On the other hand he indicates that gust soaring is feasible for aircraft with low wing loadings. It is therefore of direct application to man-powered flight.

There is some evidence from the Jupiter flights that height was gained during gusts. Gust soaring represents the simplest form of atmospheric lift to investigate and exploit. Any man-powered aircraft designed to utilise gust soaring techniques must have a wing loading suitable for operation in 10 knot winds. This would again point to the need for 'compact' configuration with wing loadings approaching 1.5 lb/ft .Such an aircraft design is already feasible. An aircraft with a wing span of 65 feet would have a take-off power requirement of 1 h.p. in still air conditions. It is envisaged that such an aircraft would initially gain altitude in the wind gradient and thereafter maintain flight through both man-power and gust soaring.

Conclusions

Although it is inevitable that most man-powered aircraft will be designed with the £50,000 Kremer competition performance requirements in view, it is not clear at the present time how design can progress in order to achieve this. Designers must give more consideration to the compromise between performance criteria and the practical constraints associated with control, construction and flying.

Experience with Jupiter emphasises the need for concentrated flying experience for improved performance. The proposed trend towards compact man-powered aircraft would ensure more consistent flight attempts as well as allowing gust soaring techniques to be investigated. In the future attempts at the Kremer prize could well be based on the use of two man-powered aircraft, a simple compact machine for training purposes and a sophisticated high performance machine for the final attempt.

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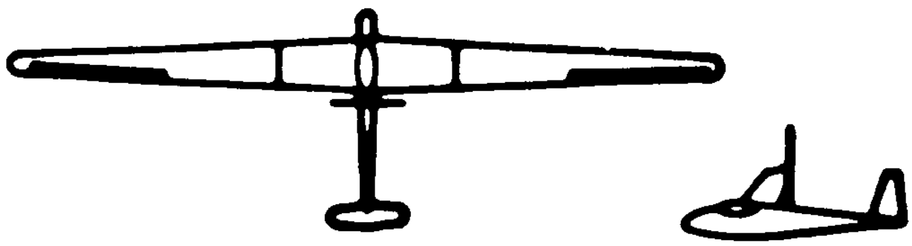
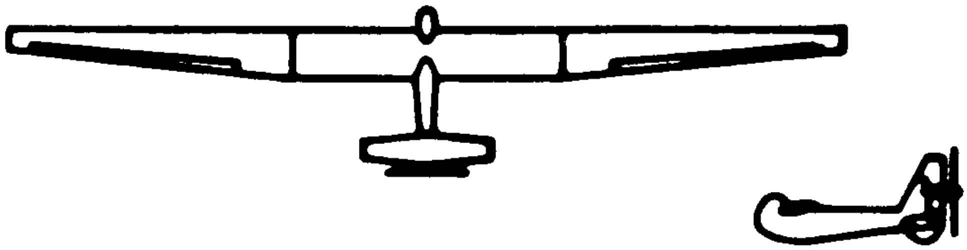


S.U.M.P.A.C



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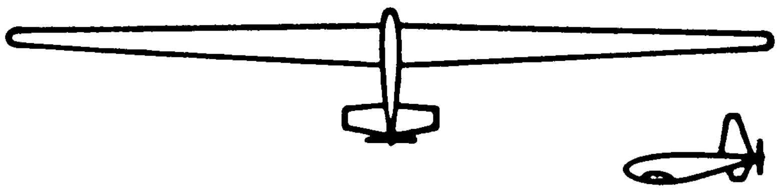
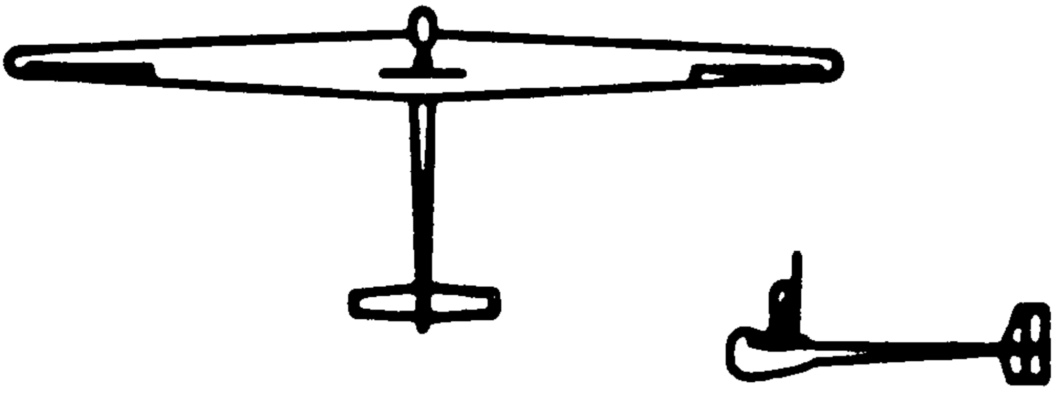


DUMBO/MERCURY



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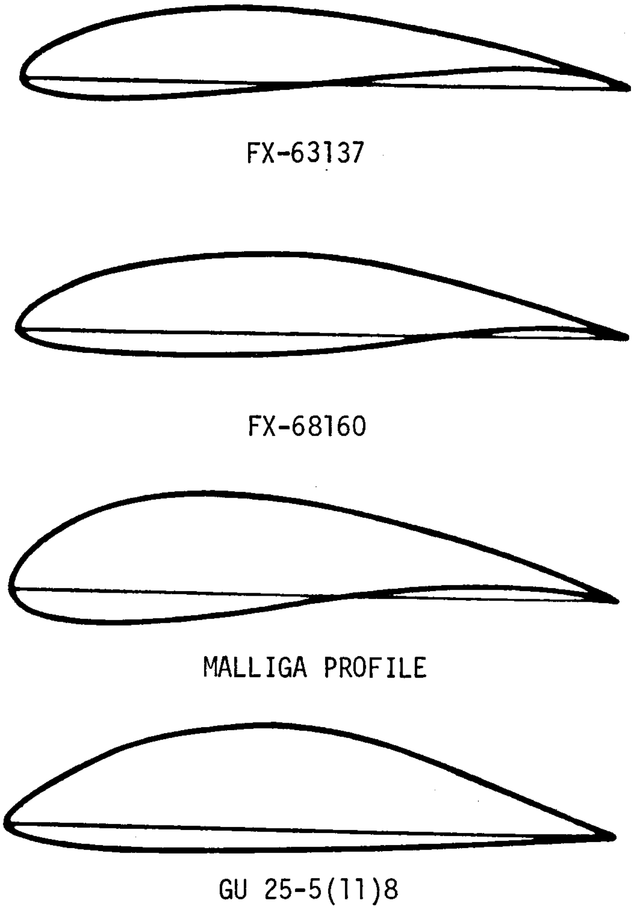

Figure 2. Man powered aircraft aerofoil sections

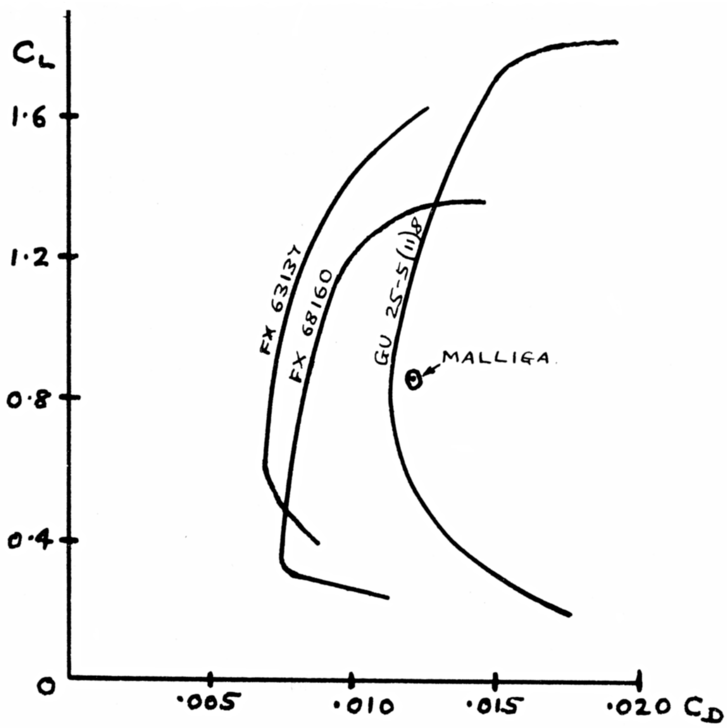

Figure 3. Lift/Drag characteristics.

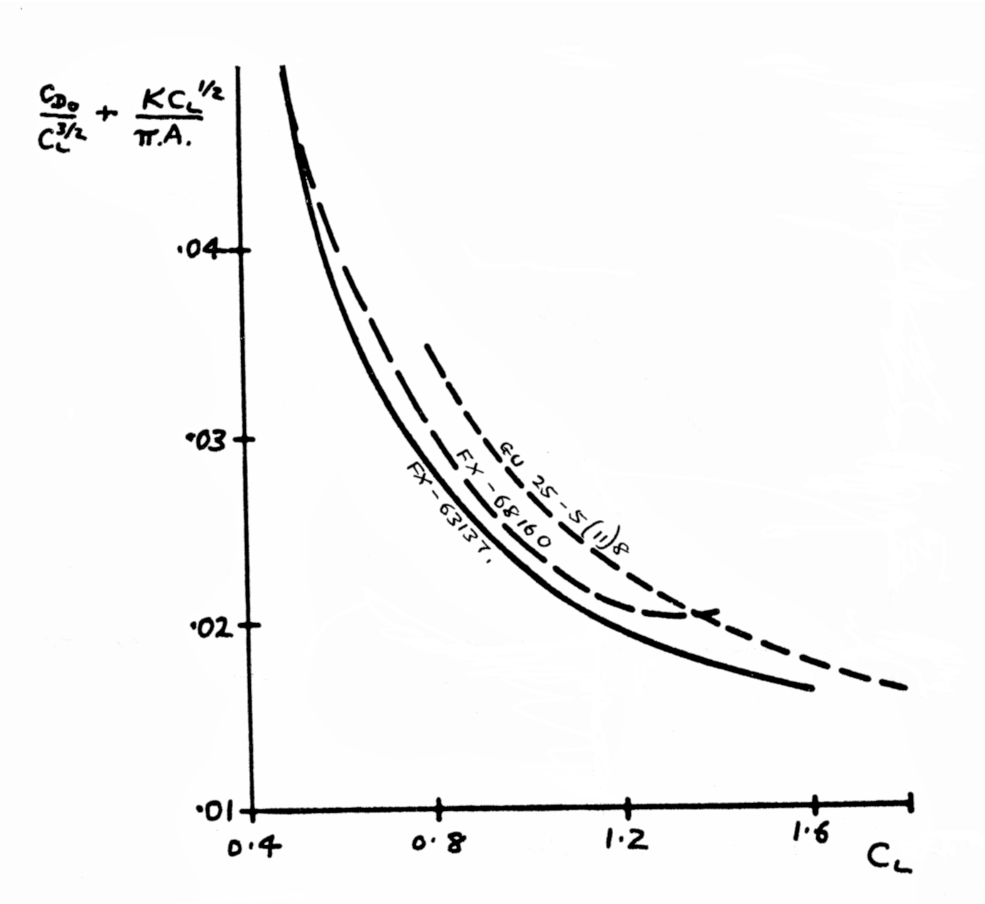

Figure 4. Variation of weight/power parameter with C_L

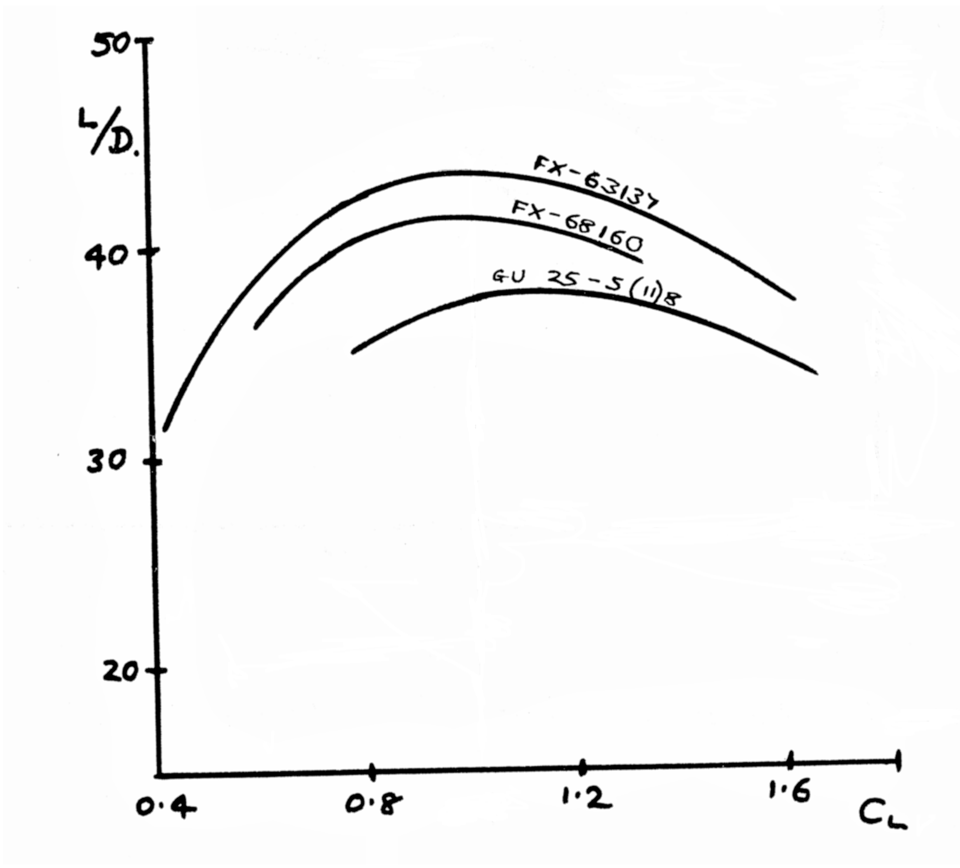

Figure 5. Variation of overall $^L/_D$ ratios with C_L.

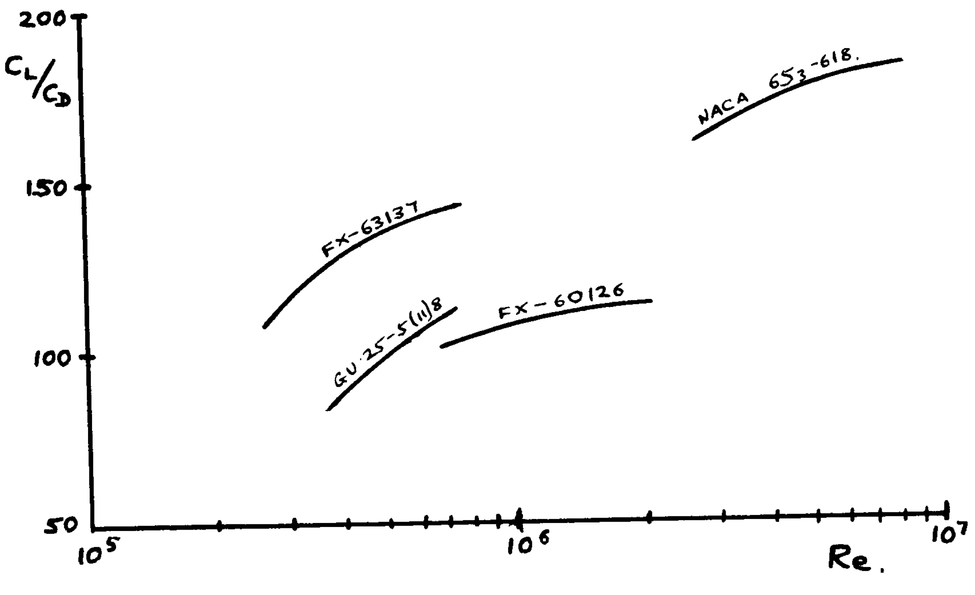

Figure 6. Variation of C_L/C_D with Reynolds No.

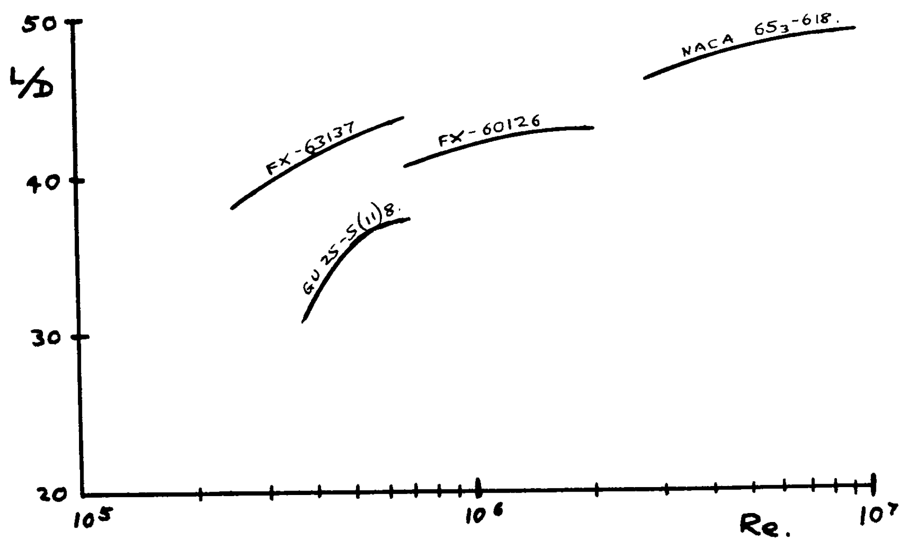

Figure 7. Variation of overall $^L/_D$ with Reynolds no.