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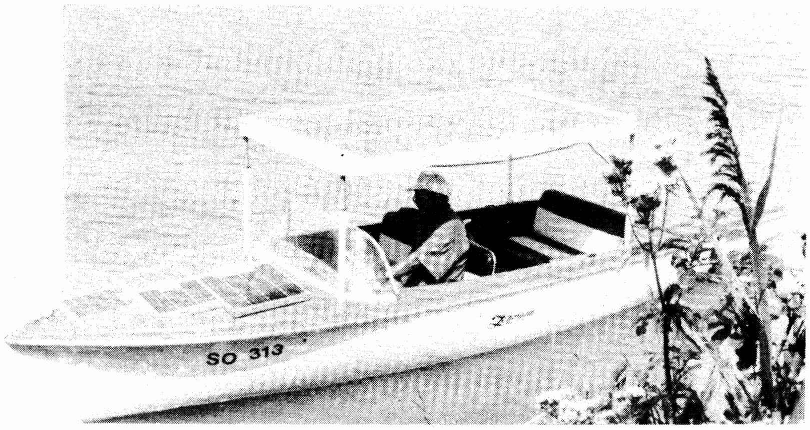
PROPELLERS & SOLAR BOATS



Hans Tschirren in his 4-Seater Solar Boat *Photo ExPress*

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Authors: Reg Frank, Philip Thiel, Theo Schmidt

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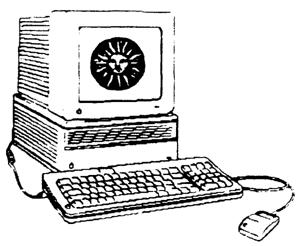
Editorial

This issue is about propellers and solar boats, two subjects I can claim to know a little about. This has resulted in an overweight of my own articles, for which I beg your indulgence. Editing own's own papers is far easier than those of others and I must confess to being somewhat lazy and short of time. This brings me to our new editorial concept:

Putting together an issue is far more work than you can believe unless you've tried it, and I sit in awe of the work done by John Morwood and Michael Ellison, putting out publication after publication for all these years. This is a very tough act to follow and we must rotate editors if we are to get anywhere near the target goal of 4 publications per year. The AYRS funds can just cover printing and postage and all work is now voluntary. Although we now have powerful computers for typesetting which can do just about *anything*, this just makes it easier to come up with terrible layouts and you will have to bear with us while we "learn by doing"!



Playing with a computer doesn't mean being any good at typing and the last two issues were only possible thanks to the scanning in of articles by Peter Zeller, which however only works if typed with a good ribbon. Reg Frank has volunteered to type in handwritten material—if he can read it! So keep those articles coming, preferably with neatly done line drawings.

The environmental/ political message in my last editorial was not appreciated by all and was thought to be indulging in doomsday revelery by some. It all depends where you live. Most of us who read this are sitting pretty, having enough to eat, relative peace, and time to indulge in esoteric pastimes. But for a number of people far, far greater than the membership of the AYRS, the world has already come to an end or is doing so. Daily.

Theodor Schmidt, Editor of No. 109

The views expressed by authors and editors are their own!

Designing efficient Boat Propellers

by Reg Frank

A propeller works by accelerating water (or air) backwards. This backswards thrust must be balanced by an opposite force facing forwards and this is what drives the boat along.

There is a loss of kinetic energy, since the water down the wake has velocity. This kinetic loss per second = mass going through the propeller disc per second x velocity increase of the wake squared x 1/2. When the swept area is increased, the same thrust can be obtained by putting more mass per second through with a reduced velocity increase and the loss of energy is reduced. A fast boat can use a small propeller because a large amount of water passes even through a relatively small propeller disc. At low speeds the efficiency drops unless a larger prop is used. It is the slowest boats which need the largest propellers.

Propeller efficiency, not including friction loss in bearings and glands, equals induced efficiency x blading efficiency. *(Induced efficiency is also called Froude efficiency. Ed.)*

Induced efficiency is concerned with the above-mentioned loss of kinetic energy. Power output = thrust x boat speed. Power put into the water = thrust x water speed through the propeller. So induced efficiency = boat speed / water speed through the propeller. *(this can also be expressed as 1/(1+slip). Ed.)*

Blading efficiency = useful power put into the water divided by power put into the prop from engine or other source. Blading efficiency is a maximum at those blade segments where the angle is about 45 degrees. The blade segments about two thirds radius out from the hub do the most work and an efficient propeller will thus have these segments at about 45°. The blade lift-to-drag ratio is also involved. I generally use a coefficient of lift (C_L) of 0.4 and a L/D ratio of 20, corresponding to a blade aspect ratio of about 5. Analysis of published aero propeller charts suggest that C_L = angle of attack in degrees / 13. *(The angle of attack must be measured from the middle line of the foil section for this and not from the bottom surface. A typical flat-bottomed foil already has a C_L of about 0.35 at zero angle of attack when measured from the bottom surface. I use the formula C_L = (angle of attack (in degrees from bottom surface) / (10(1+ (2 / aspect ratio)))) + 0.35. (from Hoerner's Fluid Dynamic Lift) This gives about the same result as Reg Frank's formula. Ed.)*

The tangential forces from the blades generate swirl; this loss is allowed for in formulae.

The basic principle used in designing blades is that the required thrust calculated by using momentum theory is set equal to the axial thrust produced by the blades. As both lift and drag forces are inclined, they must be resolved into axial and tangential components, the axial component being the thrust and the tangential component making up the torque which has to be produced by the power source. All this has to be done for several radial blade segments (each corresponding to a swept ring) and the results summed up for the whole propeller. Partial efficiencies should not be summed up: they are calculated from the total values of the whole propeller.

These procedures are like those used for designing sub-sonic aeroplane propellers. But such propellers can be large; there is plenty of space available. Induced efficiencies can be around 95%. Most boat propellers are small and the water speed through the prop is noticeably faster than the boat speed. Aeroplane design charts cannot usually be used for boat propellers.

The aeronautical propeller formulae can be very complex. They use the concept of Advance Ratio J = Flight speed / revolutions per second x diameter and also the concepts of power and thrust coefficients. This is fine for dealing with test data but terrible for explaining theory. However we only need to use two simple rules:

1: Water velocity, in the axial direction through a propeller, is the arithmetic mean of water aproach velocity some distance ahead and wake velocity some distance astern.

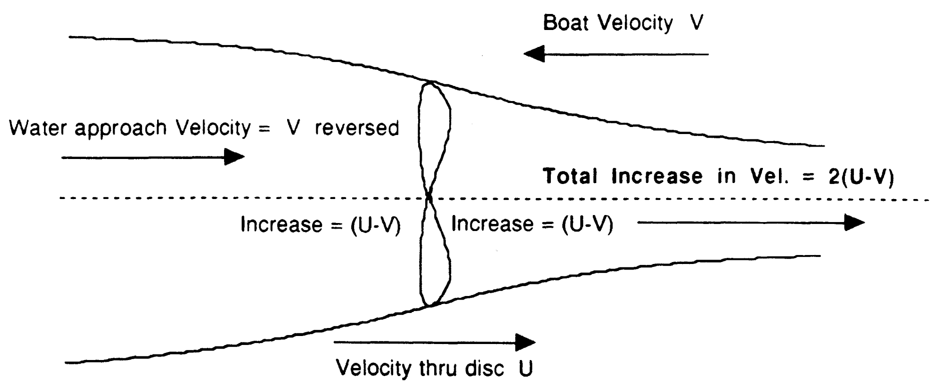
2: Thrust = rate of change of momentum = mass flowing through prop per second x increase in axial water velocity component = density x swept area x axial velocity component x increase in water velocity.

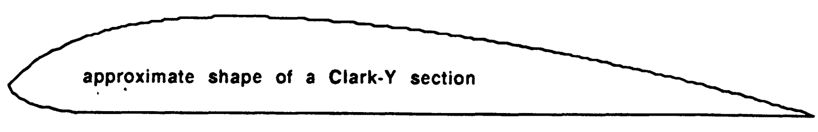
When using equations consistent systems of units must be used. Mass can be measured in lb.mass with force in poundals (1 lb.mass weighs 32.18 poundals). Or mass in slugs with force in lb.force (1 slug weighs 32.18 lb.f.). Or mass in kilograms with force in Newtons (1 kg weighs 9.81 N).

Doing the required calculations for several swept rings and working out the different values is extremely time-consuming unless done by computer. Please write for propeller calculation programs written in BASIC which will run on most home computers.

Reg Frank, 87 Staincross Common, Barnsley S75 6NA, Telephone 0226-382272

Note by the editor: Reg Frank is a very prolific writer and has sent in over 20 pages on propeller calculations. Anyone interested in designing propellers is urged to request the full report from Reg as well as the programs. A report "Making Propeller Blades" is also available. This describes methods of making blades from thin sheet material.





Basic Propeller Performance Prediction

by Theo Schmidt

Why is (good) propeller design so difficult? This is mainly because a large number of variables all influence each other, requiring calculus and/or numerical methods to work out solutions. Fig. 1 shows that there is a balance between factors which increase and which decrease efficiency and the best propeller for a given set of conditions is far from obvious.

Diameter:

The maximum efficiency obtainable by a perfect propulsor at a certain operating point is called the Froude efficiency and is easily worked out (line 1120 of the BASIC program). It tends toward 100% for large diameters, high vehicle speeds, and low loading forces.

Propellers used at low speeds and high loads (eg towing) are almost always too small and benefit from an increase of diameter to as much as can be tolerated in view of draught and strength of materials used. At high speeds, too large a diameter becomes inefficient because the increase of blade surface drag and resulting lower blade L/D ratio outweighs the high Froude efficiency which may be already be over 99%. As a rule of thumb, many propellers for low-drag craft achieve their best total efficiency at a Froude efficiency of around 98% and a corresponding slip of about 2% (half the value of wash velocity increase). Designing for this value at the desired boat speed will give a good diameter to use.

Chord:

The blade chord and the number of blades must be chosen such that the blades operate operate at a sensible lift coefficient. Many narrow blades have less induced drag than few wide ones, but the latter operate at higher Reynold's Numbers, so the choice of blade number is not straightforward. Lightly loaded propellers are usually two-bladed for practical reasons.

Pitch:

Any good lifting surface propels most efficiently at an angle of about 45° to the direction of vehicle motion. Propellers with a very course pitch never reach this angle, those with a very fine pitch have the 45° segments too near the hub to be of much use, as it is the outer blade segments which do the most work. Fine-pitched propellers never stall and are good for for low speed/ high load conditions where course-pitched propellers may be nearly useless, but the latter have less drag and are efficient at high speeds. Good allround practical propellers will have pitch to diameter ratios of 1-1.5, high speed racing propellers up to around 2.

Planform:

The optimum planform, or chord distribution, is chosen such that the wash velocity through the propeller disc is as uniform as possible, i.e. that the slip values of all the blade segments are similar (except for the hub, where it doesn't matter much). This is the condition for minimum induced drag and mathematical alogarithms developed by Prof. Gene Larrabee and others, which automatically work out the optimum planform for a given operating point, should be used if an extreme racing propeller is to be optimised. The optimum planform can be aproximated by a rule of thumb: make the widest part of the blade about where the 45° angle condition is met and taper off gently toward tip and hub, leaving the relatively unimportant hub segments wide enough to ensure adequate strength. Fig. 2 shows some typical planforms of high-efficiency propellers. Advanced propeller planforms may also have skewed-back shapes designed to shed weeds or ease vibration and cavitation.

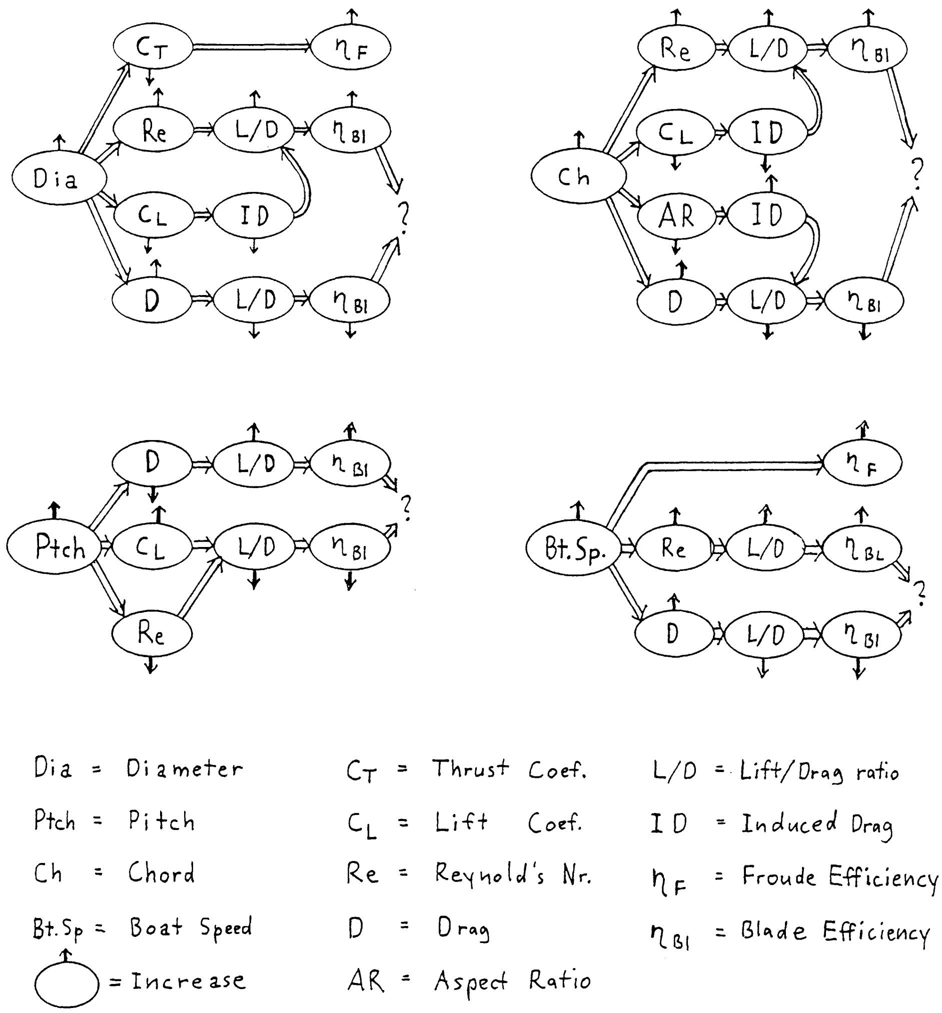
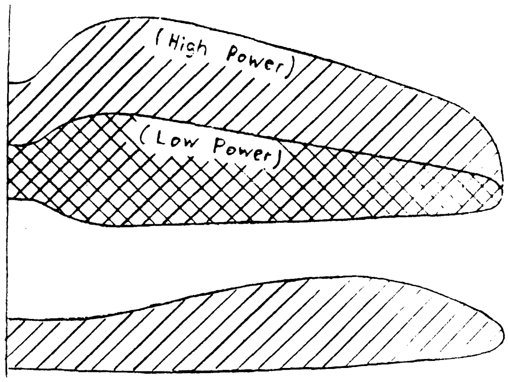


Fig. 1. This shows some of the ways propeller variables influence each other and that the value of blade efficiency is not easily optimized from first principles.

Fig. 2



Low Speed

High Speed

Blade Profile:

Any reasonable slightly cambered foil section such as the flat-bottomed Clark-Y is good. Highly cambered sharp-nosed sections should not be used on high aspect-ratio blades. Fancy sections are only sensible if the means exist for making them accurately.

Boat Speed:

Studying Table 1, it is evident that at low speeds only very little power can be produced before efficiency drops severely, whereas at high speeds the maximum efficiency is developed at very high power levels (Efficiency is of course zero when standing still: this is approximated by the first set of values). Thus a propeller of fixed size and pitch is well adapted to a displacement hull except when accelerating, towing, or labouring into a strong wind, in which cases controlable pitch can help greatly. Hydrofoil boats have a problem in that the best propeller for foiling won't be so good for cruising in displacement mode or for taking off.

The Program:

Working out all these variables is best done by computer. The following program does not design propellers, but rather simulates performance as if doing measurements in a test tank. The copius output quickly gives insight into the effects of changing the parameters and allows designing in a "try it and see" manner. This is not so good if the best possible performance at a single operating point is sought, but works very well in establishing a good compromise over a range of conditions. This is usually what is needed, except for the most extreme racing craft.

The program works by by calculating basic data such as blade aspect-ratio, etc., dividing the blades into 9 segments, calculating all values for these, and finally summing up and printing out. The propeller data to be used is entered directly into the program (variables up to line 330) before running it.

Lift coefficients are calculated as a function of angle of incidence and aspect ratio (line 890). Drag coefficients are are looked up in an array (DATA statements at the end of the program) where they are stored as a function of C_L (Lift Coefficient) and Re (Reynold's Number) (line 1000). The values used are shown in Fig. 3. A stalled blade is assumed to have a C_L of 1.2 (line1010). This is not very elegant and could be improved. Induced drag is calculated as a function of C_L and aspect ratio (line 1020).

Lift, drag, thrust and torque and associated coefficients and efficiencies are calculated and a slip value is derived. All calculations are then repeated using the new slip and this is done several times until all values stabilize, usually requiring about three passes. Then the segment values are summed up for the whole propeller and printed out. Occasionally the loop oscillates instead of settling down. Sometimes increasing the value in line 1140 helps, but a proper solution would be to find a more positive way for converging the values. Another improvement would be to include the ability to handle negative slip values which occur at low prop speeds or when "windmilling", i.e. taking power *from* the water or air stream.

The equation used to calculate induced drag actually implies an optimum (elliptical) lift distribution, so that the values for a non-optimal planform will be slightly optimistic. In practice this seems to make little difference as long as reasonable planforms are used. This can be checked by examining the segment slip values (line 1130). These are nearly the same spanwise for an optimal propeller (except near the hub) and can be adjusted by fine-tuning the chord distribution (i.e. planform). Normally this procedure is unnecessary.

The program can be used for fresh water, sea water or air. SI units are used throughout except that the traditional RPM is used instead of Hz or rad/s. The program automatically calculates geometrically correct blade twist at zero angle of incidence measured from the bottom surface (corresponds to C_L of about 0.35 for the near Clark-Y section used). Hub and shaft drag is ignored and the program has to be altered for very large hubs.

The results seem to be accurate for fairly large, lightly loaded blades. Most motorboat propellers are of small aspect ratio and they are often highly loaded and cavitate or ventilate. Such behaviour is beyond the scope of this program. It was written to work out propellers for human-powered and solar-powered craft.

There are various versions of BASIC and slight changes may be necessary depending on the computer used. The output is to a screen of at least 70 characters. Output to a printer is more complicated and is very specific to the type of printer, so these commands have to be added individually.

Anyone is welcome to copy this program for personal use only. Disks will be available at some unspecified time. Criticisms and mainly improvements would be greatly appreciated.

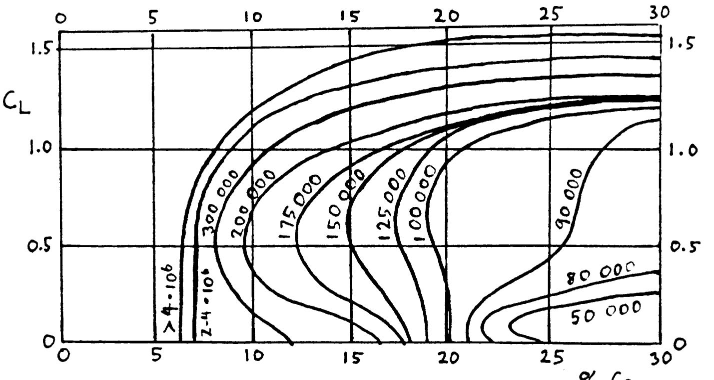


Fig 3. C_D vs C_L vs Re for Clark-Y section
(compiled from various sources)

```
100 REM PROPELLER SIMULATION
110 REM COPYRIGHT THEODOR SCHMIDT
120 REM VERSION 9/91
130 REM Input data thru variables at beginning of program
140 REM Program runs from low rpm to high rpm
150 REM in steps of the given increment
160 DIAMETER=.5 : REM prop diameter in meters
170 PTCH=.66 : REM pitch in m
180 U=2 : REM boat speed in m/s
190 R1=100 : REM low rpm
200 R2=500 : REM high rpm
210 INCR=10 : REM increment in rpm
220 BLADES=2 : REM blade number
225 MEDIUM$="FRESH WATER" : REM "FRESH WATER",
     "SEA WATER", or "AIR"
230 HEADERS$="Y" : REM "Y" or "N" (prints              header)
240 RANGE$="N" : REM "Y" or "N" (limits high rpm)
250 CH(1)=.075 : REM chord at station 1 (near hub) in m
260 CH(2)=.08
270 CH(3)=.087
280 CH(4)=.091
290 CH(5)=.091
300 CH(6)=.087
310 CH(7)=.08
320 CH(8)=.07
330 CH(9)=.055
340 DIM FF(16,14)
350 FOR K=1 TO 14
360 FOR J=0 TO 15
370 READ FF(J,K)
380 NEXT J
390 NEXT K
400 PI=3.14159
410 CIRCUM=PI*DIAMETER
430 TA=ATN(PTCH/CIRCUM):TD=TA*57.296 : REM tip angle
440 SWPTAREA=PI*(DIAMETER/2)^2
450 FOR I=1 TO 9
460 A(I)=CH(I)*DIAMETER/20*BLADES
470 BETA(I)=ATN((PTCH/CIRCUM)/(I/10))
480 A=A+A(I)
490 NEXT I
500 A=A+A(9)/4 : REM total blade area
510 BAR=A/SWPTAREA : REM blade area ratio
520 AR=(DIAMETER/2)^2/A*BLADES : REM aspect ratio
525 IF MEDIUM$="FRESH WATER" THEN VISC=1000000: DENS=1000
526 IF MEDIUM$="SEA WATER" THEN VISC=1000000: DENS=1024
527 IF MEDIUM$="AIR" THEN VISC=70000 : DENS=1.25
530 IF HEADERS$="N" THEN 650
540 PRINT"PROPELLOR SIMULATION PROGRAM"
550 PRINT:PRINT "BLADE NUMBER =              ";BLADES
555 PRINT"MEDIUM =           ";MEDIUM$
560 PRINT"DIAMETER =         ";DIAMETER;"M"
570 PRINT"PITCH =            ";PTCH;"M"
580 PRINT"SWEPT AREA =       ";INT(SWPTAREA*10000+.5)/10000;"SQ M"
590 PRINT"BLADE AREA RATIO =  ";BAR
600 PRINT"BLADE ASPECT RATIO = ";AR
610 PRINT"TIP ANGLE =          ";TD "DEGREES"
620 PRINT"STATION    CHORD [M]    ANGLE [DEGREES]"
630 FOR N=1 TO 9
640 PRINT N;SPC(9);CH(N);SPC(9);57.296*BETA(N):NEXT N:PRINT
650 PRINT"DIA PITCH  BT SPD  PR SPD  P IN  P OUT  ETA  ";
660 PRINT"ETA F  THRUST CL(5) SLIP"
670 PRINT"[M]  [M]   [M/S]  [RPM]  [W]   [W]   [%]   [%]    [N]":PRINT
680 R3=R1:R4=R2
690 FOR RR=R1 TO R2 STEP INCR
700 VR=CIRCUM*RR/60
710 I=1
720 DELTA(I)=ATN(U/(VR*(I/10)))
730 ALPHA(I)=BETA(I)-DELTA(I): REM angle of incidence
740 IF ALPHA(I) < -.1 THEN R3 = RR + INCR : GOTO 770 : REM limits
     program to positive lift
750 IF ALPHA(I)>.26 THEN R4=RR : GOTO 780 : REM restricts blade
     loading
760 IF I<8.5 THEN I=I+1: GOTO 720
770 NEXT RR
780 IF RANGE$="N" THEN R4=R2
790 FOR RPM=R3 TO R4 STEP INCR
800 VR=CIRCUM*RPM/60
810 PP=0:PW=0:T=0: REM power in, power out, thrust
820 UR=U*(1+Q): REM speed thru disc, q is slip
830 FOR I=1 TO 9
840 UR(I)=U*(1+Q(I))
850 VR(I)=VR*(I/10)
860 W(I)=SQR(UR(I)^2+VR(I)^2): REM resultant speed
870 DELTA(I)=ATN(UR(I)/VR(I))
880 ALPHA(I)=BETA(I)-DELTA(I)
890 CL(I)=ALPHA(I)*5.75/(1+2/AR)+.35
900 IF CL(I)<0 THEN GOTO 1470
910 RE(I)=VISC*W(I)*CH(I): REM Reynold's number
920 X=ABS(INT(10*CL(I)+.5))
930 IF X>15 THEN X=15
940 IF RE(I)<45000 THEN Y=1:GOTO 1000
950 IF RE(I)<105000 THEN Y=INT(RE(I)/10000-2.5):GOTO 1000
960 IF RE(I)<212500 THEN Y=INT(RE(I)/25000 +3.5):GOTO 1000
970 IF RE(I)<2000000 THEN Y=12:GOTO 1000
980 IF RE(I)<4000000 THEN Y=13:GOTO 1000
990 Y=14
1000 CD(I)=FF(X,Y)/1000 : REM profile coeff. of drag
1010 IF CL(I)>1.2 THEN CL(I)=1.2
1020 ID(I)=CL(I)^2/(PI*AR) : REM induced drag
1030 L(I)=DENS/2*A(I)*CL(I)*W(I)^2 : REM lift
1040 D(I)=DENS/2*A(I)*(CD(I)+ID(I))*W(I)^2 : REM drag
1050 T(I)=L(I)*COS(DELTA(I))-D(I)*SIN(DELTA(I)) : REM thrust
1060 F(I)=L(I)*SIN(DELTA(I))+D(I)*COS(DELTA(I)) : REM lateral force
1070 PP(I)=F(I)*VR(I) : REM power in
1080 PW(I)=T(I)*U : REM power out
1090 ETA(I)=PW(I)/PP(I) : REM efficiency
1100 CT(I)=T(I)/(DENS/2*DIAMETER*(I/10)*PI*U*U*DIAMETER/20)
     REM coefficient of thrust
1110 C2(I)=Q(I)*4*(1+Q(I)) : REM also coeff. of thrust
1120 EF(I)=2/(1+SQR(1+CT(I))) : REM Froude efficiency
1130 Q(I)=1/EF(I)-1 : REM slip
1140 IF ABS(C2(I)/CT(I)-1)>.05 THEN 840
1150 T=T+T(I)
1160 PP=PP+PP(I)
1170 PW=PW+PW(I)
1180 NEXT I
1190 ETA=PW/PP
1200 CT=T/(DENS/2*SWPTAREA*U*U)
1210 EF=2/(1+SQR(1+CT))
1220 Q=1/EF-1
1230 C2=4*Q*(1+Q)
1250 P$=RIGHT$(STR$(INT(DIAMETER*100)/100),5)
1260 PRINT P$;SPC(4-LEN(P$)); : REM output formatting and printing
1270 P$=RIGHT$(STR$(INT(PTCH*100)/100),5)
1280 PRINT P$;SPC(7-LEN(P$));
1290 P$=RIGHT$(STR$(INT(U*100)/100),5)
1300 PRINT P$;SPC(7-LEN(P$));
1310 P$=RIGHT$(STR$(INT(RPM)),5)
1320 PRINT P$;SPC(7-LEN(P$));
1330 P$=RIGHT$(STR$(INT(PP+.5)),5)
1340 PRINT P$;SPC(7-LEN(P$));
1350 P$=RIGHT$(STR$(INT(PW+.5)),5)
1360 PRINT P$;SPC(7-LEN(P$));
1370 P$=LEFT$(STR$(INT(ETA*100+.5)),5)
1380 PRINT P$;SPC(6-LEN(P$));
1390 P$=LEFT$(STR$(INT(EF*100+.5)),5)
1400 PRINT P$;SPC(6-LEN(P$));
1410 P$=RIGHT$(STR$(INT(T+.5)),5)
1420 PRINT P$;SPC(7-LEN(P$));
1430 P$=RIGHT$(STR$(INT(CL(5)*100)/100),5)
1440 PRINT P$;SPC(6-LEN(P$));
1450 P$=RIGHT$(STR$(INT(Q*1000+.5)/1000),6)
1460 PRINT P$
1470 NEXT RPM
1480 REM The following values represent CD as a
1490 REM function of CL and RE
1510 DATA 25,23,27,50,70,80,80,80,75,70,60,50,50,200,1000,1000
1520 DATA 24,22,25,40,50,55,57,58,55,50,45,42,46,180,1000,1000
1530 DATA 23,21,23,35,40,46,46,46,46,46,42,38,45,150,800,1000
1540 DATA 22,21,22,31,35,39,39,39,39,39,37,35,41,140,700,1000
1550 DATA 22,21,21,27,30,33,33,33,33,33,32,31,37,130,700,1000
1560 DATA 21,21,21,23,25,27,27,27,27,27,27,27,33,120,600,1000
1570 DATA 20,20,20,20,19.9,19.5,19,19,19.1,19.5,20.2,23,30,100,
     600,1000
1580 DATA 19,16.8,18.6,18.3,18,17.5,17.2,17.3,17.8,18.3,19.2,21,28,84,
     600,1000
1590 DATA 18,17.7,17.2,16.5,15.6,15,14.6,14.8,15.3,16.2,17.3,20,25,80,
     500,1000
1600 DATA 17.5,16.3,15,13.6,12.7,12,12,12.4,13.6,14.6,16,18,24,60,
     400,1000
1610 DATA 17,14.5,12,10.2,9.5,9.3,9.3,9.8,10.8,12,13.8,16,21,42,84,168
1620 DATA 12,10.3,9.3,8.6,8.3,8,8,8.3,9,10,11.1,13,15.5,20,40,80
1630 DATA 7,7,7,7,7,7,7,7.1,7.5,8,8.8,10,12,15,20,30
1640 DATA 6.2,6.2,6.2,6.2,6.2,6.3,6.4,6.6,6.9,7.3,8,9,10.1,12,14,17
```

PROPELLER SIMULATION PROGRAM

DIAMETER = .5 M
PITCH = .66 M
SWEPT AREA = .1963 SQ M
BLADE AREA RATIO = .1858
BLADE ASPECT RATIO = 3.43
TIP ANGLE = 22.8 DEGREES

STATION	CHORD [M]	ANGLE [DEGREES]
1	.075	76.61
2	.08	64.55
3	.087	54.47
4	.091	46.41
5	.091	40.04
6	.087	35
7	.08	30.97
8	.07	27.71
9	.055	25.03

DEFINITIONS:
BT SPD = BOAT SPEED
PR SPD = PROP SPEED
P IN = POWER INPUT
P OUT = POWER OUTPUT
ETA = TOTAL EFFICIENCY
ETA F = FROUDE EFFICIENCY
CL(5) = LIFT COEF. AT STATION 5

BT SPD [M/S]	PR SPD [RPM]	P IN [W]	P OUT [W]	ETA [%]	ETA F [%]	THRUST [N]	CL(5)	SLIP
.01	20	1	0	2	15	1	1.2	5.51
.01	30	2	0	1	11	3	1.2	8.52
.01	40	6	0	1	8	6	1.2	11.52
.01	50	10	0	1	6	9	1.2	14.6
.01	100	81	0	0	3	36	1.2	29.78
.01	150	129	1	1	2	90	1.2	47.43
.01	200	244	2	1	2	167	1.2	64.65

BT SPD [M/S]	PR SPD [RPM]	P IN [W]	P OUT [W]	ETA [%]	ETA F [%]	THRUST [N]	CL(5)	SLIP
.5	40	1	0	66	99	1	.1	8E-03
.5	50	3	2	73	96	4	.43	.041
.5	60	6	4	72	92	9	.67	.084
.5	80	17	11	63	84	22	.97	.187
.5	100	37	18	50	78	37	1.14	.289
.5	120	68	27	39	72	54	1.2	.393
.5	140	120	36	30	67	73	1.2	.496
.5	160	157	51	32	61	101	1.2	.632
.5	200	278	83	30	53	166	1.2	.894

BT SPD [M/S]	PR SPD [RPM]	P IN [W]	P OUT [W]	ETA [%]	ETA F [%]	THRUST [N]	CL(5)	SLIP
1	80	5	3	71	99	3	.1	8E-03
1	90	12	10	80	98	10	.28	.024
1	100	22	18	80	96	18	.43	.043
1	120	48	36	76	92	36	.67	.085
1	140	85	59	70	88	59	.83	.134
1	160	135	87	65	84	87	.96	.187
1	180	199	119	60	80	119	1.06	.244
1	200	283	149	53	77	149	1.14	.294

BT SPD [M/S]	PR SPD [RPM]	P IN [W]	P OUT [W]	ETA [%]	ETA F [%]	THRUST [N]	CL(5)	SLIP
1.5	120	15	11	75	99	8	.1	8E-03
1.5	130	31	26	84	98	17	.22	.019
1.5	140	50	42	84	97	28	.33	.031
1.5	150	72	60	83	96	40	.43	.043
1.5	160	97	79	81	95	53	.52	.056
1.5	170	126	100	79	93	66	.59	.07
1.5	180	160	122	77	92	82	.66	.085
1.5	190	197	147	74	91	98	.72	.101
1.5	200	239	173	72	90	115	.78	.117

BT SPD [M/S]	PR SPD [RPM]	P IN [W]	P OUT [W]	ETA [%]	ETA F [%]	THRUST [N]	CL(5)	SLIP
2	150	11	5	43	100	2	0	1E-03
2	160	35	28	80	99	14	.1	9E-03
2	170	62	53	85	98	26	.19	.017
2	180	94	80	85	98	40	.28	.025
2	190	130	110	84	97	55	.36	.034
2	200	170	141	83	96	70	.42	.043
2	220	264	211	80	94	106	.55	.063
2	240	379	291	77	92	145	.66	.085

BT SPD [M/S]	PR SPD [RPM]	P IN [W]	P OUT [W]	ETA [%]	ETA F [%]	THRUST [N]	CL(5)	SLIP
3	230	61	42	68	100	14	.03	4E-03
3	240	117	94	81	99	31	.1	9E-03
3	250	177	150	85	99	50	.16	.014
3	260	244	208	85	98	69	.22	.019
3	270	316	270	86	98	90	.28	.025
3	280	395	335	85	97	112	.33	.031
3	290	480	404	84	96	135	.38	.037

BT SPD [M/S]	PR SPD [RPM]	P IN [W]	P OUT [W]	ETA [%]	ETA F [%]	THRUST [N]	CL(5)	SLIP
4	300	84	39	46	100	10	0	2E-03
4	310	175	130	74	99	32	.05	5E-03
4	320	276	223	81	99	56	.1	9E-03
4	330	381	321	84	99	80	.15	.013
4	340	496	422	85	98	105	.19	.017
4	360	749	640	86	98	160	.28	.025
4	380	1036	877	85	97	219	.35	.034
4	400	1359	1131	83	96	283	.43	.043

BT SPD [M/S]	PR SPD [RPM]	P IN [W]	P OUT [W]	ETA [%]	ETA F [%]	THRUST [N]	CL(5)	SLIP
5	380	235	145	62	100	29	.02	3E-03
5	390	380	288	76	99	58	.06	6E-03
5	400	538	434	81	99	87	.1	9E-03
5	410	702	587	84	99	117	.14	.012
5	420	877	744	85	99	149	.17	.015
5	440	1257	1077	86	98	215	.24	.021
5	460	1681	1432	85	97	286	.31	.028

Table 1. This shows the performance of a good allround propeller designed for human-powered and solar-powered boats. It has two blades and about 30 of these have been made and many are in use worldwide. (Many have also been lost!)

How to make a wooden propeller

by Philip Thiel

The following notes describe a method for constructing a propeller of epoxied laminations of marine-grade plywood, suitable for the low power and rpm of human-powered watercraft, and within the capabilities of one competent in elementary geometry and basic woodworking. We will illustrate the procedure as applied to the making of a three-bladed „right-hand" propeller, one which rotates clockwise in driving the boat ahead when viewed from behind the boat, with a 16-inch (400-mm) diameter and a 24-inch (610-mm) pitch, based on the Troost B3.35 model of 0.35 developed-area ratio to absorb 1/5-hp (150 watts) at 240 rpm and produce about 13 lb. (58 N) of thrust in open water at 4.2 knots (2.2 m/s) with 80% efficiency [1]. The same procedure, of course, may be used for the construction of propellers of similar characteristics and other dimensions.

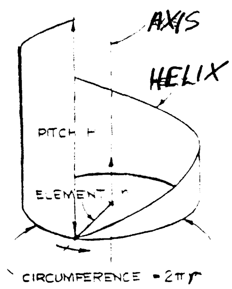


Figure 1 Heli

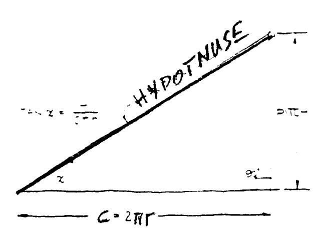


Figure 2. Pitch angle x @ radius r

As is the case with most propellers we will use a helicoidal surface for the „face", or after side, of the propeller blade. This helicoidal surface is generated when a straight line (the „element") revolves with uniform speed about an axis through one of its ends and at the same time moves with uniform speed parallel to itself along the axis. Any point on the straight line then generates a curve in space called a helix, which lies on the surface of a co-axial right circular cylinder. This distance along the element between the axis and the given point is the radius, r, and the distance this point moves parallel to the axis during one revolution (360°) is the pitch, H. The successive positions of the element constitute the helicoidal surface.

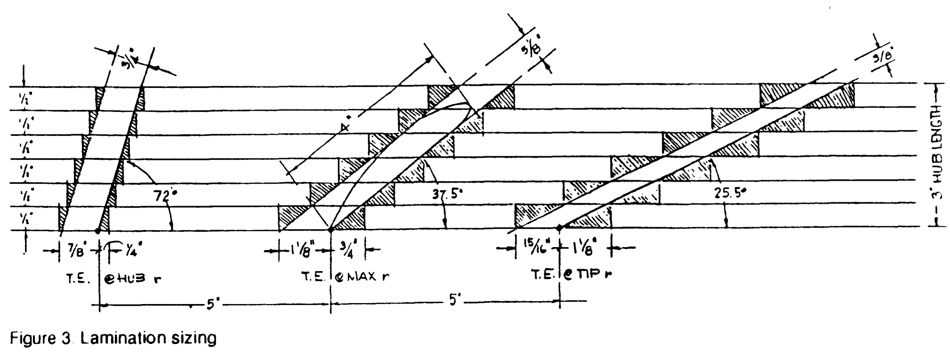


Figure 3 Lamination sizing

If we unwrap one of these co-axial right circular cylinders and lay it out flat, the helix it contains will appear as the hypotenuse of a right triangle whose base is the circumference C of that cylinder ($C = 2\pi r$) and whose altitude is the pitch H. The angle between the hypotenuse and the base is the pitch angle x, whose tangent is $H/(2\pi r)$.

Assuming a maximum blade width of 4 inches (102 mm) at a radius of 5 inches (127 mm) [2], a 2-1/2-inch- (63.5 mm)-diameter hub, blade thickness of 3/8 inches (9.5 mm), 5/8 inch (16 mm), and 3/4 inch (18 mm) at tip, maximum width, and hub, respectively, and 1/2 inch (12.7 mm) plywood, we can start to determine the pattern for the blade laminations as follows.

First, calculate the pitch angles at the radii of the hub, of the point of maximum blade width, and of the blade tip. These are

$$\tan x\ (\text{hub}) = 24/(2\pi 1.25) = 3.0564 \quad x\ (\text{hub}) = 72°$$
$$\tan x\ (\text{max}) = 24/(2\pi 5) = 0.7641 \quad x\ (\text{max}) = 37.5°$$
$$\tan x\ (\text{tip}) = 24/(2\pi 8) = 0.4776 \quad x\ (\text{tip}) = 25.5°$$

Next, draw a series of seven straight horizontal lines 20 inches (500-mm) long on a sheet of drawing paper, exactly 1/2-inch (12.7-mm) apart. About two inches (50 mm) from the left on the bottom line locate three points about five inches (130 mm) apart. These points represent the straight-line element which will be the trailing (after) edge of the propeller blade. At the left element-point, draw a line at the hub pitch angle of 72°; at the center point draw a line at the maximum blade-width radius pitch angle of 37.5°; and at the right draw a line at the tip pitch angle of 25.5°. These inclined lines are the hypotenuses representing the blade face at each radius.

Above and to the left of the hypotenuse for the pitch angle at maximum blade-width, lay out maximum blade-width of 4 inches (102 mm), and the blade thickness of 5/8 inch (15 mm), as shown in the figure. The enclosing rectangle will then determine the required number and required width of the plywood laminations on each side of the trailing-edge element at this radius. A similar procedure, for the same number of laminations and specified blade thicknesses, is followed at the hub and tip to determine the plywood dimensions on each side of the element at those radii.

We are now ready to make the pattern for the blade laminations. On a sheet of tough, thin cardboard, draw three concentric circles at the hub radius of 1-1/4 inches (31.75 mm), maximum blade-width radius of 5 inches (127 mm), and tip radius of 8 inches (203 mm). Then draw three radii at 120 degrees, which will be the trailing-edge elements of the propeller blades. Taking each radius in turn, lay out the lamination widths we have just found, at the appropriate radial distances from the center, along the arcs. To be pre cise, these distances should be laid out along the arcs, but measuring them as chord dimensions here will provide a little extra margin for the plywood. Connect these points with smooth, fair lines, and we then have the pattern for the laminations. Carefully cut this out of the cardboard, "saving the line", and check for interblade uniformity by tracing each blade pattern one on top of the other on a piece of paper to see if they coincide.

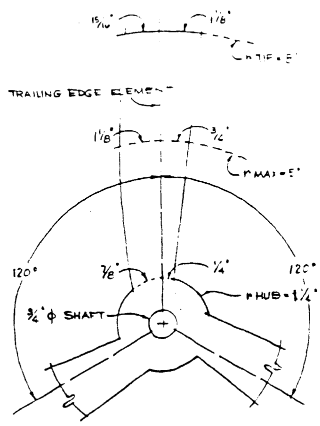


Figure 4. Lamination pattern

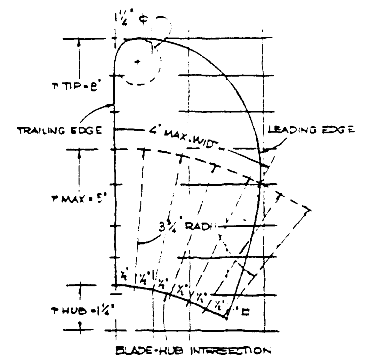


Figure 5 Blade patterr

Use this pattern to lay out the required number of laminations on a sheet of 1/2-inch (12.7 mm) marine-grade plywood („marine" because this grade is less likely to have internal voids than is common plywood). Be sure to carefully locate the center point in each case. The patterns can be interfingered on the sheet to minimize waste. Use a sabre or band saw to carefully cut out the laminations – again saving the line – and then carefully drill each for a 3/4-inch- (19-mm)-diameter propeller shaft.

The next step is to make the assembly platform, exactly 16 inches (406.4 mm) square. The same 1/2 inch (12.7 mm) plywood may be used, solidly mounted on a 1-1/2-inch- (38-mm)-thick frame on the underside, and with a block 1-1/2-inch (38-mm) thick by 4-inch (100-mm) square underneath in the center. This should be drilled carefully for a 3/4-inch (19-mm) dowel, perpendicular to the platform and extending 6 inches (150 mm) above it. Taking each lamination in turn, place it over the dowel on the platform and, using its outer edge as a guide, sand off the tip of each blade to a uniform 8-inch (203-mm) radius.

Before we assemble the laminations we must prepare three jigs to insure their proper positioning while being epoxied together. These jigs are made of thin, stiff cardboard (manila file folders will do). Each consists of a strip of width of the same number of 1/2-inch (12.7 mm) laminations as the propeller itself, and cut to a step-like profile identical with that of the lamination-blanks at the blade tips.

The next step is to make a trial assembly of the laminations on the platform. Position the helicoidal-surface up on the dowel, with each blade having the trailing-edge element at the left, and the laminations rotated clockwise from the top down to the platform in accordance with the tip-jig used as a guide on the outer surface of their tips.

When all is in order, remove them from the platform, rub the dowel thoroughly with some wax and cover the platform with a sheet of waxed paper cut to fit over the dowel. Now start the epoxied assembly, being sure each successive surface is completely and uniformly coated, and carefully positioned with the aid of the jigs pinned around the outer surface. Place the same amount of weights uniformly over each blade-stack while curing.

A wood rasp is the best tool for the initial removal of the corners of the laminations down to the helicoidal surface of the face of the blades, followed by progressively finer wood files. In doing this, note that all the plywood laminations should be kept as straight radial lines. Do not deal with the other side of the blades at this time. With the helicoidal face of the blades thus roughed out, we can now turn our attention to the outline shape of the blades themselves.

To make a pattern for the blade profile we will fit a piece of thin, tough cardboard to the present fan-shaped surface of the blade face. Since the helicoidal blade surface is three-dimensional and the cardboard is two-dimensional, it will not lie flat, but the difference is not too great and the approximation is reasonable. Align a straight edge of the cardboard with the radial line of the trailing edge, and by cut-and-try, fit the inner edge of the card-board as close as possible to the curve where the blade surface meets the hub cylinder. (Note that the length of this line equals the length of the hypotenuse at x(hub) = 72°: in our case, 3-1/8 inches (79.4 mm). When this is done, lay the cardboard flat and spot a series of points about 1/2-inch (12.7 mm) apart along this line. Using them as centers, and a compass setting of 3-3/4 inches (95.25 mm), the radius at maximum blade curvature, 5 inches; minus hub radius, 1-1/4 inch, draw a series of arcs on the pattern. A smooth curve across their tops will be the intersection of the cylinder of 5-inch (127-mm) radius with the helicoidal surface. We must next lay off the required blade-width along this line.

To do this take a strip of paper and lay out the required blade width of 4 inches (102 mm) along one edge. Then place this edge outside, on the convex side of the above curve, with one endpoint at the straight trailing edge and tangent to the curve and, in essence, „roll" this edge along the curve. This is done by using a sharp pencil-point pressed close to the edge of the strip as a pivot, and rotating the strip just a bit to a new point of tangency along the curve. Holding the strip in this new position, the pencil point is shifted a bit further along the strip, and the strip again rotated to a new point of tangency. This process is called „ticking off" the length along the curve, and obviously the closer together the successive pivot points, the more accurate the transfer of the dimension.

Turning our attention next to the tip of the blade, draw in a circle of 1-1 /4-inch (31.75-mm) diameter tangent to the straight-line trailing edge and tangent to a line perpendicular to it at its end. A fair curve drawn through the end of the hub intersection, the point of maximum blade width, and tangent to the last-mentioned circle will be the profile of the leading edge of the blade. This pattern is then cut out and used to trace the outline on each blade, being careful to keep the straight edge in line with the trailing edge, and the hub cut-out snug against the hub. Use a coping saw to trim the wood to this profile.

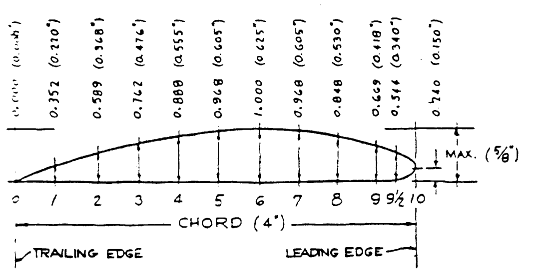


Figure 6 Blade section @ max. width

At this point, we can turn the propeller over and rasp off just the corners of the laminations on the back surface of the blades. Before we can proceed with the final shaping of the blade sections, we need to make one more template: that of the blade-section at maximum blade width.

This will be an airfoil shape, whose heights („ordinates") above the straight-line face of the blade, at ten equally-spaced stations along the blade width or „chord", are shown first as percentages of the maximum blade thickness at this radius (in our case, 5/8 inch (16 mm) and 5 inches (127 mm), respectively, for a chord length of 4 inches (162 mm), and then as inches for our example.

Thus, the next task is to carefully lay out this blade-section profile on a sheet of tough, thin cardboard and cut it to shape. The cardboard is then trimmed to the form shown in the figure and mounted perpendicularly around the edge of a 10-inch-(254-mm-) diameter disk of 1/2-inch (12.7-mm) plywood, which fits over the 3/4-inch (19-mm) dowel on the assembly platform.

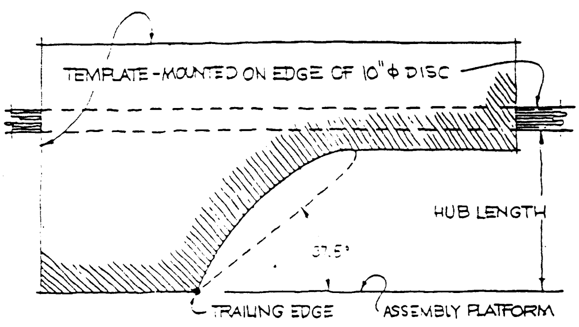


Figure 7. Blade section jig

With the propeller helicoidal surface face down on the platform, use this jig to check your profiling of the back of each blade at the 5-inch (127-mm) radius. When this is done, rasp and file off the rest of the blade surfaces, using the radial lines of the plywood laminations as guides to produce a smooth, fair surface based on this key section.

The tip of the blades should be trimmed to about a 1/8-inch (3-mm) radius. The final step is to form the curved part of the blade face at the leading edge, and then the surface of the entire propeller is smoothed off with progressively finer grades of sandpaper.

The last step is to paint the propeller with two coats of epoxy, sanding after each to end with a very smooth finish. Be sure to epoxy the inside of the bore for the propeller shaft, too. The propeller can be secured to the propeller shaft by means of a roll pin through the hub and shaft. If desired, a tail-cone of laminated plywood can be epoxied behind the hub.

If the propeller becomes damaged in use, it may be easily repaired by cutting out the affected area to reach sound material, and filling in the void to the original profile and contour with a stiff paste of epoxy and fine sawdust. A subsequent filing and sanding to the original form completes the repair.

Notes

1. According to DeLong, an „average" person can sustain an output of about 0.225 hp (170 watts) over a one-hour period, with near maximum efficiency at a pedal speed of 60 rpm. Assuming a mechanical efficiency of 0.9 and a gear ratio of 1:4, this results in 0.2 hp (150 watts) and 240 rpm at the propeller.

The Troost B.3.35 model is a high-efficiency pattern with good acceleration characteristics, suitable for an all-weather cruising boat. As embodied here it differs from the original with the elimination of the 15 degrees-aft blade rake and a slightly thicker blade section.

See: Fred DeLong, DeLong's Guide to Bicycles and Bicycling, Radnor, PA: Chilton Book Co., 1978; and L. Troost, „Open Water Test Series with Modern Propeller Forms", Newcastle, G.B.: Transactions of the North-East Coast Institution of Naval Architects, 1950-51. For an accessible introduction to the details of empirical propeller design, see Dave Gerr, Propeller Handbook, Camden, ME, USA: Internat'l Marine Publishing Co., 1989.

2. To give a developed-area ratio of 0.35. The developed-area ratio (DAR) is the true area of the blade (not the projected area) times the number of blades; divided by the disc area of the propeller, or πR^2, where R is the radius of the propeller.

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Book Review

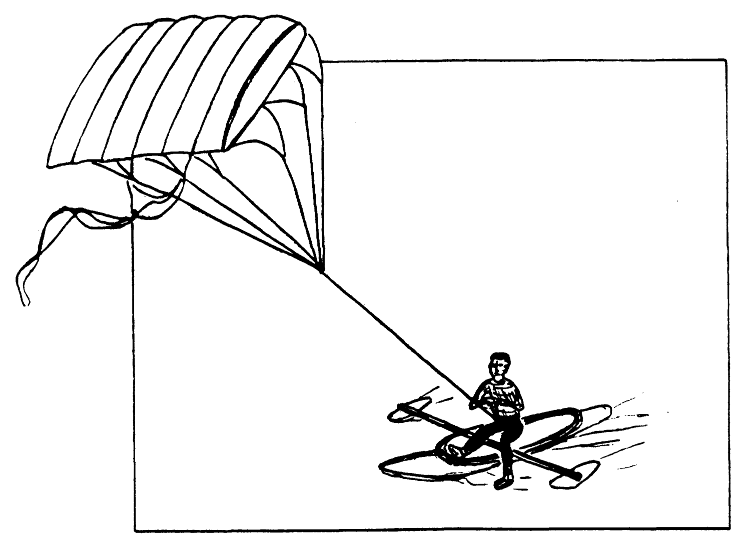
Arnaud de Rosnay
Tout m'est défi Editions Maritimes et d'Outre-Mer, Paris 1981

German edition:
Mit dem Surfbrett über den Pazifik Pietsch Verlag, Stuttgart 1984

This is a kind of mini-autobiography by well-known sailboarder Arnaud de Rosnay. In a self-confident manner he describes his various adventurous exploits and his motivations, ending with his crossing from the Marquesas to Tuamotu: over 900 km of open Pacific on a sailboard. In contrast to some other long-distance sailboarders, de Rosnay never relied on support boats. At night the sailboard became a trimaran with the mast as outrigger beam and small inflatable floats on the ends. An inflatable collar on the sailboard made de Rosnay's berth. He had two Jalbert parafoil kites for nighttime sailing, 4.6 and 7.6 m2, usually using the smaller one. The provisions consisted almost entirely of dates and a bit of water, with an inflatable solar still carried to stretch this.

A few years after this astonishing feat, Arnaud de Rosnay died while attempting a sailboard crossing from Taiwan to China.

Arnaud de Rosnay deploying his Jalbert Parafoil for nighttime sailboarding. Note inflatable collar. (drawn from a photograph)



Building a Solar Boat

(using Hans Tschirren's as an example)

by Theo Schmidt

Hans Tschirren is Switzerland's solar boat pioneer. Before anyone had heard of such craft over here, Tschirren fitted solar panels, batteries and an electric motor to a small rowing boat and quietly cruised around on the river Aare. Never having been trained in mechanical and electrical matters and by now celebrating his 70th birthday, Tschirren needed someone to help with the planning and construction of a new boat. When he ask me to do this, I felt honoured and the following describes the result with advice on how to build a similar craft.

The Hull

All low-power boats must have an efficient, low-drag hull. This either means a pure displacement hull going at speeds well before the drag hump or very fine lines such as those of a multihull. For a given load-carrying capacity, the former concept results in a smaller but slower boat. The planing hulls of speedboats or the dreadful lines of most modern cruisers are useless for us and a good hull shape will either be derived from a sailing boat or a traditional motor or rowing boat. Tschirren managed to find a second-hand Pehn, an electric boat made in Austria for the hire market, where hundreds of such craft are used on waters where other engines are prohibited. These have the lines of a sailing dingy but with a seating arrangement like in a car.

Any type of small sailing or rowing craft is suitable for conversion, as are various traditional craft. For a very small boat, the canadian canoe is hard to beat, as it combines low drag with seaworthiness even when heavily loaded. Larger boats can be purchased ready made in Austria, Britain and USA, but at a price! Some of these already have roofs suitable for solar panels. (Finished Solar Boats are available in Germany and Switzerland, from about £10000 to £100000!)

The Motor

You cannot yet buy a really efficient electric drive! Custom-made inboard or outboard installations perform better than the commercial outboards available, although some of these are pretty good. Top of the line in quality and price is the Austrian Accumot, while some of the American outboards are more efficient, but less reliable. In general, at non-planing speeds, an electric drive will do the job of a petrol outboard rated several times the power. Tschirren purchased an 800 Watt Accumot (1 HP=746 W) which comes with two forward and two reverse speeds. For prolonged cruising at low power, an electronic chopper control unit is essential. This will get you home with nearly flat batteries or under solar power alone. For Tschirren's boat, we chose a unit made by Brusa, which also protects the battery by progressively reducing the maximum current as the battery becomes exhausted.

The Battery

For a displacement boat, the battery question is not a crucial one. This is because the resistance of such hulls does not change greatly with loading; it is far more sensitive to speed variations. Lead-acid batteries are fine and just about any type can be used, except that starter batteries will not last long if deeply discharged. Marine or traction batteries are better in this respect, but even they should never be completely discharged. Used batteries no longer good enough for road vehicles can be used. Batteries which are connected together should all be of a similar type and in a similar state.

On Tschirren's boat, we had two different sets of batteries and had to connect these in two different circuits, which are connected together in parallel only when using the motor. The total is about 250 Ah at 24 V, giving a full day's running even with no solar input. It is difficult to give a rule for the ideal amount, as so many factors are involved. One suggestion is to fit the amount that will not involve not more than about 50% discharge in normal running or occasional 80% discharges.

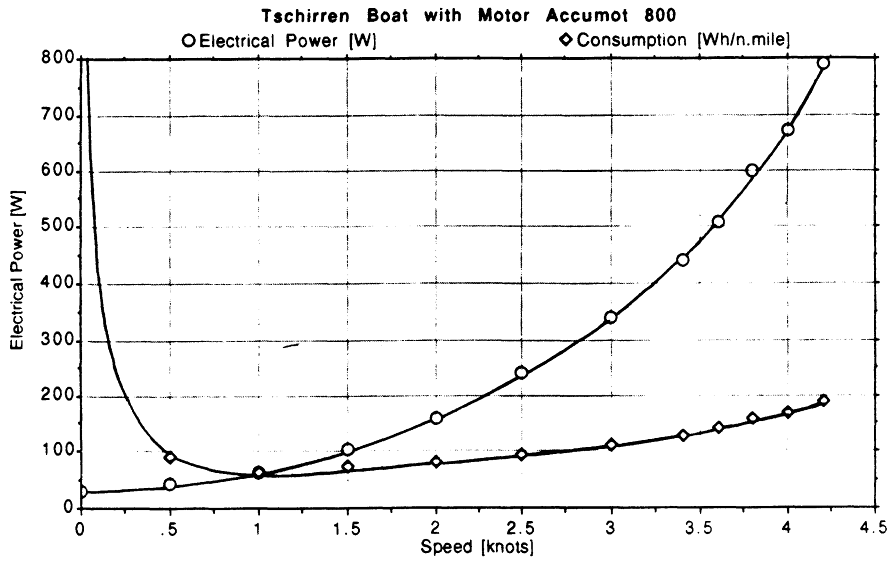
The Solar Panels

You use what you can get at the cheapest price and as many panels as you can fit or afford. At the moment, crystalline silicon cells (blue or black in colour) have at least twice the efficiency of the amorphous types (brown in colour). They will also last longer, with a life expectancy of over 30 years. For decks there are several types available which can be walked on. For roofs, special lightweight versions are obtainable. Some of these can also be walked on if mounted on a flat, rigid surface. Most panels have aluminium frames which may eventually corrode in salt water. So-called marine panels with stainless steel frames are quite expensive. For larger quantities of panels, substantial discounts are available if you ask! Tschirren's boat has six 12W and six 24 W panels made by Siemens mounted on deck (can be walked on) and six 40 W Solarex panels as the roof. The two different types are connected to two different controllers called Maximum Power Trackers. These transform the voltage to the correct level for charging the batteries and prevent overcharging, maintain the best operating point of the solar panels, and prevent the batteries discharging through the solar cells at night. Only in very small installations is it advisable to do without any controller and here a series diode is required to prevent nightly discharge. Any voltage over 24 V could be lethal in salt water and systems with higher voltages must be exceptionally well insulated. Keep in mind that the solar panel's open circuit voltage can be nearly twice its nominal voltage and you cannot turn it off except by shorting it out.

Tilting panels provide quite a bit more power when the sun is low but it is difficult to do and often not worth it. On Tschirren's boat, the roof can be tilted, but it is so awkward to do that we now always leave it horizontal. The mass aloft of a solar roof can make the boat unsafe; Tschirren's boat rolls dreadfully in waves from abeam and will need a keel or other device for damping (Any good advice on this aspect would be appreciated!). A horizontal roof is normally no danger even in high winds except in the case of a very tender boat or excessive wave-induced rolling. (Aren't you glad you've got all those batteries for ballast!)

Performance

The top speed is governed by hull and motor; the range is governed by these and the amount of cells, the season and weather, and the chosen boat speed. These values are shown below for Tschirren's boat, which is a practical, reliable low-to-medium-performance boat, and for the trimaran Basilisk on page 26. As a pure displacement craft, Tschirren's boat is not very sensitive to loading and the top speed of about 4.2 kts is the same whether driving alone or with 4 people on board. By drawing a tangent to the curve from the origin, the best speed-to-power ratio is found, i.e. the speed at which the range is greatest. This is usually rather slow, as the power needed to drive the hull decreases with over the third power of the speed decrease. Given flat water and no wind, very little power is actually required, as has been demonstrated by British solar boat pioneer Alan Freeman, who built a one-person solar catamaran running at 1-2 kts using only 20 W of power! Theoretically you can travel with an infinately small amount of power if you go infinately slow, but in reality the motor will have a power level below which its effciency drops off rapidly. Thus Tschirren's boat has its lowest specific consumption (about 65 Wh/n.mile) at a speed of about 1 knot.



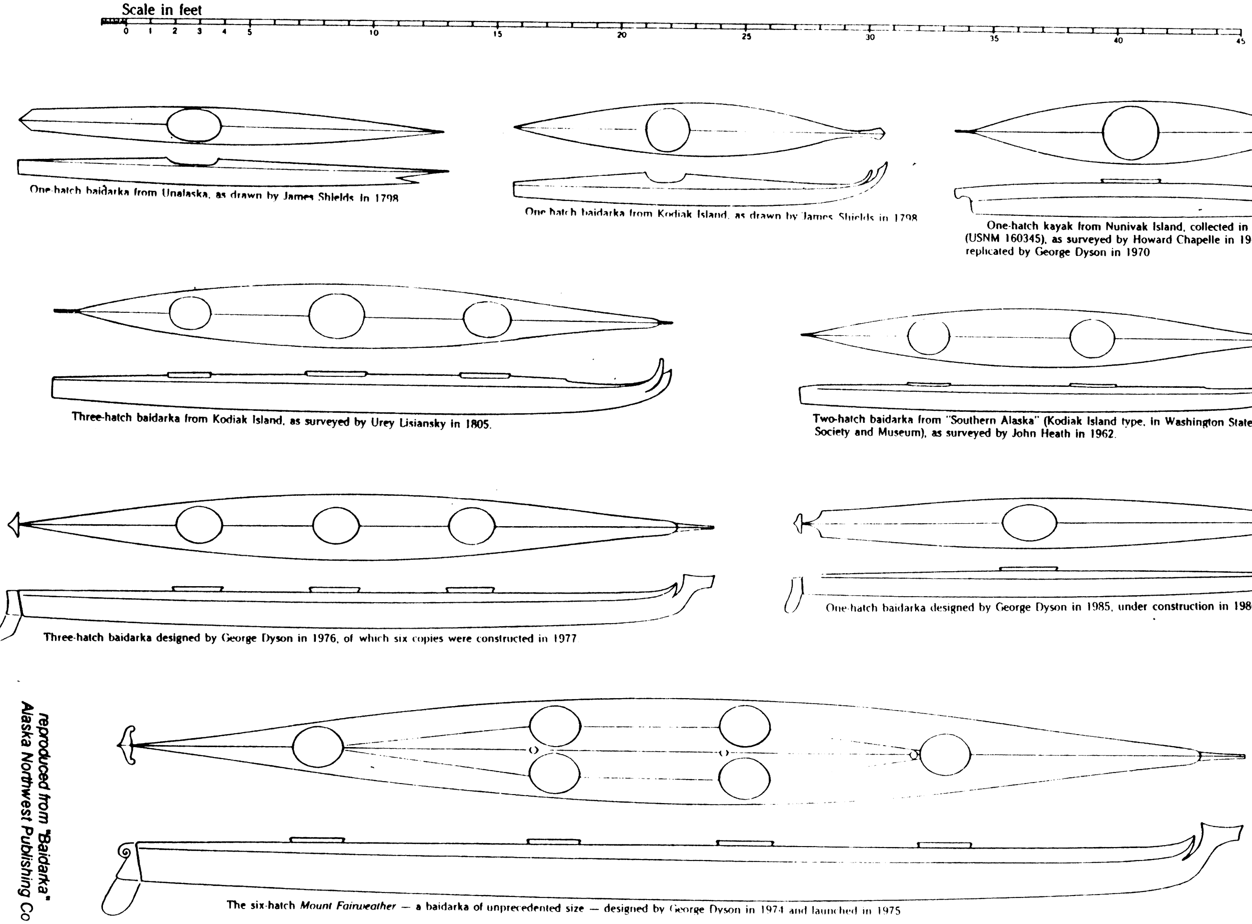
Other Research Societies

The Baidarka Historical Society
Post Office Box 5454, Bellingham, Washington, USA 98227-5454

This society was founded by George Dyson to further the knowledge of the Aleut baidarka and its role in Russian-American history, and to encourage, by way of its renaissance, the continued evolution of the skin boat. The name is that given by the Russians to the specific kayaks used by the Aleuts and Alaskan coastal natives. Members construct baidarkas from modern materials, e.g. aluminium tubing and nylon skin, and undertake adventurous journeys, mainly in the waters from Washington to Alaska. Common are boats with one, two, and three hatches and Dyson even built a giant with six hatches, which, as a keen AYRS member, he also equipped with Bruce foils and sails which could double as tents. Modern baidarkas have the forms of the original ones including split bows and flaring sterns, but they do not reach the top speeds documented over two hundred years ago: various sources giving 8-10 knots. Much of the research by the society involves this intriguing question and seeks to find a relationship between the flexible skin of such craft and the reduction of drag.

The society publishes a newsletter and sells books and plans for building baidarkas. Anyone interested in drag reduction and the construction of lightweight small craft, or in North-American history, will benefit from the various publications. A splendid book appropriately named "Baidarka" has beautiful colour photographs and many fine drawings. It is out of print but some copies may still be available. The latest publication is called "Form and Function of the Baidarka", also by George Dyson.This 50 page book summarises the present state of technical baidarka knowledge. Write to the above address for a list of publications or details of membership ($20 per year).

Baidarkas of the North Pacific, 1798-1986: An evolutionary sketch



One-hatch baidarka from Unalaska, as drawn by James Shields in 1798

One-hatch baidarka from Kodiak Island, as drawn by James Shields in 1798

One-hatch kayak from Nunivak Island, collected in 1889 (USNM 160345), as surveyed by Howard Chapelle in 1946 and replicated by George Dyson in 1970

Three-hatch baidarka from Kodiak Island, as surveyed by Urey Lisiansky in 1805.

Two-hatch baidarka from "Southern Alaska" (Kodiak Island type, in Washington State Historical Society and Museum), as surveyed by John Heath in 1962.

Three-hatch baidarka designed by George Dyson in 1976, of which six copies were constructed in 1977

One-hatch baidarka designed by George Dyson in 1985, under construction in 1986

The six-hatch *Mount Fairweather* — a baidarka of unprecedented size — designed by George Dyson in 1974 and launched in 1975

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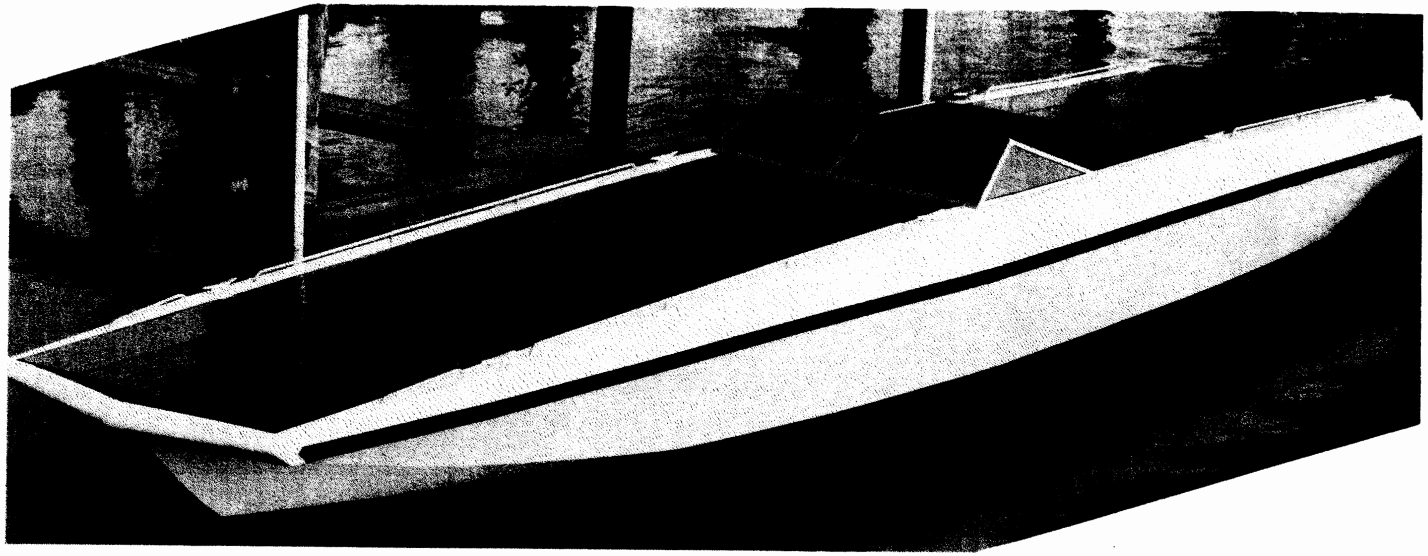
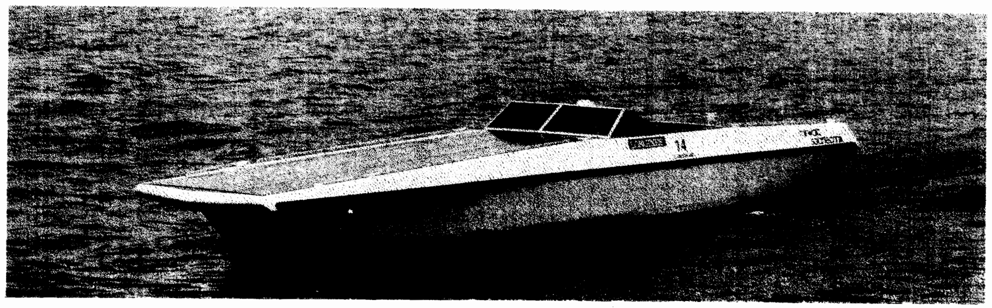




Newest Solar Craft by

mirwald solartechnik

Cruising speed: 6.5 knots

The Story of Basilisk

by Theo Schmidt

This is the tale of a rather extraordinary trimaran called "Basilisk" after the patron dragon of the city of Basel in Switzerland. Basilisk's creator, Mathias Wegmann, wanted a light sailing trimaran. Because moorings and boat parks are both rare and expensive in Switzerland and no true environmentalist would consider trailing a boat by car each time he goes sailing, the boat was to be amphibious and capable of being pedaled on the road to the water. For this the boat had to be as light as possible. Mathias used foam sandwich to make a 6m long center hull with a cabin and aft cockpit and attached sidefloats from a small catamaran called a Peanut. Three retractable Moped wheels adequately supported the boat, however it was soon seen that the craft would be too heavy and unwieldy to pedal up the hills around Basel.

An engine was needed! But what type? Petrol was out of the question, but why not use an electric motor with batteries and charge these from solar panels mounted on the wide wing decks? Said - done - and an ingenious device called a Deltamat was procured, a kind of continuously variable transmission with a 500 Watt motor. Next problem: driving on the road like this is illegal in highly regulated Switzerland, where to carry out testing? A temporary teaching job offered on the Greek island of Antiparos provided the answer. The Greek authorities were sure to be more accomodating than the Swiss and superb sailing was anticipated!

Basilisk was duly loaded up with the luggage of Mathias and his friend Theo, tools and materials, mast, sails and rigging, batteries, motors and solar panels, two of Theo's inflatable solar-powered catamarans, and a folding bicycle! The boat was trailed to Venice and pushed on board the ferry to Athens, this trip being a holiday by itself. The first test drive had been on the quayside at Venice, the first real test was negotiating heavy traffic in Pireus, where we had to drive 2 km to change ferries. This was at least flat, but arriving in Paros, the next 15 km to be driven were decidedly hilly! However Basilisk stood up bravely to the task, Mathias having been persuaded not to undertake Basilisk's maiden voyage loaded with half a ton of valuables on a choppy sound in a F5! Duly arrived in Antiparos via yet another ferry, we installed ourselves in a rented house and Basilisk on the beach.

In the coming weeks a happy time was spent sailing and modifying Basilisk and the solar inflatables. Basilisk sailed very well in light airs but creaked and moved alarmingly in stronger winds. Mathias redesigned the whole boat, which now had a roomy center cockpit and fore and aft cabins. I pottered about on my inflatables, driven by a heavily geared down motor swinging a 50 cm diameter propeller. The power consumed was about 60 watts in direct solar drive, giving about 3 knots, and 250 W with the batteries, giving 5-6 kts. Basilisk also received an electric propeller drive, which worked well enough that Mathias wanted to sail the 100 or so miles back to Pireus in Basilisk. The weather however proved too severe and we went back the way we came, by land and ferry.

Back in Switzerland, the world's first solar boat race was being organised by the Tour de Sol people. Mathias decided to scrap the sails and the centerboard case, which had always leaked, and to construct a proper electric outboard drive, as commercially available ones are rather inefficient with their small propellers. An old Solex "Flash" moped provided a high quality right angle reduction gear, upon which a special Deltamat with a 2 kW Bosch motor was mounted. The propeller was my standard 2-bladed 50 cm diameter x 66 cm pitch propeller (data elsewhere in this issue). A large second-hand solar panel was procured, providing up to 800 W in bright sunlight and still 80 W in heavy overcast (midday, summer). Batteries totalling about 60 kg in weight were installed.

Thus equipped, Basilisk became a formidable racing machine and won most of the races in which its rather under-engineered construction held together. At times, things failed; once the entire outboard dropped off just before the finish line, another time a poor electrical connection lost Basilisk a race. However the racing was fun, as well as fast and comfortable. The roomy center cockpit and fore and aft cabins gave the boat the feeling of a yacht even though it only weighed 350 kg. The large solar panel gave shelter from rain and allowed good performance even in cloud. Basilisk's worst property was the noise its drive made. Far from being silent, the deltamat variable speed gear could be louder than a petrol motor, at least to the crew; from outside the problem wasn't so bad. Later the motor was transfered to an inboard well, now making a noise almost indistinguishable from that of a large diesel engine!

Inbetween races in 1990, Mathias took Basilisk on a longer trip: down the Rhein from Basel as far as Koblenz, up the Mosel and Saar until Saarbrücken, and back through canals to Strassbourg, not far from Basel, the total trip being about 1000 km. The rivers were in flood, normally exposed rocks being covered by the murky waters. Several propellers later, Mathias's stock finally ran out and he was forced to hand-carve one from a piece of driftwood! Although efficiency dropped, the voyage could be completed without mishap, apart from the loss of Mathias's Moulton bicycle, which had been insufficiently lashed on deck.

1990 saw some interesting racing. There was the Italian "European Championship" for solar boats with about 8 races held according to rather vague rules, a Swiss race on three lakes, and a get-together in Berlin. Basilisk went to this by car-train, the German railways however requiring some pesuading to allow the lightweight boat to travel, as a solar powered vehicle had once been blown off such a train. In Berlin, the race took place in heavy rain (Basilisk took 2nd place) and the following day the small flotilla of solar boats was officially asked to celebrate the opening of the border to East Berlin by carrying letters of friendship across the once heavily patroled waters. Mathias now had sound financial backing thanks to sponsor Weleda, makers of natural body care products. He now planned a big trip, from Basel to Ibiza in Spain. The route was to go via canals and the rivers Rhein, Doubs, Saône, and Rhône down to the Mediterranean and along the French and Spanish coasts to Denia, crossing from there to Ibiza, the return a year later.

The voyage started rather late in October 1990 and a temporary closure of the Canal Rhône-au-Rhin meant a detour of 300 km and 70 locks. The weather was also unkind, yet Basilisk made steady progress day by day, an average of 70 km daily while under way. Several friends went to crew and enjoy the Basilisk experience for different portions of the journey. The crew had the front cabin, extremly comfortable for lying and sitting in and watching the world go by through the front hatch. One bicycle shared the cabin, the other being lashed to an outrigger. The aft cabin was the skipper's by night and galley, chart table, saloon, "engine room" and "bridge" by day. Nights were spent moored to the riverbank or sometimes in a marina in a town, which are usually free in France.

Eventually Basilisk reached the seaside, now being crewless as the temperatures fell. Mathias had a few exciting experiences going along the coast and yet again rebuilt Basilisk, increasing the beam with new outriggers and taking all solar panels to deck level. The weather was said to be the worst for many years and

Basilisk made slow progress in the gloomy short days. Previously it had been possible to run at 2 knots in the rain while still recharging the batteries. Now, in the waves, more power was required just to keep steerage way, and the distances covered daily grew shorter and shorter. Although this gave plenty of time for sightseeing, much of the coast is no longer beautiful, being largely covered with hideous hotels. Eventually Basilisk reached Denia, in early december. From here, the final stage to Ibiza is only about 100 km, or 5% of the distance covered so far. Mathias set about waiting for a stretch of good weather and prepared the boat for the crossing. He had two spare motors, an autohelm, a small inflatable, a marine radio, and a few flares. Later, he would sorely miss an additional means of propulsion, more flares, a radar reflector, and a crew! The weather improved, and with a good forecast, man and boat set off. Mathias took the advice of friend Theo to set off into the dusk, in order to make landfall later by daylight. For a solar boat, this turned out to be bad advice, as daybreak found Basilisk halfway, with empty batteries and changed weather: no sun and a headwind. Mathias decided to limp back with the wind, but was still 15 km away from shore at nightfall.

The next day was even gloomier and Basilisk drifted about aimlessly. Mathias decided to request a tow and indeed reached the coastguard by radio, who decided to come out themselves in spite of nearby fishing boats. He was instructed to shoot off his flares in order to provide a fix, which he duly did. The coastguard boat saw the flares but was unable to find Basilisk, so another night was spent drifting around Cape de la Nao. The coast guard gave up even though Basilisk's situation was getting worse: the waves had partially filled one float and damaged an outrigger. Upon realising the extent of the damage and feeling unable to repair it in the night, Mathias called "Mayday" into the radio and was picked up half an hour later by a Dutch freighter, who however refused to salvage Basilisk or any of the valuables on board, and later deposited Mathias in Genoa. Unsinkable Basilisk is probably still floating about somewhere, complete with solar panels, three motors and a Moulton bicycle!

The Moral

The loss of Basilisk was in hindsight foreseeable, as solar boats require the same standard of seamanship as any small craft and a night crossing of 100 km of open water in the middle of winter is an undertaking for any small boat, especially single-handed by a Swiss sailor with limited salt-water experience.

Basilisk was not sturdy enough for the prolonged bashing of the waves and the outrigger floats had no bilge pumps, or even permanent floatation such as foam or air-bags. A secondary means of propulsion was lacking, such as a good set of oars, a pedal propeller, a small jury sail or even a kite. Three or four hand flares is not enough if you really want to use them and a radar reflector should always be carried, especially if you want to be found by the Spanish coast guard.

Starting into the night is obviously not a good idea for a solar boat. Starting in the morning, you can decide not to go if it is cloudy or reduce speed to the most economical level.

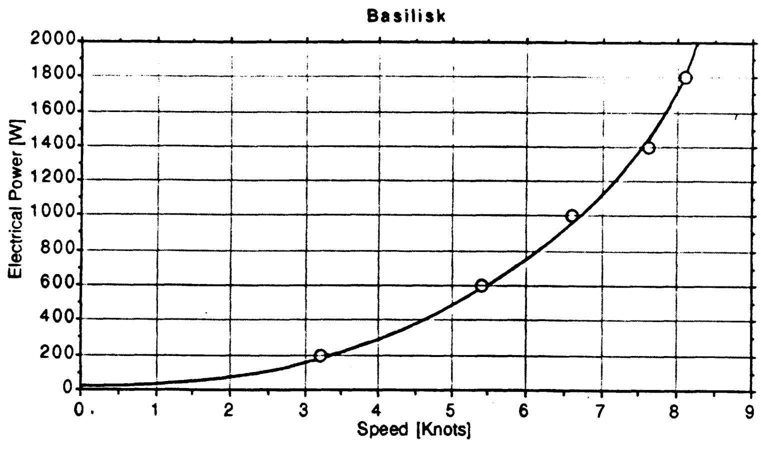
Tough and cold-blooded sailors occasionally perform amazing feats of daring and survival but even their luck runs out at some time and the rest of us must make doubly sure that we have the odds in our favour before even setting off. Still, one musn't overdo it, as more people lose their lives driving to their boats than do using them.

TECHNICAL DATA BASILISK-WELEDA

Dimensions:	Length 6 m Width 4.2 m
Weight:	350 kg (including batteries)
Carrying capacity:	up to 5 people 2 berths
Solar cells, tiltable 45° sideways:	max. 800 W
Motor:	max. 2000 W
Reduction gearing: variable	1:4-1:16
Propeller:	50 cm Diameter 66 cm Pitch 400 rpm at V max. 85% efficiency max.
Batteries:	80 Ah at 48 V
System voltage:	12/24/48 V

Performance:
(calm water)

Motor power (electrical)	Speed
200 W	3.2 kts
600 W	5.4 kts
1000 W	6.6 kts
1400 W	7.6 kts
1800 W	8.1 kts



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Solar Trimaran "BASILISK", made by Mathias Wegmann, shown here in her 1990 version. Top speed: 8 knots
Photo Th. Schmidt