TABLE 4

WT-11 CHINOOK TAIL TEST

RUN LOG SHEET TEST NO. 2073

	RUN	TARE	V_{mph}	δ_R	δ_{RANGE}	δ_r	β_{RANGE}		
07/05/85	73	- 72	25	0°	- 8, +20	0°	0°		
	74	- 72	30	0°	- 8, +20	0°	0°		
	75	- 72	36	0°	- 8, +20	0°	0°		
	76	- 72	40	0°	- 8, +20	0°	0°		
08/05/85	79	- 78	45	0°	-12, +20	0°	0°		
	81	- 78	40	5°	-12, +20	0°	0°		
	82	- 78	30	5°	-12, +20	0°	0°		
	84	- 78	30	10°	-12, +20	0°	0°		
	86	- 78	40	10°	-12/+20/-12	0°	0°		
09/05/85	88	- 78	30	15°	-10, +20	0°	0°		
	89	- 78	40	15°	-10, +20	0°	0°		
	91	- 78	30	20°	-10, +20	0°	0°		
	92	- 78	40	20°	-10, +20	0°	0°		
	93	- 78	30	- 5°	-10, +20	0°	0°		
	94	- 78	40	- 5°	-10, +20	0°	0°		
	96	- 78	30	-10°	-10, +20	0°	0°		
	97	- 78	40	-10°	-10, +20	0°	0°		
	99	- 78	30	-15°	-10, +20	0°	0°		
	100	- 78	40	-15°	-10, +20	0°	0°		
	102	- 78	40	0°	0°	0°	-10, +20		
10/05/85	104	-103	40	0°	-10, +20	0°	0°	Yellow tail	
	106	-103	40	10°	-10, +20	0°	0°	Yellow tail	
	107	-103	30	0°	- 8, + 8	0°	0°	Yellow tail	6" Rip Bottom
	108	-103	40	0°	-10, +16	0°	0°	Yellow tail	2/3 L.E. Starboard

TABLE 5

NRC 30 Foot Wind Tunnel
Transport Canada Aviation Safety Investigation
WT-11 Chinook

Report No.: 2073

Date: 01-MAY-85 Time: 10:38:20 Averaging- Digital (in sec) 5 Analog (samples) 5

Run No. 36 Tare No. -23 Ref. Tare No. -35 Pressure 100.72

Basic Coefficients

Pt	Q	Vel	Alpha	CL	CD	CM	CY	Cn	Cl	K	Temp.
1	3.339	36.0	0.00	0.630	0.065	-0.145	-0.001	-0.022	-0.202	1.012	284.8
2	3.358	36.2	-6.05	0.040	0.064	-0.126	0.009	-0.021	-0.017	1.014	285.0
3	3.358	36.2	-4.02	0.239	0.059	-0.144	0.002	-0.019	-0.078	1.013	285.0
4	3.355	36.1	-1.97	0.440	0.060	-0.144	-0.002	-0.019	-0.142	1.012	285.1
5	3.337	36.1	4.13	0.986	0.084	-0.144	-0.020	-0.026	-0.313	1.011	285.1
6	3.358	36.2	8.12	1.191	0.131	-0.150	-0.007	-0.043	-0.376	1.017	285.2
7	3.394	36.4	12.02	1.234	0.187	-0.160	-0.016	-0.061	-0.383	1.028	285.2
8	3.410	36.5	14.01	1.278	0.215	-0.154	-0.029	-0.068	-0.396	1.033	285.2
9	3.429	36.6	16.01	1.272	0.242	-0.159	-0.034	-0.076	-0.390	1.039	285.4
10	3.443	36.6	18.02	1.272	0.271	-0.147	-0.032	-0.086	-0.388	1.045	285.4
11	3.452	36.7	20.02	1.250	0.301	-0.157	-0.036	-0.095	-0.377	1.053	285.4

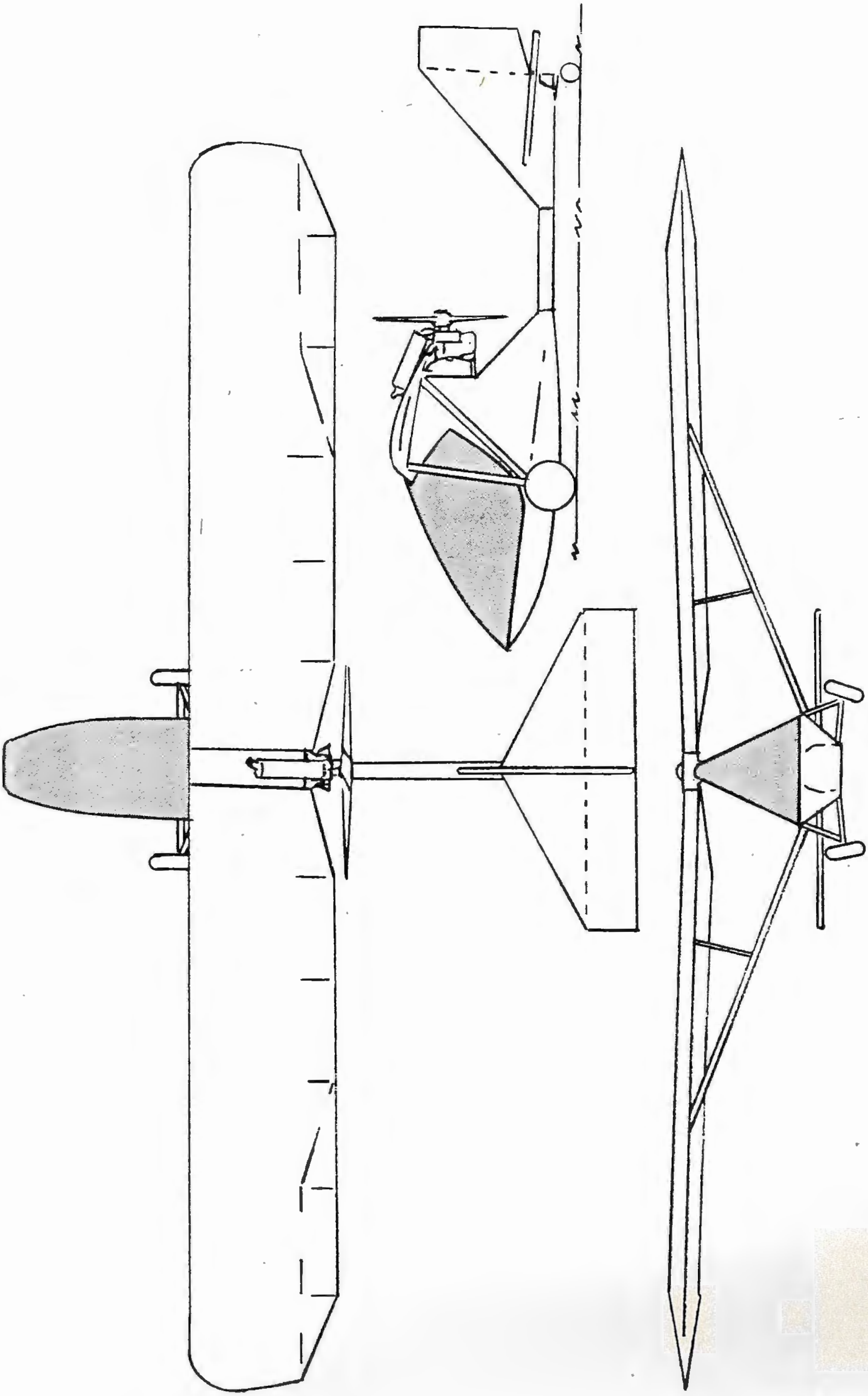

FIG. 1: WT-11 GEOMETRY

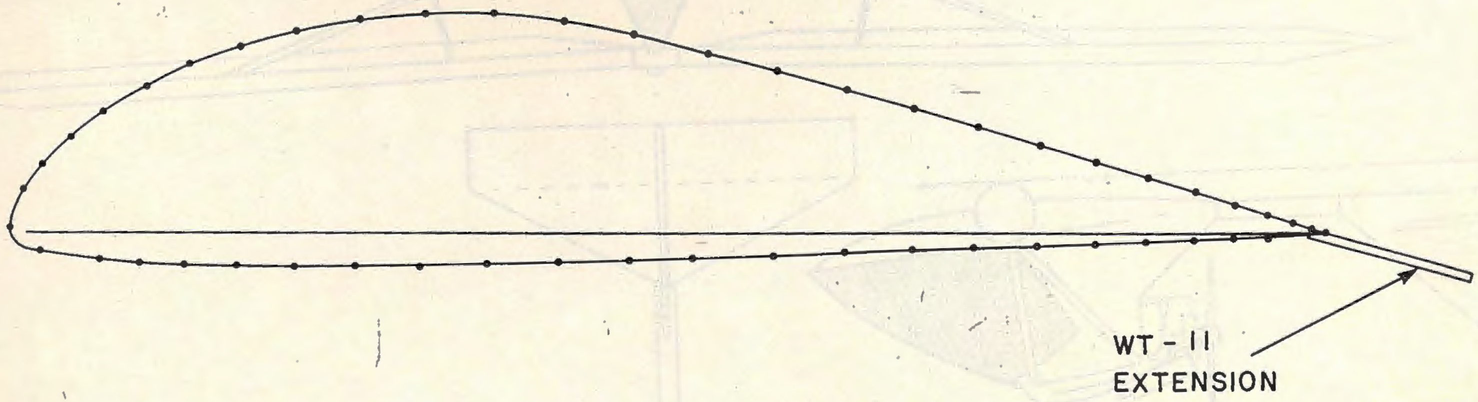

FIG. 2: UA 81/2 18% HIGH LIFT SECTION

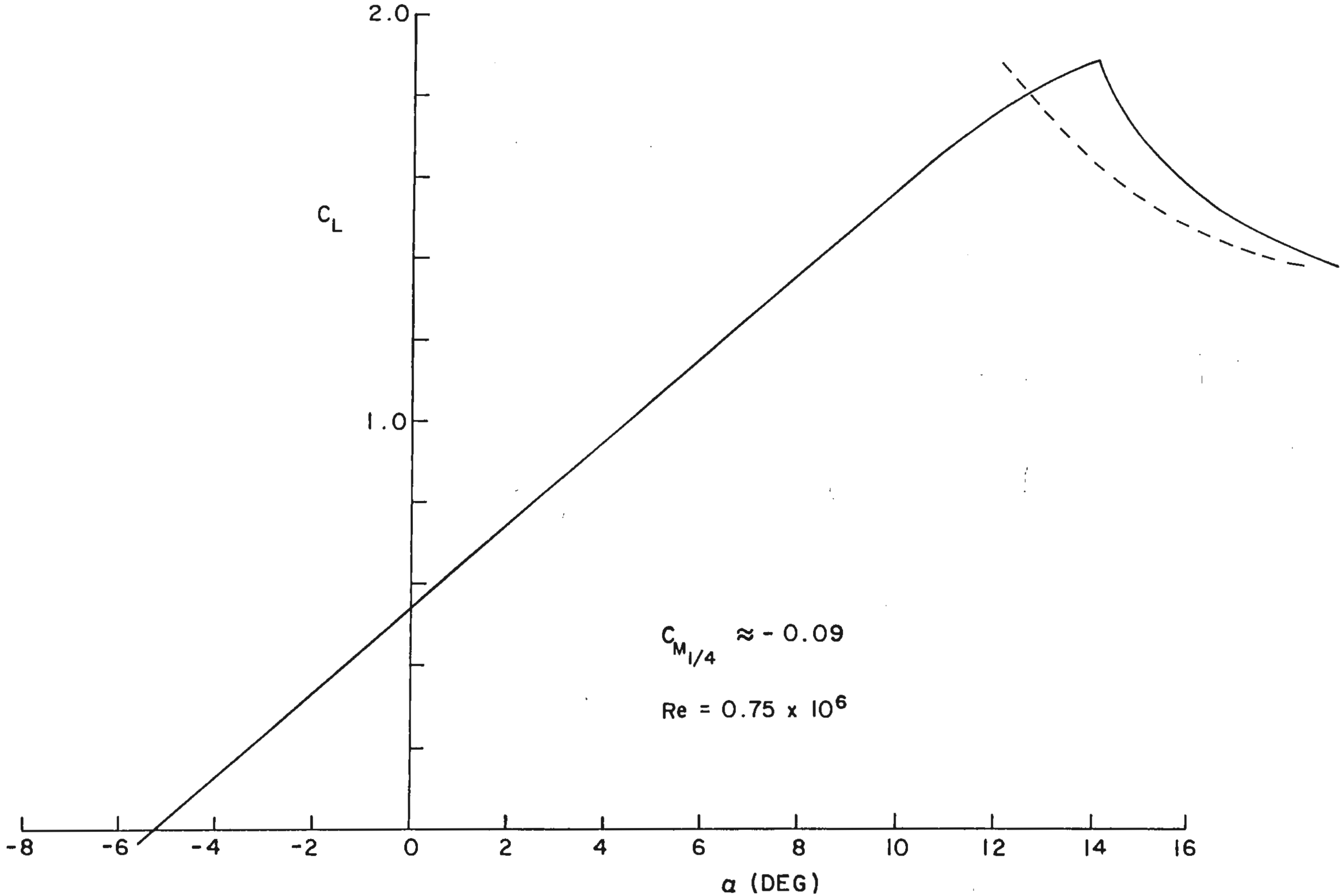

FIG. 3: UA 81/2 C_L VERSUS α

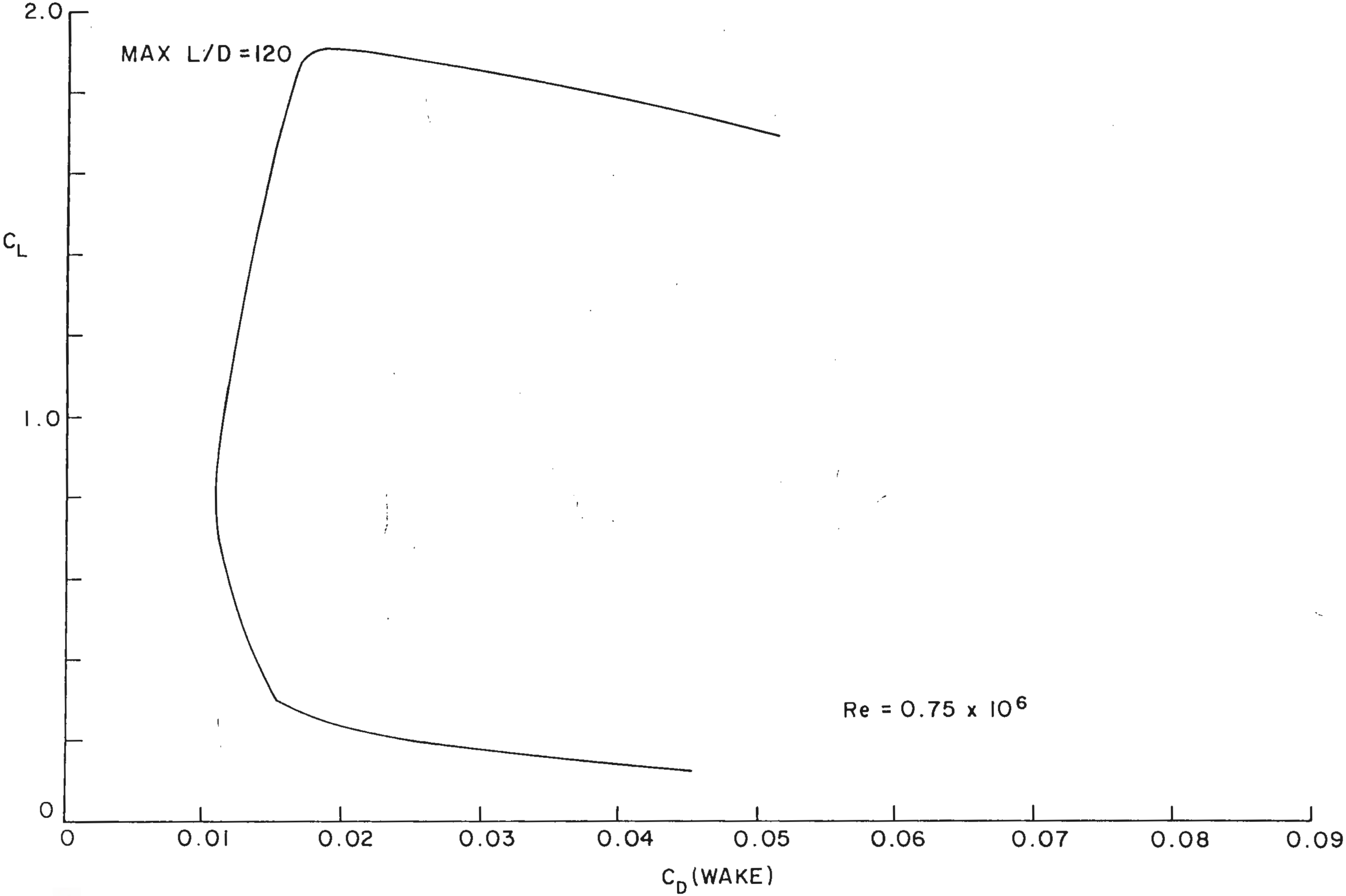

FIG. 4: UA 81/2 C_L VERSUS C_D

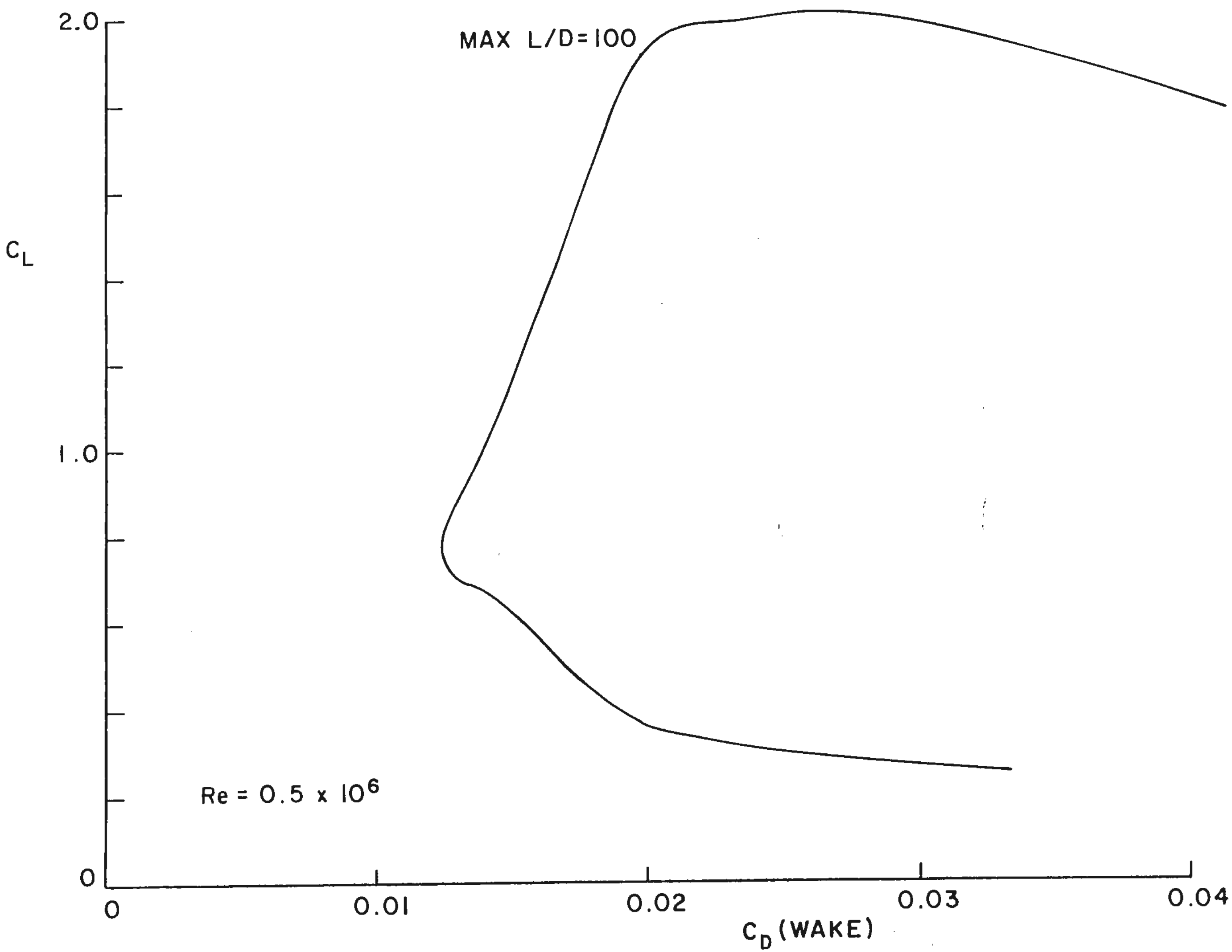

FIG. 5: UA 81/2 C_L VERSUS C_D

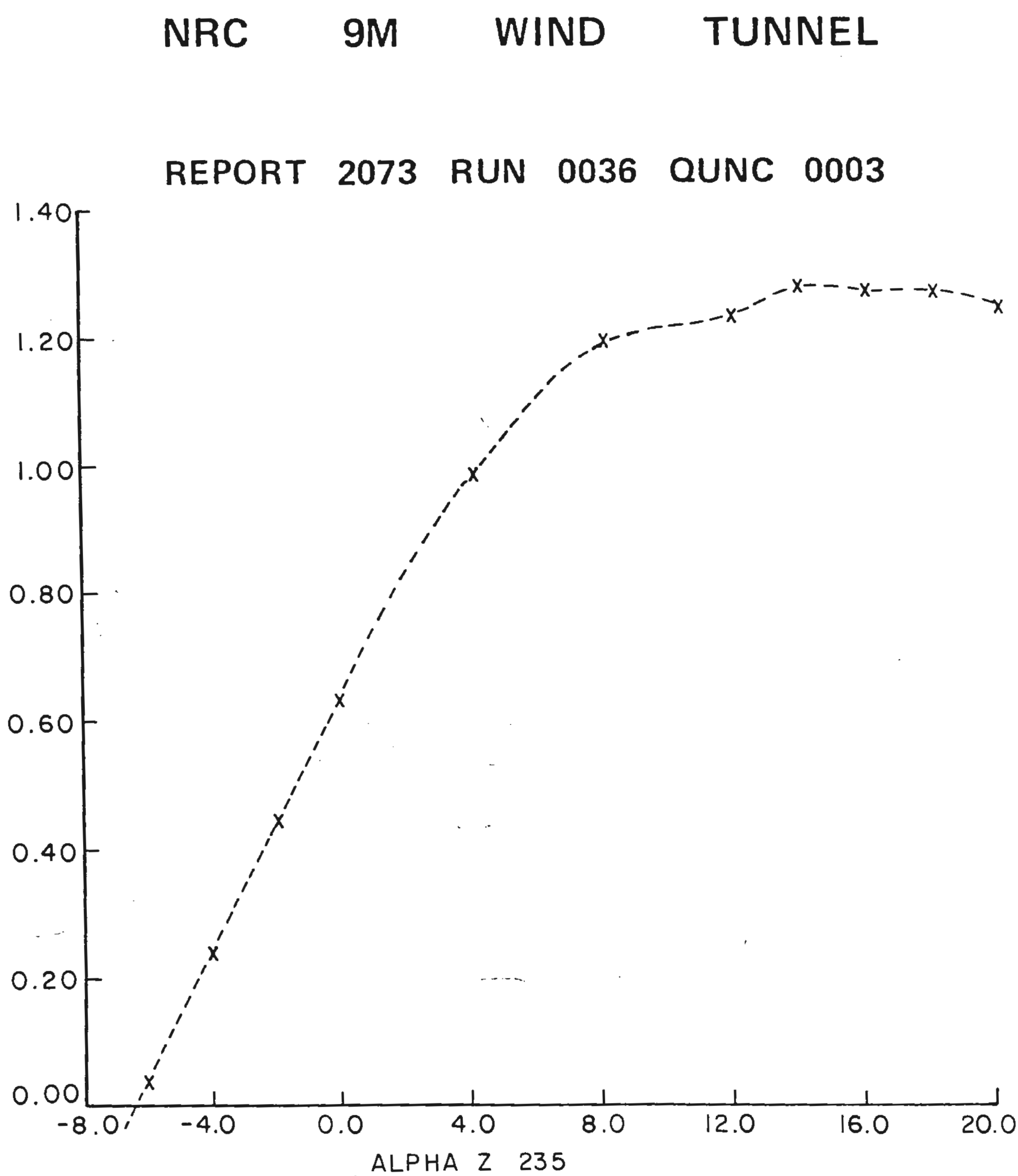

FIG. 6: 9m X 9m TUNNEL PRINTOUT AND C_L VERSUS α CURVE

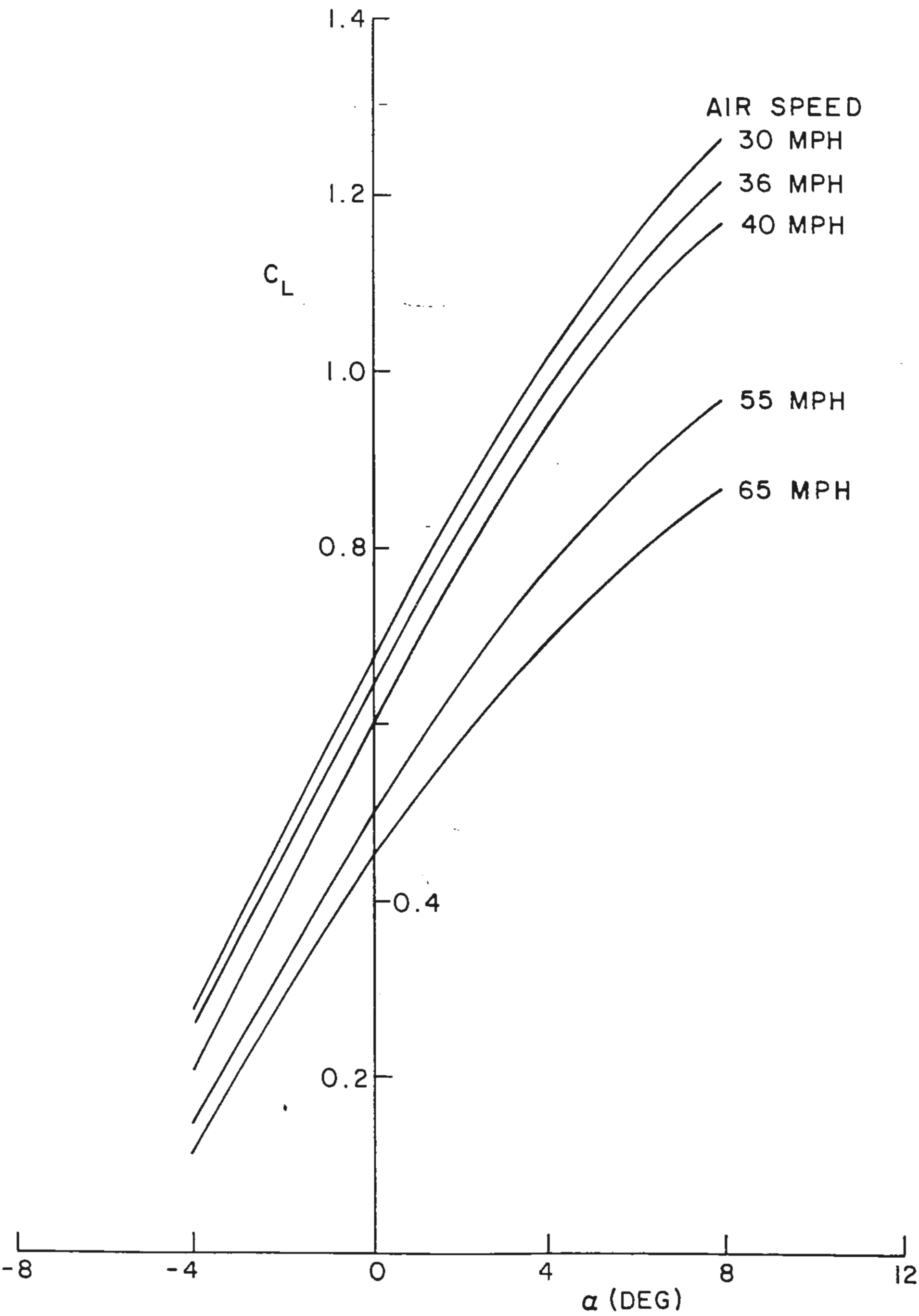

FIG. 7: C_L VERSUS α FOR VARYING q, $\delta_a = 0°$

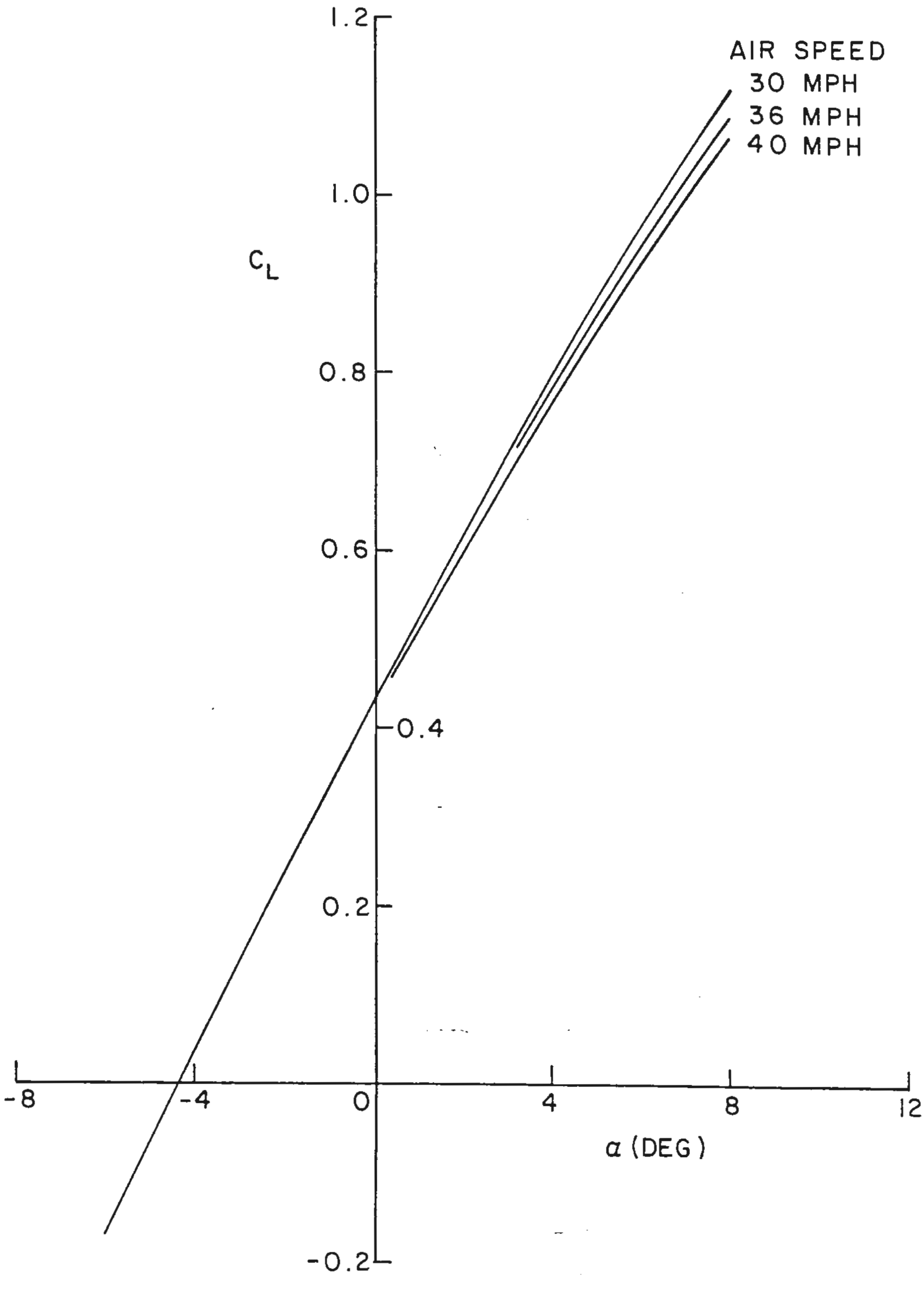

FIG. 8: C_L VERSUS α FOR VARYING q, δ_a MAXIMUM NEGATIVE VALUE

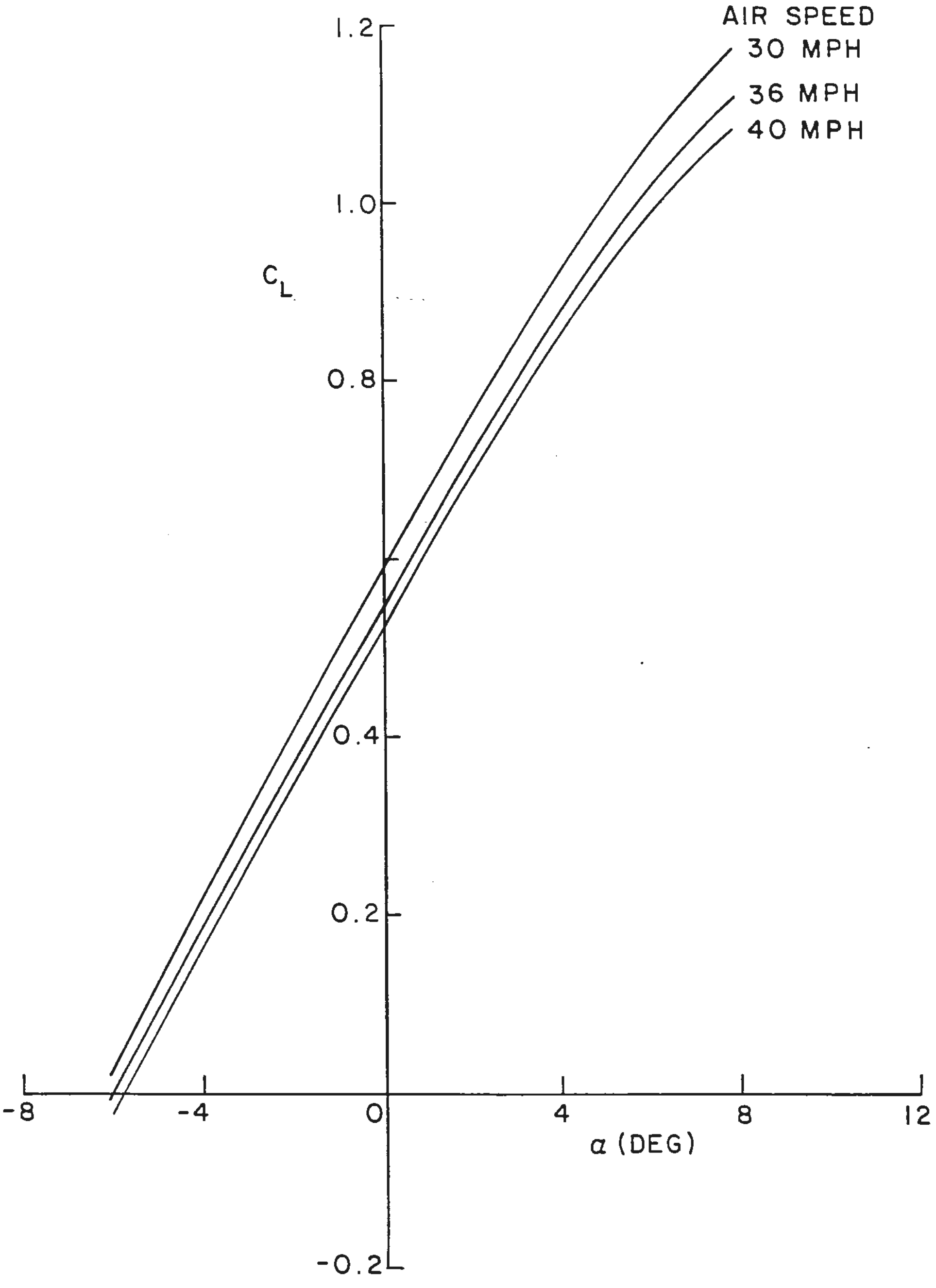

FIG. 9: C_L VERSUS α FOR VARYING q, δ_a FREE

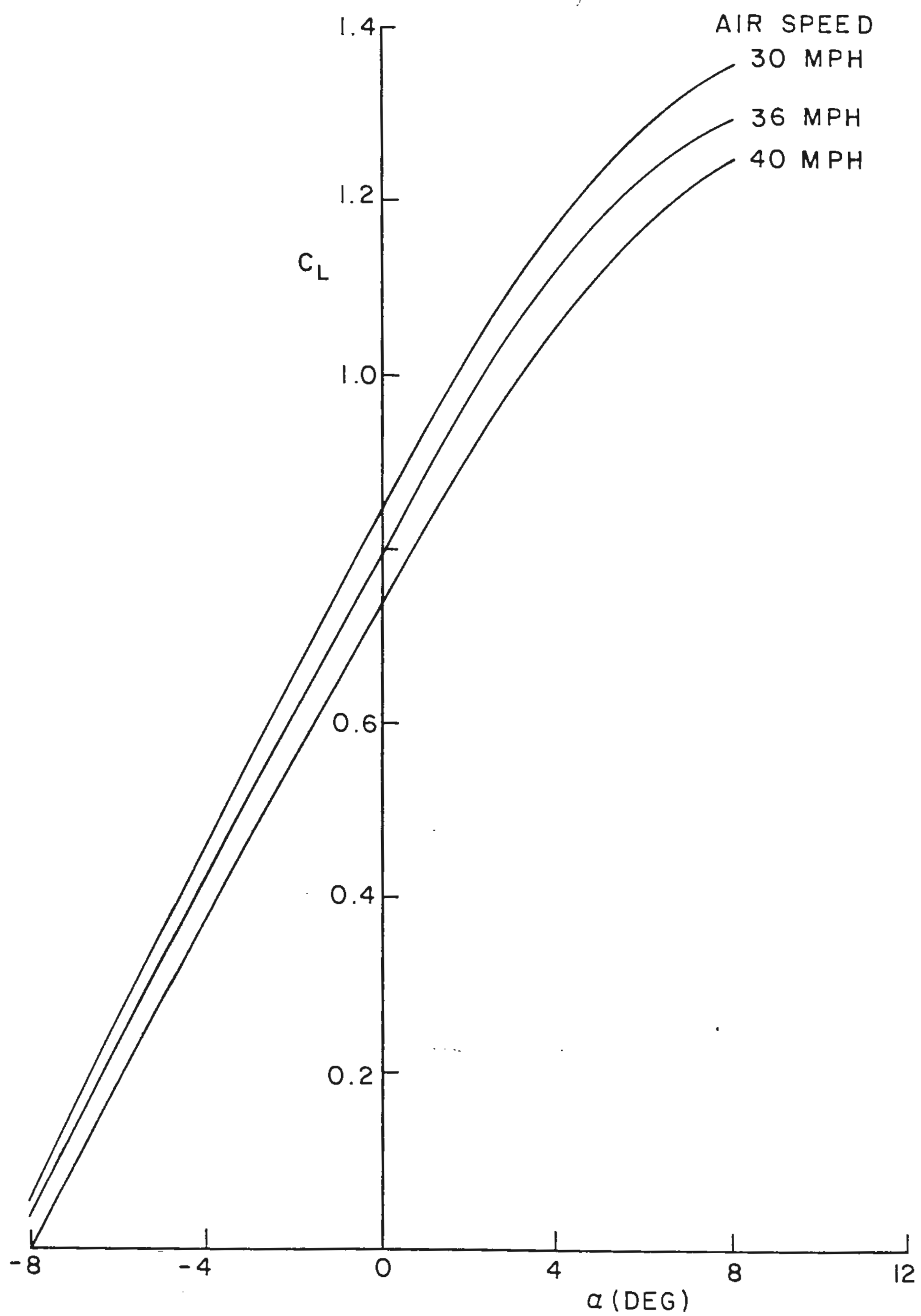

FIG. 10: C_L VERSUS α FOR VARYING q, δ_a MAXIMUM POSITIVE VALUE

WT-11 HORIZONTAL STABILIZER
THEORETICAL SPANWISE CONTROL EFFECTIVENESS

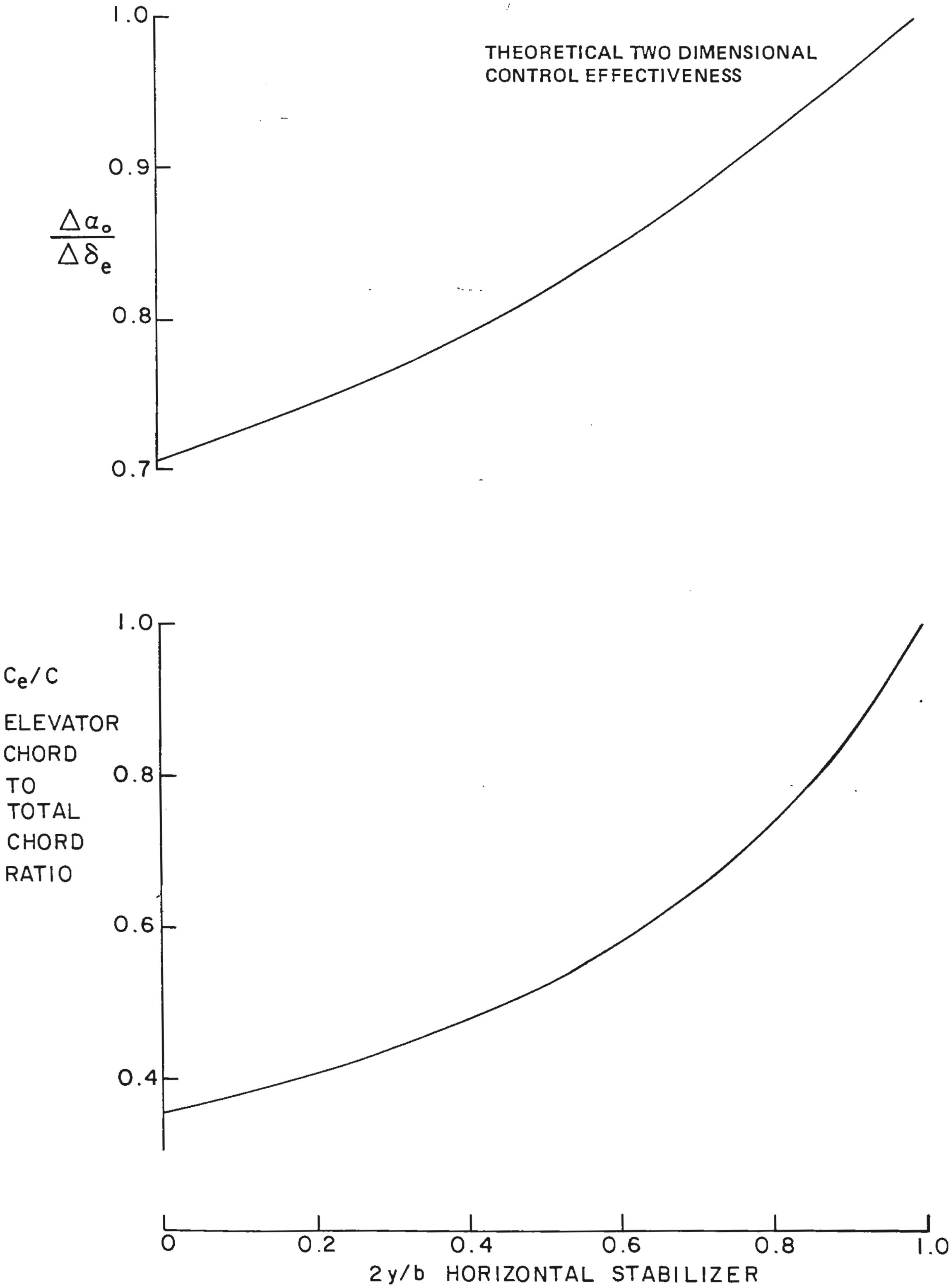

FIG. 11: THEORETICAL $\Delta\alpha°$ VERSUS $\Delta\delta_e$ FOR WT-11 EMPENNAGE

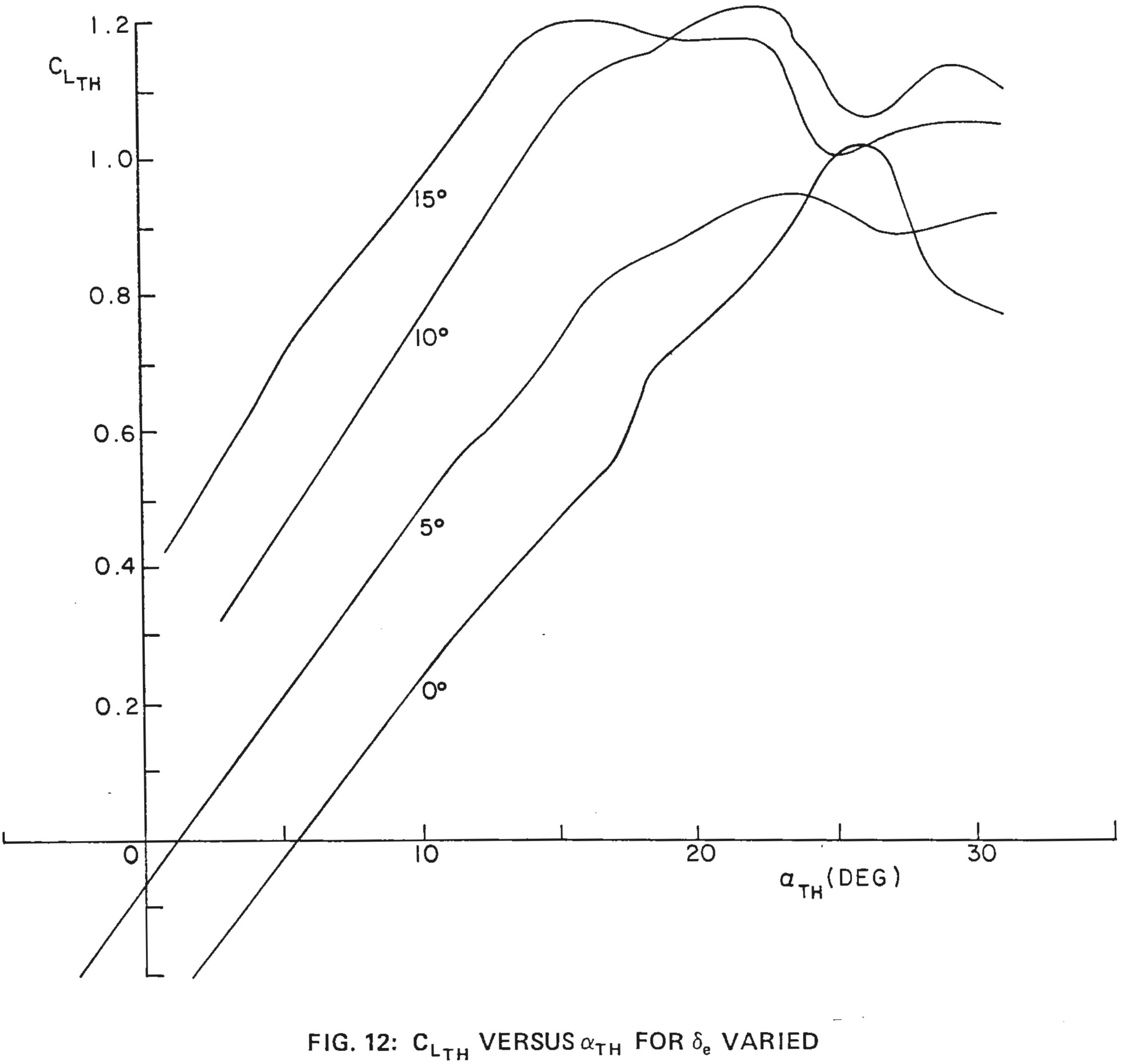

FIG. 12: $C_{L_{TH}}$ VERSUS α_{TH} FOR δ_e VARIED

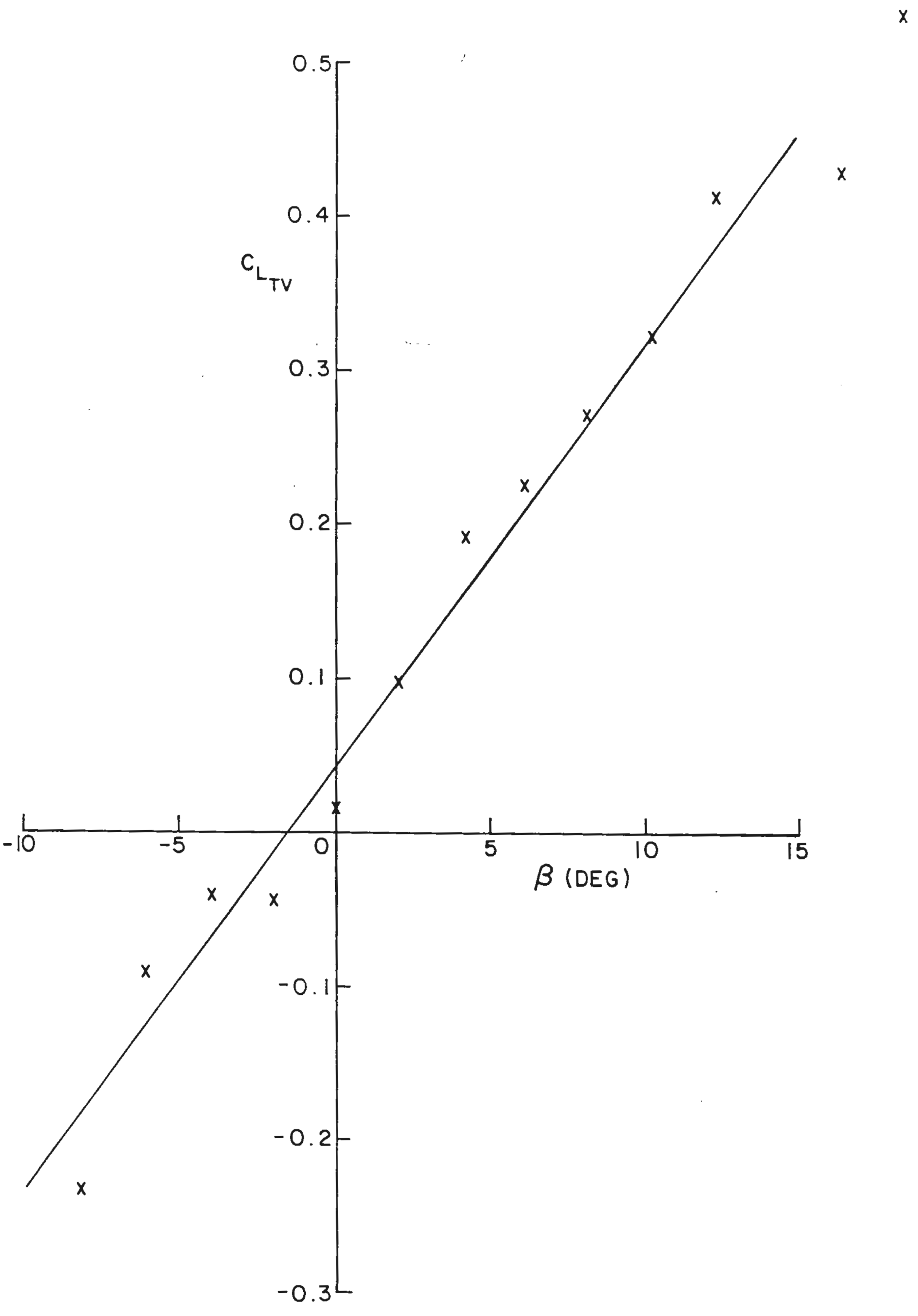

FIG. 13: $C_{L_{TV}}$ VERSUS β

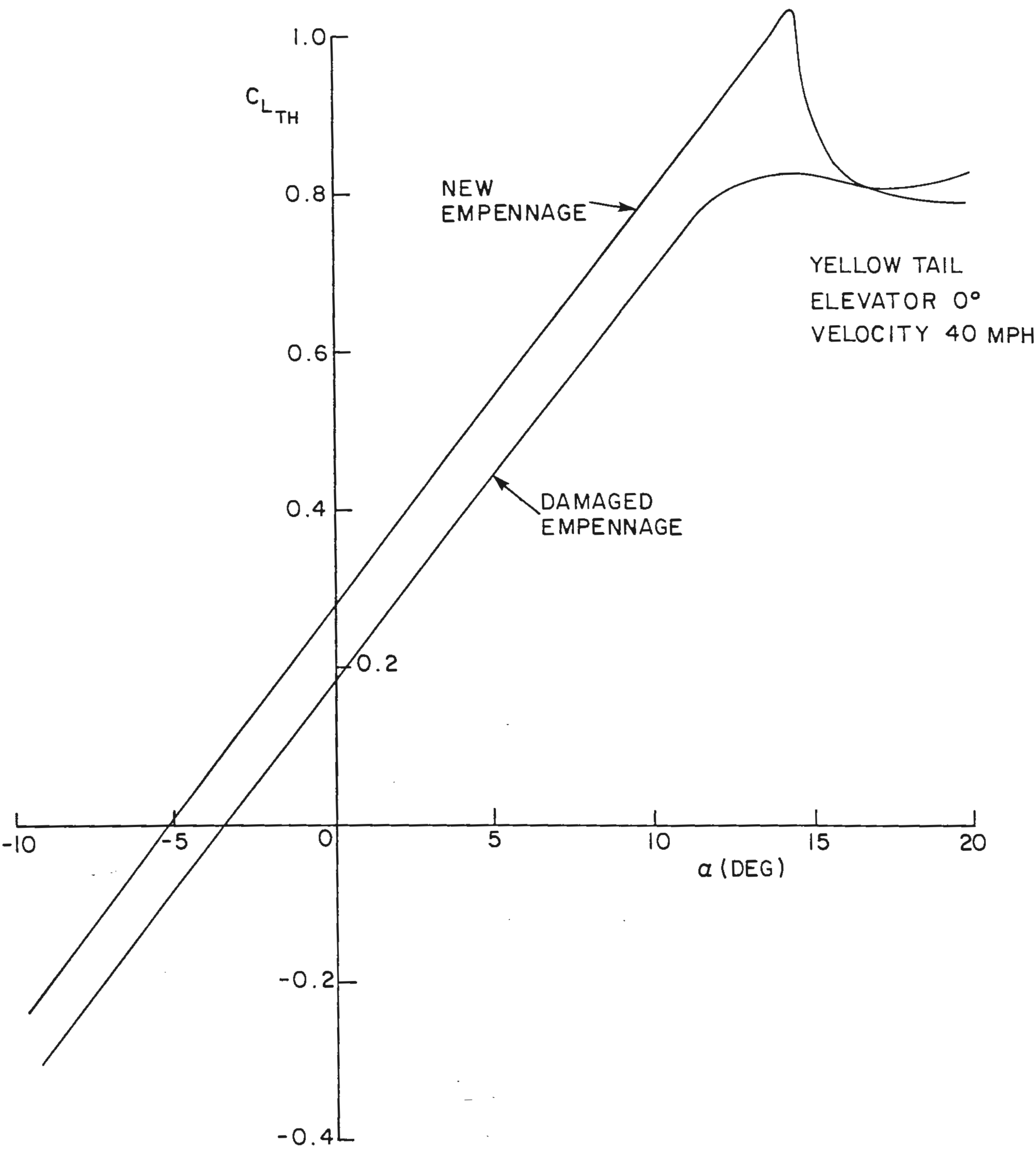

FIG. 14: DAMAGED TAIL ASSEMBLY

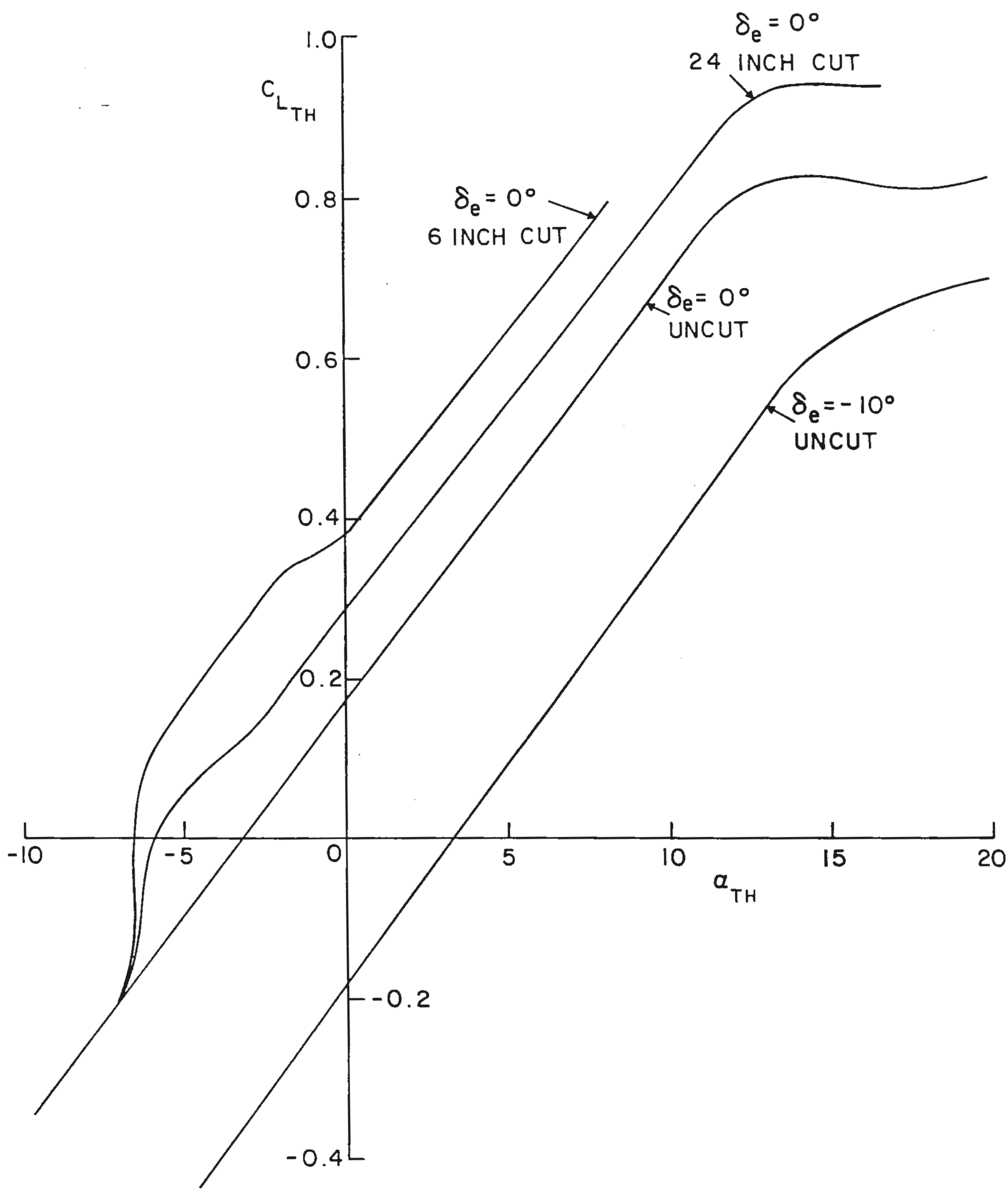

FIG. 15: CUT FABRIC $C_{L_{TH}}$ VERSUS α_{TH}

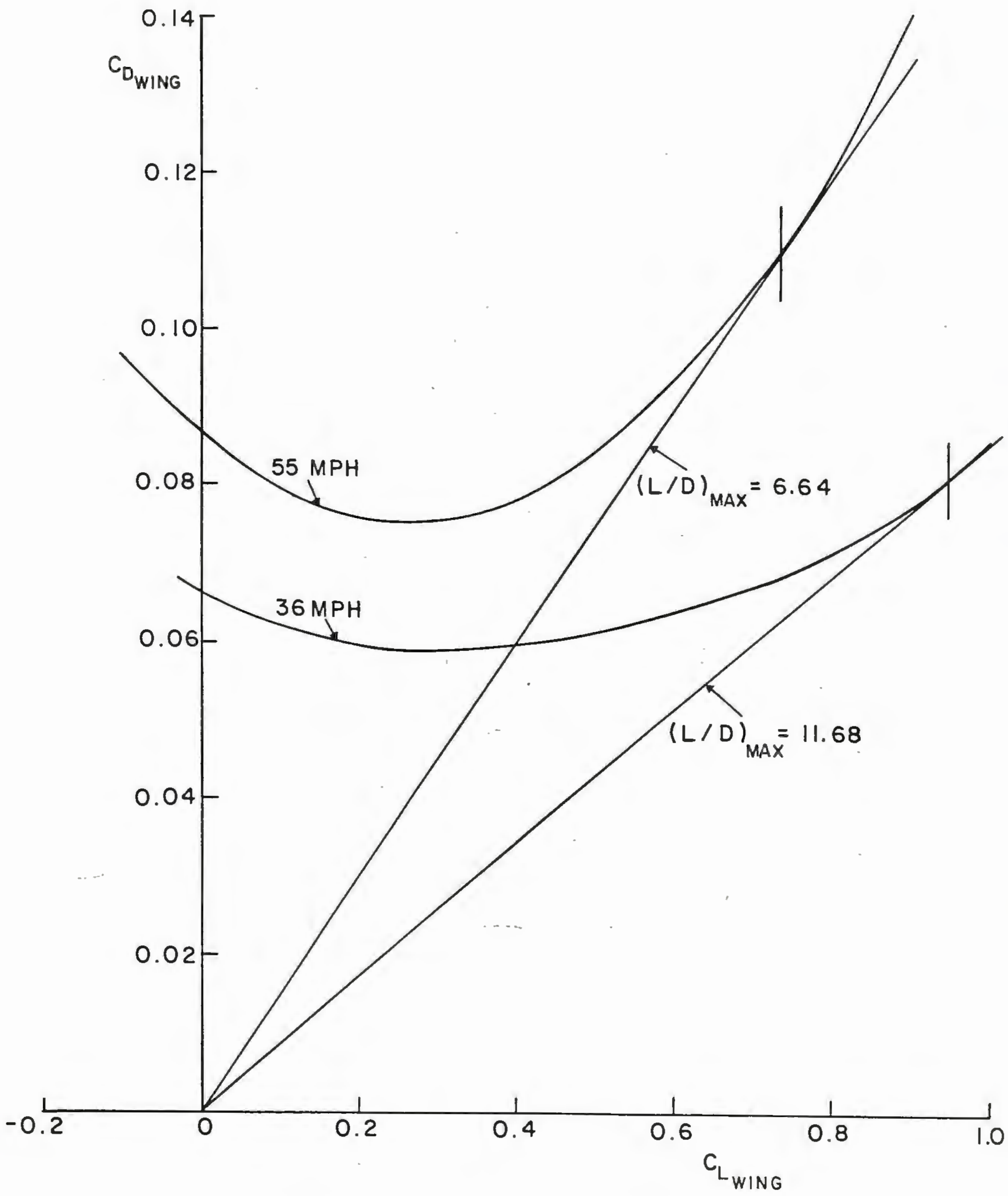

FIG. 16: EFFECT OF VELOCITY ON DRAG POLAR

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Wind Tunnel Evaluation of Chinook WT-11 Ultra Light

4

AUTHOR(S)/AUTEUR(S)

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5

SERIES/SÉRIE

Aeronautical Note

6

CORPORATE AUTHOR/PERFORMING AGENCY/AUTEUR D'ENTREPRISE/AGENCE D'EXÉCUTION

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9	10	11	12a	12b

NOTES

13

DESCRIPTORS (KEY WORDS)/MOTS-CLÉS

1. Aircraft (Birdman WT-11 Chinook)
2. Aircraft (Private)
3. Aircraft (Ultra Light) — Aerodynamic Characteristics
4. Wing Tail Configurations

14

SUMMARY/SOMMAIRE

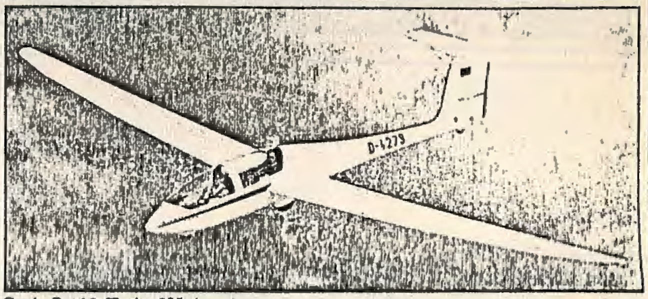
Full scale wind tunnel tests were carried out on the wing and empennage of WT-11 Chinook ultra light aircraft in the NAE 9m X 9m Low Speed Wind Tunnel. This test program was initiated in response to a request from the Canadian Aviation Safety Board, Ottawa, Ontario to determine the aerodynamics of the vehicle and measure the gross structural airloads. The purpose of the test program was to establish if there were any unusual characteristics that might have contributed to several accidents involving this design.

Aside from considerable distortion of the wing at higher dynamic pressures, corresponding to 50 to 60 mph, and considerable aeroelastic effects on lift curve slope and maximum lift coefficient, at these higher dynamic pressures the basic wing does not appear to possess any inherently dangerous characteristics. However, the empennage exhibits some non-linear characteristics that could possibly cause handling qualities problems. The combination of wing stalling characteristics with horizontal tail characteristics could result in large amplitude pitch down at the stall.

15

Sailplanes

The lightest aircraft in our buyer's guide make up just about the longest list. Almost 40 types of sailplane, range from those with lift/drag ratioes of less than 30 to those in the mid-40s, and minimum sink rates are between 1·8ft/sec and 2·5ft/sec. Almost all gliders offer wingspans from 15-18m. Several are two-seaters. New technology and materials have found their way into production and many manufacturers are realising the possibilities of applying composite glassfibre techniques to the building of powered aircraft. The Grob G.103 Twin III Acro is a 1987 newcomer, replacing the G.102 Standard Club designs.



Grob G.103 Twin III Acro

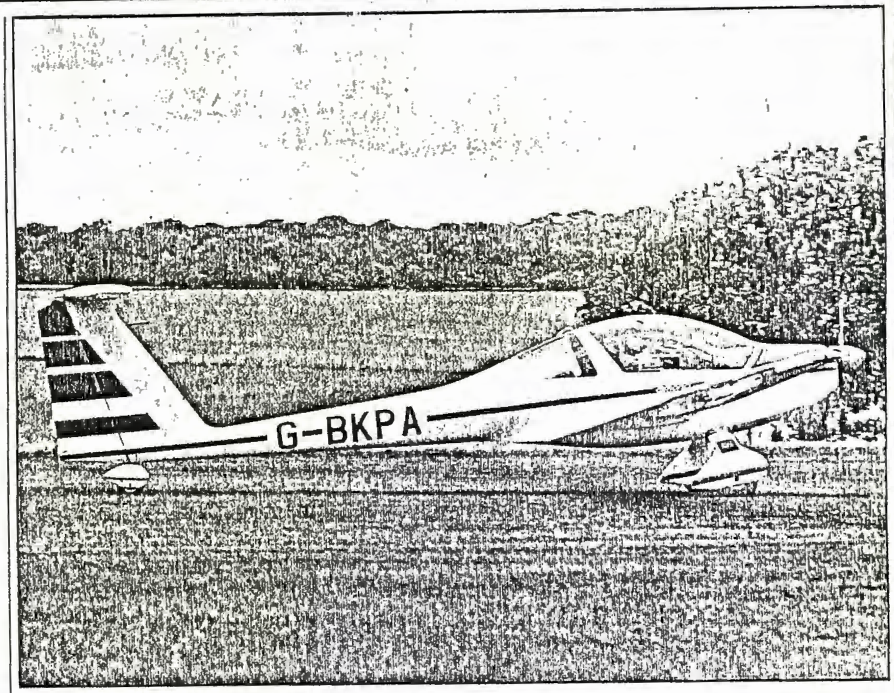
Sailplanes

Type	Wheel	Seats	Span/length (m, ft in/ft in)	Weights (lb) Empty/max	Max L/D at (kt)	Min sink ft/sec at kt	VNE (kt)	Price
Brauchle Glasflugel 304B	R	1	15, 49 2/21 2	518/992	42(52)	1·9(42)	135	DM44,500
Scheibe SF-34	2F	2	15·8, 51 10/24 7	700/1,190	35(53)	2·0(42)	139	DM52,000
Caproni Calif A21S	R	2	20, 66 10/25 4	961/1,419	43(56)	1·9(43)	136	—
Centrair 101 Trainer	—	1	15, 49 2/22 4	544/1,003	39(54)	2·0(40)	135	Fr119,000
Pegase				544/	41(54)	2·2(43)	135	Fr135,500
Marianne	—	2	18·5, 60 8/29 6	815	40(54)	1·8(40)	135	Fr235,500
Glaser-Dirks DG-101/G	R	1	15, 49 2/23 0	516/925	39(57)	1·9(40)	141	DM37,820
DG-300 Elan	R	1	/22 4	527/1,157	41(52)	1·9(42)	146	DM46,820
Grob G.103 Twin III Acro	—	2	18, 59 6/27 0	815/1,323	38(58)	2·1(39)	151	—
ICA-Brasov IS-28B2	R	2	17, 55 9/27 9	882/1,301	33(51)	2·5(46)	124	—
IS-29D2	R	1	15, 49 2/23 11	529/793	37(50)	2·1(43)	121	£12,720
IS-30	—	2	17, 55 9/27 9	882/1,301	34(51)	2·4(43)	135	£16,800
IS-32	R	2	20, 65 8/27 5	882/1,301	45(60)	2·0(49)	105	£21,840
IAR-35	R	1	12, 39 4/20 4	452/726	23(51)	2·8(43)	217	£15,360
Issoire-Siren Pik30	R	1	17, 55 49/22 5	683/1,014	45(60)	1·8(40)	140	Fr262,000
Nippi-Pilatus B4-PC11AF	R	1	15, 49 2/21 7	506/770	35(46)	2·1(39)	129	—
Rolladen-Schneider LS4	R	1	15, 49 2/22 5	529/1,040	40(54)	2·1(44)	146	DM46,250
LS6	R	1	15, 49 2/21 10	551/1,157	—	—	151	DM56,800
Schempp-Hirth Ventus A/B	R	1	15, 49 2/20 0	485/1,157	44(54)	1·9(40)	135	—
Ventus B/16·6m			16·6, 54 6/21 7	583/1,157	46(49)	1·9(4·0)	135	—
Janus B	F	2	18·2, 59 8/28 4	816/1,366	39(59)	2·3(49)	119	—
Janus C	2F1R	2	20, 65 7/28 4	805/1,543	44(54)	2·0(46)	135	—
Nimbus 3/24·5	R	1	24·5, 80 5/25 0	873/1,653	56(51)	1·4(40)	146	—
Nimbus 3D	R	2		1,045/1,653	56(55)	1·5(43)	146	—
Discus	R	1	15, 49 2/21 5	503/1,157	43(51)	2·0(44)	135	—
Schleicher ASW19B	R	1	15, 49 2/22 5	523/1,000	39(51)	2·0(39)	138	—
ASW20B	R	1		573/1,158	43(54)	1·9(54)	151	—
ASW20C				550/1,000	43(54)	1·9(45)	143	—
ASW20BL			16·6, 54 5/22 5	584/948	46(54)	1·8(44)	143	—
ASW20CL				562/838	46(49)		135	—
ASK21	2F	2	17, 55 9/27 4	805/1,323	34(49)	2·3(39)	151	—
ASW22B	2R	1	25, 82 0/26 7	990/1,655	60(55)	1·5(50)	146	—
ASK23	2F1R	1	15, 49 3/23 4	507/838	34(49)	2·0(38)	119	—
Schweizer 2-33	—	2	15·5, 51 0/25 9	600/1,040	23(52)	3·1(42)	85	—
Sprite	—	1	14·1, 46 2/20 7	475/710	31(53)	2·3(42)	105	—
SZD Puchacz	—	2	16·6, 54 8/27 6	837/1,258	30(46)	2·3(41)	119	£16,500
Jantar 2B	R	1	20·5, 67 3/23 7	978/1,430	50(66)	1·5(60)	135	£18,000
Standard Jantar 3	R	1	15, 49 2/22 0	496/1,415	40(66)	2·0(33)	154	£13,000
Junior	—	1	15, 49 2/21 10	486/785	35(44)	2·0(39)	119	£12,000

Motor gliders

These motor gliders range from 20 h.p. to more than 100 h.p. Most designs boast L/D ratios in the 30-50 range and minimum sink rates of 2·0-4·0ft/sec at speeds of 40-55kt. More than half of the manufacturers listed here also appear in the following section on sailplanes (page 50). Our anticipation in 1986 that this year might see even more glider companies entering the powered aircraft stakes has not been fulfilled; indeed, one established motor glider—Grob's G.109B—is deleted at the manufacturer's request since it is no longer in production. Waiting in the wings for inclusion next year in the up-to-200 h.p. single-engined category is Grob's new G.115 two-seater (see flight-test in this issue) for which West German certification is still awaited. Grob expects the machine to enter production later this year.

Changes this year include deletion of the Glaser-Dirks DG.400/17. This 17m-span model is available as a DG.400/15 with extended wingtips yielding improved lift/drag ratio and reduced sink rate. The 22m-span DG.500 has been redesignated the DG.500M.



Hoffman H36 Dimona motor glider

Motor gliders

Type	Power	Seats	Span/length (ft in)	Weights (lb) Gross/baggage	Fuel (Imp gal) Std/opt	Cruise 75% (kt)	Range (n.m.)	Price
Caproni Jet Calif A21SJ	286lb thrust Microturbo TRS	30	66 10/25 4	1,165/1,763	65	2·2(52)	136	—
Centrair Marianne M	60 h.p. Volkswagen JPX	3·3	60 8/29 6	1,102/1,598	31(54)	3·3(52)	108	—
Fournier RF10	80 h.p. Limbach L-2000LO1	19·8	57 4/25 11	1,234/1,700	30(54)	2·6(49)	119	—
Glaser-Dirks DG-400/15	43 h.p. Rotax 505	4·5/13	49 2/23 0	619/1,058	42(59)	2·0(43)	146	DM88,425
DG-500M	60 h.p. Rotax 535	6·3/13·2	72 2/28 5	1,014/1,819	—	—	146	—
Hoffman H36 Dimona	80 h.p. Limbach L-2000EB1C	17·6	52 6/22 6	1,191/1,698	27(57)	3·0(43)	148	DM93,500
ICA-Brasov IS-28M2A	80 h.p. Limbach L-2000EOI	13·2	55 9/23 0	1,236/1,676	25(57)	3·8(43)	113	£29,760
IAR-28MA		13·2	32 9/22 11	1,147/1,676	15(60)	6·2(50)	135	£29,760
IAR-34		13·2	55 9/25 7	1,232/1,676	—	—	127	£30,000
Scheibe SF-25C Falke 2000	80 h.p. Limbach L-2000EA	12	50 5/24 11	880/1,430	23(41)	3·3(38)	103	DM85,000
SF-25C Falke 87	65 h.p. Limbach SL-1700EA							DM87,500
SF-36	80 h.p. Limbach L-2000	11·7	53 5/23 7	970/1,450	28(52)	3·0(41)	112	DM98,000
Schempp-Hirth Janus CM	60 h.p. Rotax 535	9·4	65 7/28 4	1,058/1,543	44(59)	2·1(49)	135	—
Nimbus 3T	26 h.p. Solo 2350	3·9	80 5/25 0	972/1,653	56(51)	1·5(40)	146	—
Ventus BT	20 h.p. Solo 2350		54 6/21 7	562/948	46(49)	1·9(41)	135	—
Schleicher ASW 21BE			82 0/26 7	1,150/1,655	58(65)	1·6(52)	146	—
Schweizer SGM 2-37	112 h.p. Lycoming O-235-L2C	11·8	59 6/27 5	1,260/1,760	22(52)	2·8(43)	115	—
Siren Pik 20E	43 h.p. Rotax 505	6·6	49 2/25 6	682/1,040	41(60)	2·3(43)	135	Fr246,750
Pik 30E/17m			55 9/23 0	702/1,040	45(54)	2·0(42)	135	Fr262,000
Valentin Taifun 17E	90 h.p. Limbach L-2400EB	19·8	55 9/25 6	1,323/1,808	30(57)	3·1(46)	132	DM107,500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Voyager circles the World

EDWARDS AFB

Not since Charles Lindbergh flew solo from New York to Paris has light aviation captured such world enthusiasm. Despite near disaster on take-off, ferocious weather, and fuel pump failure, Dick Rutan and Jeana Yeager have succeeded in their bid to be the first pilots to circle the world non-stop, unrefuelled. Despite the physical ordeal, the crew were reported to be in good shape on arrival, though suffering from temporary deafness owing to prolonged noise. Each had lost some 10lb in weight, having consumed only 10 per cent of their food supplies.

The Voyager landed at Edwards AFB, California, at 0805hr local time on December 23, nine days, 3min, 44sec after departing Edwards on December 13. The distance covered totalled 21,720 n.m. (25,012 miles), some 2,000 miles shorter than the route originally proposed. Owing to the sophisticated use of pressure pattern navigation, which optimised the use of favourable winds, Voyager averaged 100·56kt (115·8 m.p.h.), arriving a day earlier than expected.

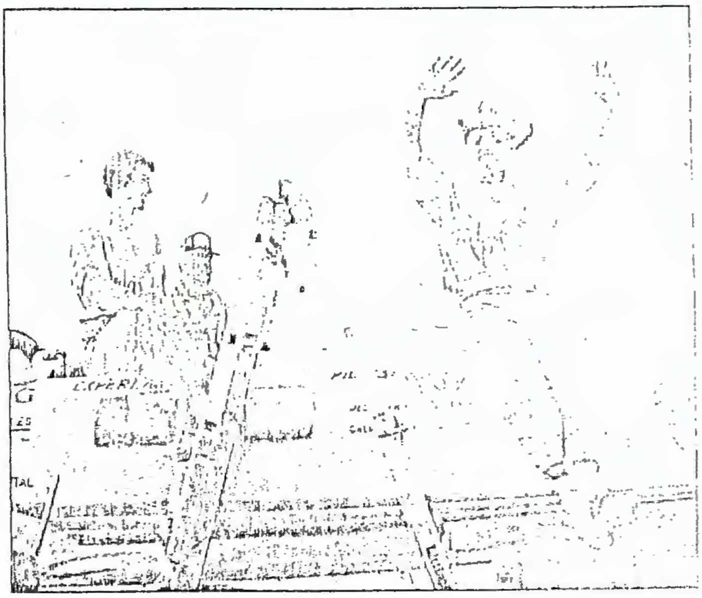
Grossing at 9,750lb (including 1,000 US gal of fuel), Voyager came close to disaster on take off when the wingtips were damaged by ground contact during the 14,000ft ground roll. The right winglet broke free, and the left one was left dangling for the remainder of the flight.

The Pacific route passed close to Hawaii, Wake Island, and Guam, staying well north of Australia to take advantage of favourable winds. Skirting South-East Asia, Voyager took a westerly course over Sri Lanka and flew across Central Africa, passing close to Nairobi.

After leaving the West African coast, Voyager turned north-west, heading for the Caribbean, where a more southerly course than planned was necessary because of storms in the Gulf of Mexico.

Over the Atlantic the crew forgot their six-hourly oil level checks on the liquid-cooled rear engine on which they were relying (the. front engine having been shut down early in the flight, as planned, to conserve fuel). A warning light indicated falling oil pressure and rising temperature. Pumping in additional oil and reducing power restored pressures and temperatures to normal.

Turbulence was a constant threat to Voyager, owing to the aircraft's light and ultra-flexible structure. The aircraft was twice thrown into a vertical bank as it passed South America.



Jeana Yeager and Dick Rutan acknowledge the vast crowd at Edwards AFB

Uncertainty over fuel quantity, caused by fuel flow measurement problems, caused further anxiety to the Voyager team.

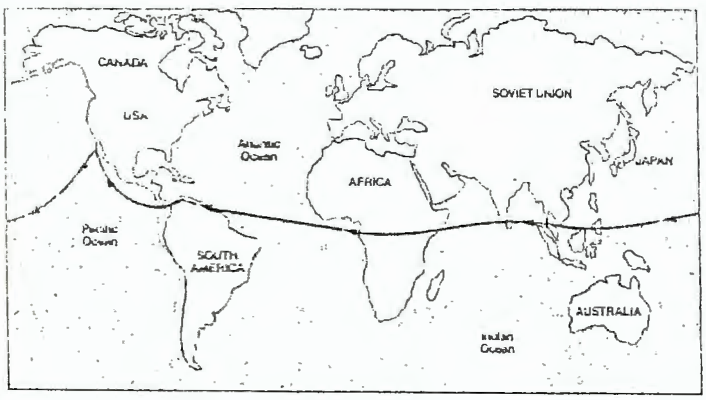
Because of adverse conditions in the Gulf of Mexico, Voyager crossed central America between Yucatan and Costa Rica before heading north off the Pacific coast of Mexico and southern California.

With just 450 miles to go, disaster was again narrowly avoided when a fuel pump malfunctioned and the rear engine cut out at 9,500ft. To save weight Voyager is not fitted with engine starters, and it took a 3,500ft dive to achieve a windmill start of the reluctant front engine.

Weather conditions at Edwards were perfect, allowing Rutan to make a leisurely flypast before his immaculate touchdown in front of a crowd of thousands.

Voyager was designed by Burt Rutan specifically for this flight, and will now be housed in the US National Air and Space Museum in Washington D.C..

Perhaps Yeager, who overcame so much physical discomfort and so often took a back seat, expressed it best to *Flight* some months ago: "We just want to do something that will go down in aviation history."



A girdle round about the Earth

It is gratifying to be able to start the year with good news. Even so, with the adulation pouring on to pilots Dick Rutan and Jeana Yeager it is worth assessing in balanced terms the significance of the Voyager flight.

First, the things it won't do. Voyager, for all its originality, will not transform the general-aviation scene. It is unlikely that tomorrow, or even the day after, we shall see low-cost H-shaped airframes with lightweight piston engines carrying high-powered yuppies to business appointments in cities 20,000 miles from their bases.

Nor is this version of the Rutan (Burt) dream likely to appeal to the wealthy young owner-pilot as a means of whisking his (or her) favourite companion off to an island or mountain hideaway.

The truth is, of course, that Voyager was designed not to meet an aviation market, but to realise an aviation dream. It attracted its sceptics, who thought the exercise singularly pointless, and were not a bit surprised when setbacks delayed the project. A departing blade nearly grounded it for good, and even in the last days before take-off unfavourable weather promised to postpone it well into 1987. Such a delay would have put intolerable pressures on the crew, who had already nearly impoverished themselves, and might well have disenchanted the many sponsors and industry contributors who were helping to keep the dream alive.

Even after the flight had started, the dream came close to turning into a brief nightmare, and any one of several incidents could have yielded disaster and an end in oblivion for the pilots and for the project. The wingtips scraped on take-off and were damaged to an extent that cast some doubt on the aircraft's capacity to fly, and must have affected its aerodynamics and handling. A forgotten oil change almost destroyed an engine. And the rear engine did fail over the Pacific Ocean, necessitating a 3,500ft descent to start the front engine by windmilling the propeller.

A measure of crew heart rates during those emergencies might have produced illuminating medical information. No such data are available, the events were overcome, and the aircraft landed as though an unrefuelled non-stop aerial circumnavigation were an everyday occurrence. It isn't. And it won't become such, because flying round the world has no particular justification other than itself.

That is not to say that there are no benefits; there are, and they can be found not so much in the feat which Rutan, Rutan, and Yeager achieved, but in the means by which it was achieved. Voyager's technology, for a start, if not revolutionary in detail, was remarkably advanced in its combined application.

Carbon-epoxy composites with honeycomb interiors are well understood, and have already gained application in aviation from RPVs to business aircraft. The engines are derivatives of existing drone engine, with improvements in synthetic lubrication, and they clearly offer range improvements which could find application in the motorglider field. To put these elements together in a craft which could carry its own weight, two crewmembers, and enough fuel for nine days of flight, including some periods of material-cracking turbulence, was a technology achievement of a high order.

Behind the aircraft there existed also a matrix of less concrete achievements, many of them in the avionics and communications field. Voyager, carrying miniature King Radio avionics, was in touch constantly with the web of ground and satellite communications equipment which enabled it to take spectacular advantage of the weather. Aided by some fancy meteorological interpretation work by Leonard Snellman and his team, Rutan was able to slip into the outer edges of Typhoon Marge and gain speed.

If a satellite and ground network can achieve that degree of navigational control, and can maintain it for more than nine days, then acceptance of intensive long-range, long-endurance, low-cost, crewless stealthy military reconnaissance cannot be far away. The line from Raytheon to Beech to Rutan to Rutan is a pretty straight one.

But the greatest achievements are the human ones; of a pilot who had a vision and pursued it doggedly until he made it come true; of a copilot who not only supported her companion in his vision, but also shared the work and went along and helped fly the aircraft; of two people who put themselves into considerable danger, and inconceivably severe discomfort, inside a flying cigar box within a flying petrol bomb; of a designer who had refused throughout his career to accept conventional solutions; of dozens of people who gave money and backing to what, throughout, was a marginal endeavour; above all to the spirit of enterprise, eccentricity, and faith which the American, or at least the Californian, ethos allows.

The more one contemplates the Voyager achievement, the more it warrants praise and congratulation.

Rutan and Yeager may not, like Puck, have put a girdle round about the Earth in forty minutes. But they missed out only on the timing.

Encircling the Earth

Fighting sleep, fear, sickness, and weather, Rutan and Yeager made it around the world. After exclusive interviews, **Robin Blech** reports on their historic achievement.

Dick Rutan and Jeana Yeager have been acclaimed for their achievement in making the first non-stop unrefuelled flight around the world—25,012miles in 216hr in their Voyager aircraft made of highly flexible Hexcel Magnamite and glassfibre.

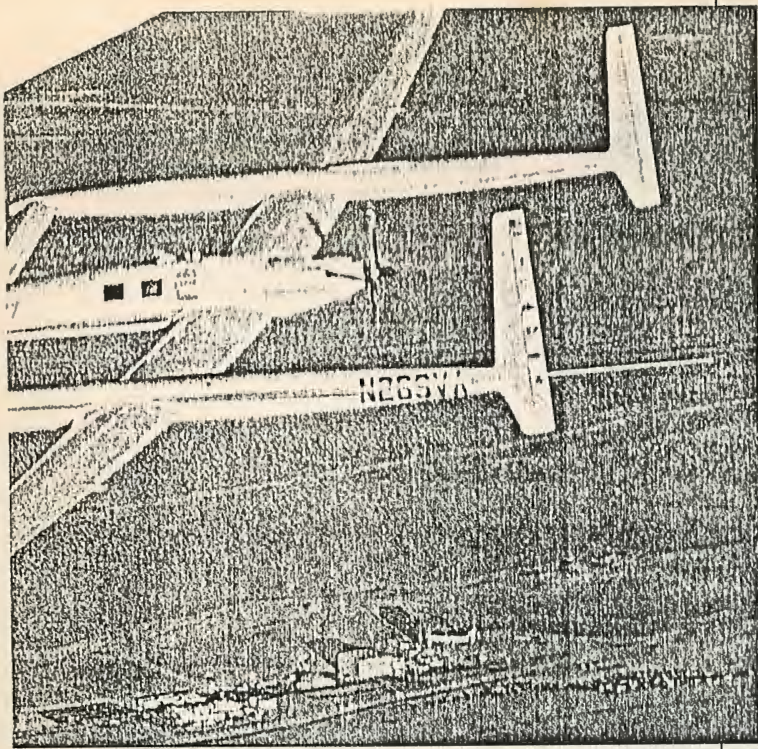
The numbers are already part of aviation history, but only subsequently have the full details of their human ordeal and achievement been revealed. So much happened during the nine-day flight that they are confused about the exact chronology of the drama that unfolded around them. Ask Jeana Yeager to highlight the worst moments, and her reply is simple: "There were no worst moments, it was all terrible".

Press reports that the flight was progressing smoothly, even that they were enjoying a scenic diversion over Sri Lanka, hid the truth. The mission continually looked as if it would fail through lack of fuel, owing to a baffling increase in specific fuel consumption. On top of severe tropical weather, discomfort, sickness, and Voyager's instability at high weights, there were many moments when Rutan and Yeager asked themselves "What the hell are we doing here?". At times they considered landing—Thailand, Sri Lanka, and Brazil all offered possible landing sites which would have enabled Voyager to be recovered for another attempt. But Yeager, who had always believed that the first attempt would succeed, "was very strong", says Rutan. They pressed on, hoping that fuel would last and that the aircraft would hold together.

The project had seemed doomed to failure so many times. Lack of money and suitable engines had dogged the six-year programme since Dick's brother Burt Rutan first designed the Voyager's layout on the back of a paper napkin in a Mojave restaurant. Low weight, flexibility, and strength were the key requisites which only composites could offer. Those very properties would also cause major handling problems, but the aircraft had only to be "mission adequate". The certification rulebook was irrelevant. Only the freedom of the USA could permit such a project, Rutan believes.

Voyager's airframe took 18 months and 22,000 man-hours to build, and this was achieved only with the help of Bruce Evans, who volunteered as crew chief, and test pilot Mike Melville (who reckons the true labour content for the programme to be nearer 167,000 man-hours). The finest expertise was sought. Veteran meteorologist Len Snellman came in to head the met, navigation, and flight-planning team at "mission control" in Mojave. "Without Snellman, the flight would not have been possible," says Peter Riva, who took over as public-relations manager, fund-raiser, and "all-round scrounger" when the programme ran out of financial steam.

Teledyne Continental was persuaded to donate engines, using Voyager as a flying test bed for the new liquid-cooled 110 h.p. IOL-200 engine, never tried before in the air. Only this engine, mounted in the rear, would give the fuel specifics needed to make the distance. Together with its Champion spark plugs, the engine would stand up to the test magnificently. The front engine, a standard air-cooled O-240, would be used at high weight, or when high altitude was required. It was re-started



Left *Oxygen was used to combat fatigue on the last day.* **Above** *Just 2 per cent of the fuel on board remained on landing.* **Right** *"We felt great—100 per cent"*

several times. An experimental long-lasting synthetic oil developed by Mobil, which also donated fuel, proved vital.

The complex fuel system had greater capacity than required because smaller engines were used than originally had been envisaged. Voyager held 1,200 US gal on take off—80 per cent of its total weight—but had capacity for "another ton" of fuel. "We took all we could safely carry for take off," says Rutan.

The aircraft had only been declared "mission ready" on December 12. Weeks of work, involving round-the-clock effort, had been required since the front propeller shed a blade during a test flight in October. It took two weeks to overhaul the front engine and to inspect all the avionics for vibration damage. The original electric MT propellers were dropped, and heavier hydraulic Hartzell units were supplied, thanks to a major propeller blade redesign effort by aerodynamicist John Roncz. Though 50lb heavier, the Hartzells gave a three-fold increase in range efficiency, says Rutan. "We should have chosen them all along."

By December, the weather picture in the tropics had radically changed, but by taking a more northerly equatorial route to avoid headwinds and bad weather over Australia, Snellman believed that a way through could be found. Although they were prepared to wait, the weather conditions on the California coastal belt, so critical to the grossly loaded craft, looked good for December 14.

At noon on December 13 the crew flew Voyager to Edwards AFB for departure the following day, merely filling the final 25 per cent of the required fuel load before departure. Rutan and Yeager, after months of non-stop work, managed to get one night's good sleep before leaving.

The near disastrous take-off caught world attention for the first time. In an attempt to prevent the sagging wing tips from bumping the ground during taxiing, Rutan had increased pressure in the undercarriage oleos and increased fuel in the forward-boom tanks. This increased the nose-down moment on take-off as speed increased. "The wings actually flew themselves [down] on to the runway at higher speeds due to negative angle of attack," he explains. While the ground team agonised, the crew were unaware of the problem until after lift-off. "The take-off seemed real smooth, though I could have done with a little more rearward stick pressure during the roll." Out on the Edwards AFB runway, Peter Riva saw it very differently: "I thought it was going to fireball".

Voyager needed 75kt for lift-off, and then had to accelerate to at least 100kt before being able to climb. With a maximum level speed of 115kt, initial performance was decidedly marginal.

Burt Rutan came alongside Voyager in a chase aircraft, and advised that the damaged tip sails, which were hanging loose, should be broken off by yawing the aircraft. Once he had proved that the aircraft would fly without tip sails, Dick Rutan decided "to go for it". The pressure for a world flight launch so late in the year was enormous.

The first day's running saw a forecast headwind change to a tailwind 200 n.m. from the Californian coast. "We then had tailwinds all the way until the final leg from Costa Rica," says Rutan.

Snellman was able to call on a continual stream of satellite pictures of the route,

Voyager's oxygen system

A Kevlar-wrapped aluminium bottle designed by Cryo Systems II and cleared for 1,850lb/in^2, was pressurised to 3,000lb/in^2 to give a three-day supply. Breathing was accomplished through cannula tubes fitted in the pilot's nose.

A stream of satellite data, coupled with local weather observation, allowed Len Snellman to navigate Voyager clear of most bad weather and optimise the use of pressure systems

and used complex calculation to achieve the ultimate in low-level pressure-pattern navigation. He was also able to call on local surface data at airports along the route *via* Lockheed's Jetplan service.

With every 5° of longitude travelled by Voyager, mission control passed a series of waypoint co-ordinates for the following three days' navigation, aimed at finding the best tailwinds and avoiding turbulence and tropical cloud buil-ups. This information would be updated every six hours in a routine broadcast to the crew, accompanied by weather information and suggested cruising altitude. The bulk of radio traffic was *via* HF, but UHF satellite-linked communication was also used.

Ideally, Voyager should cruise at 3,000-4,000ft, but it was frequently forced up to 10,000-12,000ft by weather. The first major weather hurdle to avoid was Typhoon Marge, which lay astride the south-west Pacific track. Snellman told Rutan to trust him, and took Voyager close to Marge's epicentre. Using satellite information, Snellman passed heading corrections every few minutes, avoiding the worst turbulence and improving ground speed. "It was like watching a brain surgeon at work," says Riva.

Leaving the weather system meant crossing the typhoon's outer feed bands. Snellman predicted severe turbulence. He was right. Bounced around, with Voyager's wing tips flexing through an estimated 40ft, with Rutan exhausted from non-stop piloting since take off, and with Yeager wedged into a corner of the rear cabin to prevent herself from being injured (there is no strap on the bed), the ride was unpleasant.

At one point Yeager had to slide under the instrument panel to swap wiring between two attitude indicators, one of which had toppled. "Her small size was really essential around the cockpit," says Rutan.

As they passed the Philippines, Rutan collapsed exhausted into the rear cabin while Yeager took control. To change seats earlier had been impossible, owing to the critical short-period longitudinal instability at high weights. "Without the autopilot engaged, the pitch oscillation doubles every $1\frac{1}{2}$ cycles, due to an interaction between aerodynamic instability and the structure's aeroelastic properties," says Rutan, who had calculated that the aircraft would break up within 15sec. "It's a unique self-destruct mode, aimed at keeping the pilot awake."

Changing seats takes a full minute, and autopilot failure during the changover could have been fatal. "If we were doing it over again, we would have reclining side-by-side seating with dual controls, boom, tanks further out for spanwise loading, and more stiffening material in the wings," he concedes. "Climbing over each other was a big problem. Without the autopilot, we would have been in a world of hurt."

Crossing the Pacific, the crew grew increasingly concerned at the apparent high specific fuel consumption recorded on Rutan's "howgozit" chart. More fuel per mile was being used than had been planned and, if it was correct, there might be insufficient for the world flight. The picture looked increasingly depressing, but exact fuel measuring relied on logging fuel transfer to the one 40 US gal feed tank in the cockpit.

Fuel in each tank was used selectively to maintain critical balance. Only the cockpit feed tank was gauged, being fitted with a plastic tube sight gauge. Alcor transducers measured transfer flow rate. Contents were calculated by zeroing the system, selecting tank required, and reading the feed tank sight gauge. Subtracting the result from the fuel log gave fuel remaining. "It was very complicated, with a lot of mathematics," says Rutan.

By the third day everyone was concerned that specific fuel·consumption was greater than expected. Each time the front engine was shut down airspeed decayed, necessitating several restarts. Rutan wrongly attributed the poor performance to the wing tip damage (calculated by Burt Rutan to have cost them 4 per cent range).

Passing South East Asia, Yeager—piloting at last—was forced by weather to skirt Vietnam's forbidden coastal defence zone. Rutan had always feared being intercepted. Twenty years before he had been shot down over Vietnam and ejected into the South China Sea. He knew that the Vietnamese were well aware of the flight. "They were going to shoot us down. War's a bitch—you want to avoid it. I was glad to get out of there alive. I thought, hell, here I am again."

Having avoided airsickness in the back, Yeager was violently ill while flying. Rutan heard her retching, but was

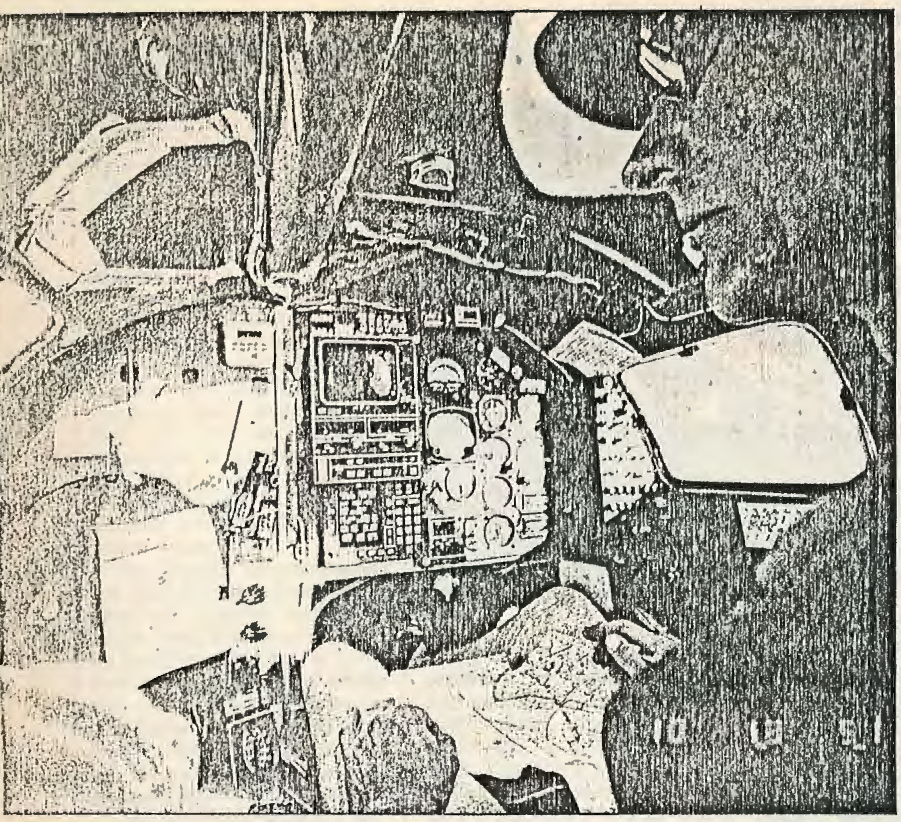
Navigation and communication

Primary navigation relied on a single King KNS660 depending on GPS/VLF/Omega signals. Its antenna was mounted in the roof of the rear cabin. Waypoints were passed by mission control at every 5° longtitude of travel for the following three days, updated every six hours.

The majority of radio traffic was via a King KHF990 HF radio. Its antenna trailed behind the left vertical stabiliser, radiating a north/south pattern. This proved less than ideal for an east/west flight. Various HF stations were used with ground-line relay to Mojave. "By the time we were halfway around the world, we had practically every HF station available to us. It was incredible."

Also carried was a lightweight LST-5 UHF satellite-link transceiver. Fitted with a portable antenna, its use was impossible when Rutan was in the rear cabin, owing to lack of available space with the antenna deployed.

Two UHF frequencies were allocated by the US Department of Defence, using Meteosat (Europe), GMS (Japan), and Goes (US) satellite systems. There were difficulties with both HF and UHF communications. "Twenty per cent of the time we were out of contact," says Rutan. Voyager also carried a standard KX-165 VHF for line-of-sight communication, together with VOR/ILS and Transponder. Bose noise cancelling headsets were praised by the crew.



Constant concern with transferring fuel and logging its consumption left no time to relax. "It was very complicated, with a lot of mathematics"

temporarily too exhausted to care. Yeager was much handicapped by being too short to see out of the bubble canopy. Avoiding cloud tops was a matter of pushing herself up with her hands to see out.

Passing Sri Lanka, the fuel situation appeared hopeless. "We had this terrible conversation, and wondered whether to land at an airport below us, but Jeana was all for continuing."

Voyager was now forced up to 20,000ft to avoid massive thunderstorms over Africa. A more northerly route in clear weather was prevented by refusal of overflight clearance by Ethiopia, Sudan, and Chad. Overflying Kenya, the crew rendezvoused with a Beech Baron which allowed measurement of speed, and both twin- and single-engined rate-of-climb performance. From that it was clear that Voyager must be much heavier than calculated, indicating a more optimistic fuel picture than painted by the log; by how much nobody knew. "Over Africa we discovered the problem, I actually saw fuel flowing backwards. It's impossible for fuel to flow uphill from the feed tank, but it was happening. I haven't yet had time to figure out how. When we made it I didn't care." Fuel had been flowing back from the feed tank into the main tanks. This "back flow" had been mistakenly logged as burn-off.

They decided to keep going and, if necessary, land on Ascension Island or in Recife (Brazil). "We discussed mission failure and what secondary achievements we could be proud of. I don't know when I have felt worse".

At 20,000ft over Africa Rutan found that Yeager had lost consciousness owing to anoxia. Having set off with a cold, she was unable to absorb enough oxygen despite using the gas [illegible] even system. Rutan had the option of risking her dying at 20,000ft or descending into fatally severe turbulence. He stayed above the weather until it cleared, but the choice was agonising.

Throughout the Atlantic portion of the flight, fuel shortage haunted them. They filled the feed tank to ensure reaching Ascension Island, then topped up with enough to go on to Recife or to back-track to Ascension. Rutan became an expert at engine mixture leaning. "The idea that leaning wrecks an engine is an old wives' tale,"—borne out by the IOL-200's subsequent clean bill of health. "You have to find the bottom of the bucket."

Because of fatigue the crew had failed to check the rear-engine oil level for 1½ days. The engine overheated while Yeager was flying, but by reducing power and pumping in a small amount of oil, normal temperatures and pressures were restored.

Following the north coast of Brazil and Venezuela, Rutan hugged the coast, encouraged by Snellman to choose a route two miles offshore, midway between the coastal updraughts and the tropical build-ups out to sea. Despite this, severe turbulence almost brought disaster once more, with Voyager flung about severely.

Off the west coast of Mexico the right-hand transfer pump failed. It doubled as a boost pump for the rear engine, which kept running on its own pump while Rutan replumbed the system by swapping over left and right transfer pumps. "Pump failure was in no way due to a faulty unit," says Rutan, who admits that pump cavitation had frequently been necessary while running various tanks dry. "A pump is not designed to run on air." With the rear engine drawing fuel from the canard, engine-pump pressure was sufficient for level flight only. Descending over the Pacific the engine cut out, spurring Rutan to restart a reluctant front engine. Once rear-engine power had been restored, both were kept running for the remainder of the flight.

"Mission Control calculated that we needed 28gal to get home. According to the sight gauge in the cockpit we had only 15gal left, so I went gleaning. In transferring fuel from the outboard tip tank to the intermediate wing tank we discovered that 15gal had leaked out through the tank cap. That hurt."

Despite this, Rutan managed to find sufficient fuel. "It was a happy moment. We had 'get home' fuel, and could relax for the first time." Voyager landed with around 7gal in the feed tank and 18.3gal throughout the system, "enough to reach Seattle at our final 2 gal/hr consumption."

Team manager Peter Riva had kept the pressure of world publicity from the Voyager's crew. "Coming up the coast of California, I was worried that we would arrive early in the morning, when Edwards AFB always has heavy test flying traffic. When they told me that they had closed down for Voyager's arrival, I thought that was real nice. I had been worrying about having left my car at Mojave and getting a ride home."

A crowd of 50,000 people was awaiting their arrival. "Being an old airshow pilot, I made a few fly-bys to show them how Voyager looked with the gear up and to make it a nine-day flight."

Despite having had an average of 2½hr sleep per day, Rutan and Yeager found that the sheer volume of work kept up their performance. Oxygen was used continually for the last couple of days to combat fatigue and depression. Anxiety over fuel and exhilaration during the final few hours kept them alert despite unremitting noise (110dB) and vibration. "Adrenalin was certainly flowing. We felt great—one hundred per cent—for the last 36 hours."

Rutan is convinced that the success of the Voyager underlines the start of a new era of composite construction. Voyager's success "will make it easier to walk up to all these old aluminium people and say 'something has got to be made of composites'."

The materials used

Hercules Magnamite graphite was used for spars and load-bearing members, (Hexcel HRH10 paper honeycomb bonded with FM73 American Cynamid adhesive). Secondary load-bearing components were of Apco E-glass and S-glass, the latter for toughness and electronics transparency for antennae. Carbon was used for the main gear struts. Because it was fitted with a wheel brake, the nose gear was made of steel.

Schweizer markets civil SA 2–37A

LEESBURG

Schweizer Aircraft has given a public airing to a special-purpose aircraft previously sold only for secret military applications, reports **Julian Moxon.**

Schweizer is now marketing the SA 2-37A for "law enforcement, border surveillance, and specialised military applications" and has begun a comprehensive tour of potential US civil and military customers. It is promoting the SA 2-37A fitted with the Hughes AN/AAQ-16 forward-looking infrared (Flir) night vision system.

For *Flight's* demonstration the SA 2-37A was flown out of Leesburg Airport, about 40 miles from Washington D.C., by Les Schweizer, one of three brothers who annually rotate the Schweizer presidency. The flight lasted about 40min, and provided an opportunity to examine this unusual aircraft/sensor combination.

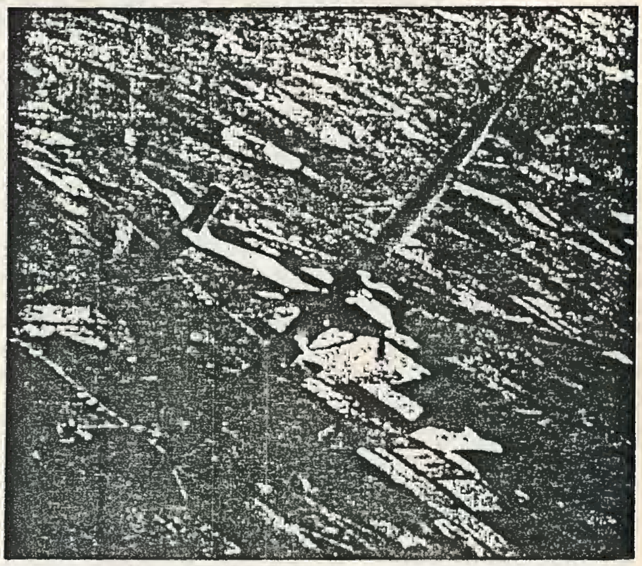
The AN/AAQ-16 is a sophisticated sensor system small enough to fit into an aircraft like the SA 2-37A. It already has several military applications (including the Bell/Boeing V-22 tilt-rotor), and is now available commercially.

The Flir sensor is mounted in a turret below the fuselage, and can be rotated through 210° in azimuth and from 85°-180° in elevation. It is operated using a hand-held control unit, which requires some skill before full use can be made of the Flir's capabilities. Simple tracking tasks can be carried out by the uninitiated almost immediately, however.

After a short warm-up, the Flir image appears on the mission operator's multifunction display (MFD) on the left-hand side of the panel. Navigation symbology from a Litton inertial navigation system is presented around the edge of the MFD.

As the SA 2-37A needs only 52 h.p. to maintain altitude, its six-cylinder 235 h.p. Lycoming IO-540 engine felt relaxed throughout. At 70kt, in "quiet mission mode", the three-bladed McCauley propeller rotates at only 1,200 r.p.m., resulting in a low noise signature. After *Flight's* demonstration the SA 2-37A was flown over Leesburg field at 1,300ft. In the presence of ordinary background noise, and with the navigation lights switched off, it was virtually impossible to locate the aircraft from the ground.

Left Schweizer Aircraft is promoting its 2-37A light surveillance aircraft fitted with the Hughes AN/AAQ-16 forward-looking infrared night vision system. **Below** *The system's sensor is mounted in a turret below the fuselage on the centreline just forward of the wing trailing edge*



The secret lies in the use of a very-high-aspect-ratio wing, coupled with advanced leading-edge technology to provide a lift-to-drag ratio double that of an ordinary light aircraft. The leading edges are extended at mid- and three-quarter span by two "cuffs", each measuring around a foot in length, which are essentially small, fixed-position leading edge slats. These interact with the ailerons to provide very good low-speed performance without an associated drag penalty. An interesting feature is a pair of dive brakes on each wing, providing a safe 14,000ft/min descent.

The long, thin wings yield more response in pitch than in roll and yaw, but without any detriment to overall controllability. Les Schweizer demonstrated the SA 2-37A's low-speed handling qualities by stalling the aircraft power-on, and maintaining control in all three axes while the aircraft was "mushing". Eventually, the right wing dropped, but was recovered immediately and without difficulty.

Our flight took place at between 1,000ft and 3,000ft, in gathering dusk. Flir images could be enhanced using a six-times magnification capability built into the hand-held control unit. Sheep and cows were easily picked out, and warm spots where cars had been parked could be distinguished. With skill, the system can be made to track moving targets automatically, images being returned to base by a microwave data link.

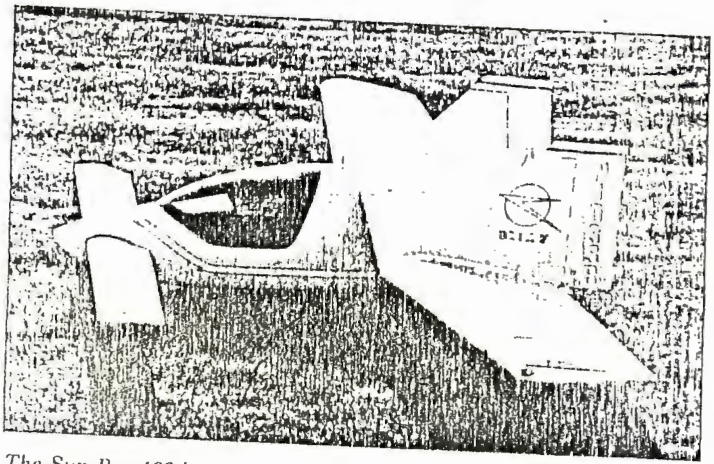
Schweizer will provide special night cockpit lighting compatible with night vision goggles for the pilot if required, along with a flat black anti-glare interior if the mission dictates.

Standard equipment on the SA 2-37A includes a 100A alternator, which was enough to run the equipment on the demonstrator aircraft. Schweizer quotes a 300A generator as one of the options, including air conditioning.

The basic SA 2-37A comes equipped with a King avionics package that includes ADF and Nav/Com with VOR/ILS. There is plenty of spare room on the console for installing additional systems, such as Loran. Besides the Litton INS, the demonstrator aircraft was fitted with a King KNS 80 RNav system and King KRA 10A radar altimeter.

Price of the basic aircraft is between $350,000-$400,000, depending on options. Addition of the Hughes Flir almost doubles the price (Hughes will not disclose the exact figure). Low light TV, or more powerful Flir, are easily accommodated in the SA 2-37A's payload bay, according to Schweizer.

FLIGHT INTERNATIONAL, 8 August 1987



The Sun Ray 100 has an unorthodox layout

Sun seeks Sun Ray licensees

INDIANAPOLIS

Sun Aerospace is seeking overseas manufacturing partners to build its Sun Ray 100 light aircraft. The Indianapolis-based company, which made its mark in Europe by exhibiting the machine outside the US pavilion at the Paris Air Show in June, says it is prepared to transfer technology or to supply airframe kits or completed aircraft, in a bid to sell abroad.

The unusual canard, which has an inverted gull wing, is pitched at surveillance duties as well as general utility use. It could even be a remotely piloted drone.

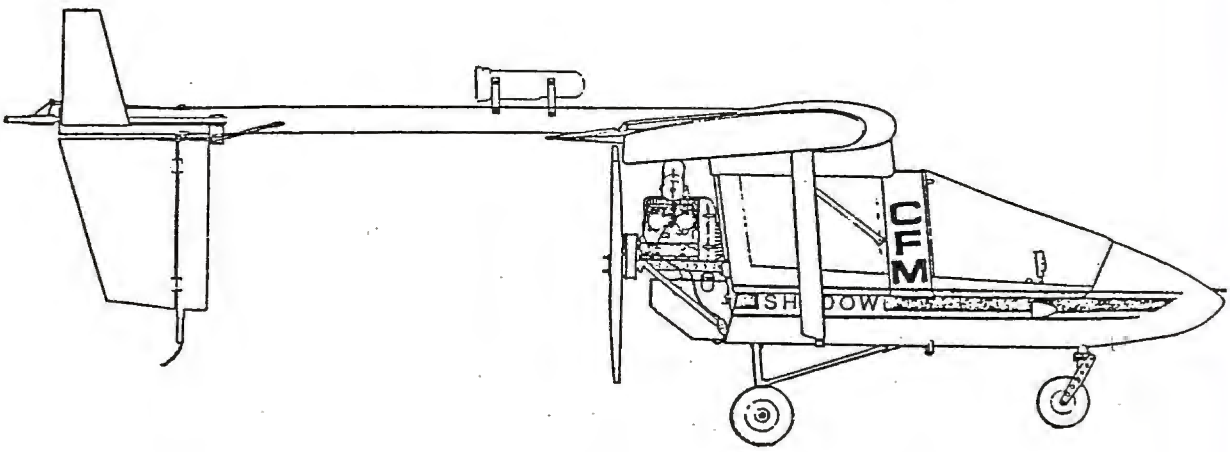
The wood/composite/fabric aircraft is powered by a Rotax 503 engine and weighs 560lb empty or 875lb gross. The range at 75 per cent power is claimed to be 510 miles without reserves. It is said to cruise at 75mph on 60 per cent power.

UK CIVIL AVIATION AUTHORITY

FULL TYPE APPROVAL

THE SHADOW

SERIES B



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From the outset we would wish to assure you of our interest in your venture and of our support. We are always available for advice; should you wish to visit our CAA Approved Factory to discuss a specific point we shall give you every attention (please telephone beforehand).

The aeroplane is not difficult nor complex to build. You will only require those hand tools that are readily available - no special items needed.

You will be well advised to join the British Microlight Aircraft Association or the Popular Flying Association and to make contact with your nearest qualified Inspector who will be pleased to advise during all phases of the construction leading up to the issue of a 'Permit-to-Fly' for your aeroplane.

Construction is primarily a task of assembly from mainly pre-cut and pre-formed materials. Finishing the aircraft is the most time consuming phase, but the one which brings a high level of satisfaction.

When you have decided to go ahead, please complete the proforma attached. You will note that the PILOT'S NOTES, SERVICE MANUAL and VIDEO (VHS or BETAMAX - PAL system) are also available.

We require a 20% Deposit in order to allocate you a production serial number and advise you of a delivery date.

Thank you for your enquiry.

Yours sincerely,

T.M. Plewman
Director

Registered in England, Registered Office 'Hillcrest', Aldeburgh Road, Aldringham, Suffolk. Co. Reg. No. 1538197
VAT Reg. No. 390 6096 38
Directors: D. G. Cook, T. M. Plewman

THE SHADOW

SERIES B

KIT

INTRODUCTION

In response to considerable demand we have designed a total package that will enable the aircraft to be built from a Kit that has four identifiable stages:

STAGE 1	FUSELAGE (including LANDING GEAR)
STAGE 2	WINGS (including CENTRE SECTION and BOOM)
STAGE 3	TAILPLANE, ELEVATOR, FIN POST and RUDDER
STAGE 4	ENGINE (including PROPELLER)

The Construction Manual comprises PROCESS SHEETS, BOLTS LIST, PARTS LIST, COMMERCIAL ITEMS LIST, STAGE BUILD DRAWINGS and STAGE BUILD INSTRUCTIONS.

All 'Critical' items have been jig produced to ensure accuracy and repeatability.

The Main Spar and complete 'D' Section will be produced in our Factory; this is to be certain that the correct assembly environment has been maintained and that specific alignments have been checked.

There is no requirements for jigs, special tools or equipment. There is no machining, forming, welding or bending to be effected.

The Kit does <u>NOT</u> contain adhesives, resins, dopes or paints. Details of these items are given and alternatives recommended. This is to facilitate packaging, transportation and to avoid the problems of the 'Shelf Life'. Flight and engine instruments are also not included.

CFM METAL-FAX LTD. will not comment on, nor provide any form of analysis on modifications undertaken by the builder. Any deviation from the plans or structural components is considered your sole responsibility and may well invalidate the Type Approval for the aircraft.

We also reserve the right to amend the SHADOW plans, specifications and Construction Manual as may be necessary.

: : : : : : : : : : : : :

THE SHADOW

SERIES B

KIT

STAGE DETAILS

STAGE 1 - FUSELAGE CONSTRUCTION

The monocoque fibrelam is pre-cut to shape, routed and drilled. Nose cone is pre-formed. Canopy screens are pre-shaped. Hanger tubes cut to length, coined and jig drilled. Wheels, tyres and tubes with complete brake assembly are included - Fuel tank components pre-cut - Hand primer bulb and filter - Seat belts - Ignition switch and all electrics - Engine mounting plates and 'Lord' mounts.

STAGE 2 - WINGS CONSTRUCTION

The Mainspar and complete 'D' section are already Factory produced. All ribs have been 'hot-wired' to shape. The rear spar, drag and compression struts are pre-shaped. The Boom is included in this stage.

STAGE 3 - TAILPLANE CONSTRUCTION

Tailplane leading edge tubes pre-bent to shape. All the other materials are provided for tailplane, elevator, rudder and fin post.

STAGE 4 - POWERPLANT

The engine is supplied complete with all ancillary equipment i.e. alternator, recoil hand start system, sparking plugs, carburettor, exhaust unit, reduction drive unit and propeller.

NOTES

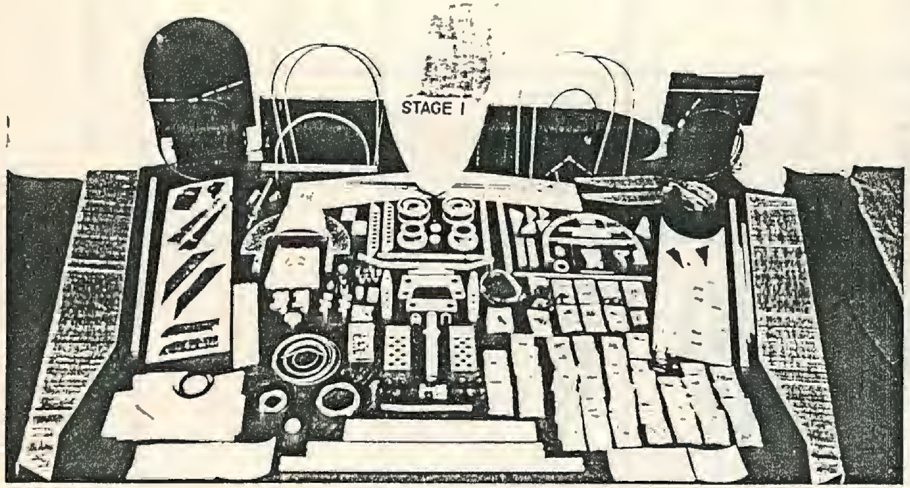
1. All Factory manufactured parts are cut out, formed, shaped and pre-drilled as necessary - they only require edges to be dressed and smoothed.
2. All Welding completed, both ferrous and non-ferrous.
3. All tube bending complete.
4. All foam parts (except wing tips) have been pre-formed.
5. A comprehensive 'Hardware' Kit is provided - aircraft bolts etc.
6. All 'Commercial items' are listed and included.
7. Glass cloth - both bi-directional and uni-directional is supplied.
8. Adequate polyester fabric for covering.
9. A comprehensive 'CONSTRUCTION MANUAL' accompanies each stage, and there is a Photographic Supplement to complement these.

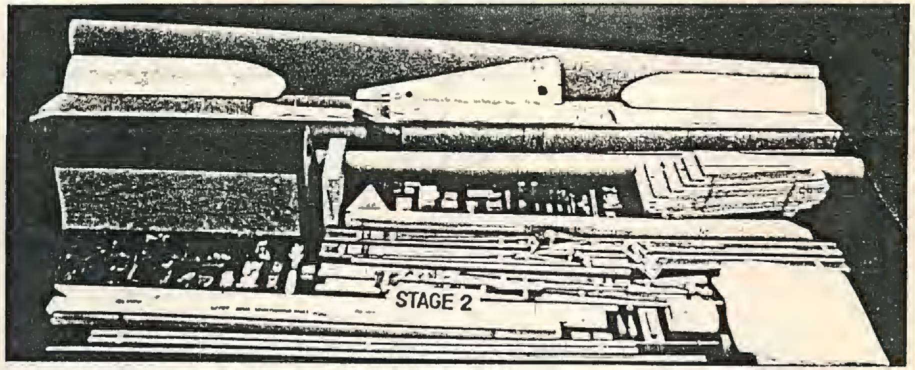
CFM METAL-FAX LTD.,
UNIT 2D,
EASTLANDS INDUSTRIAL ESTATE,
LEISTON, SUFFOLK IP16 4LL
TEL. NO. 0728-832353

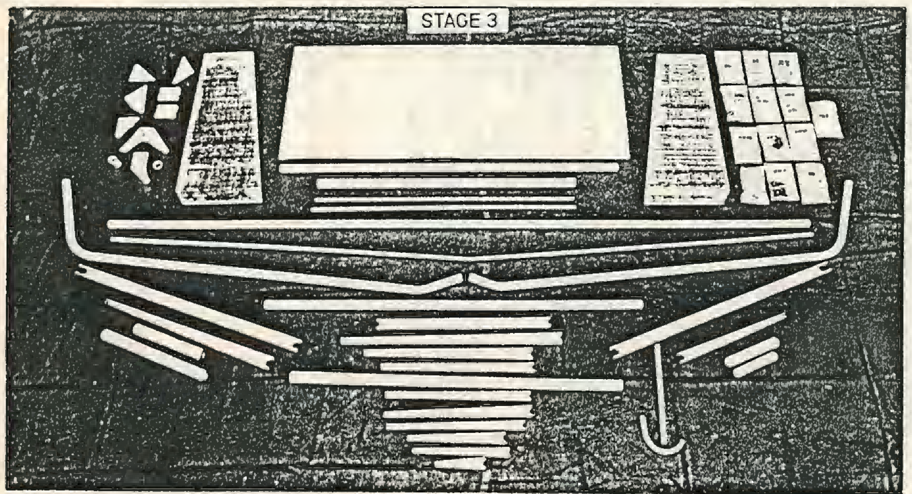
THE SHADOW - SERIES B

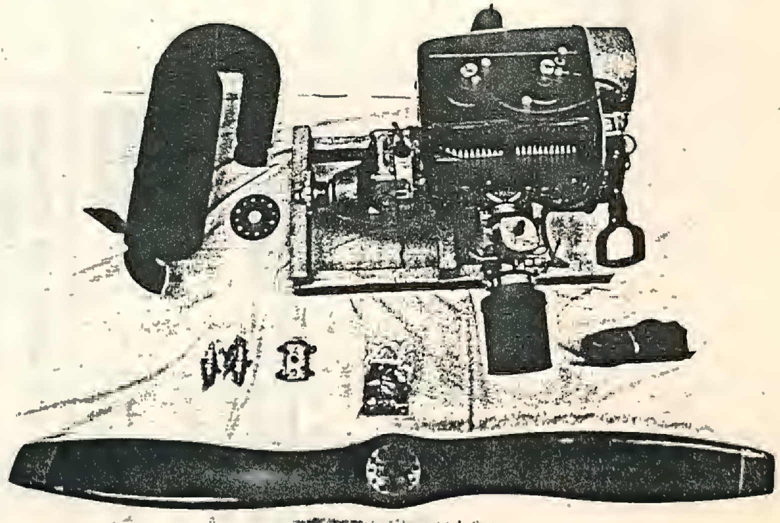
3 AXIS MICROLIGHT

38-108 MPH (VNE)
FLAPS & DIFFERENTIAL DISC BRAKES
FULLY ENCLOSED BOTH COCKPITS
ROTAX 447 ENGINE
EMPTY WT 331 LBS. MAX AUW 767 lbs
PILOT PLUS PASSENGER









STAGE 4

send for colour video - £10

THE SHADOW

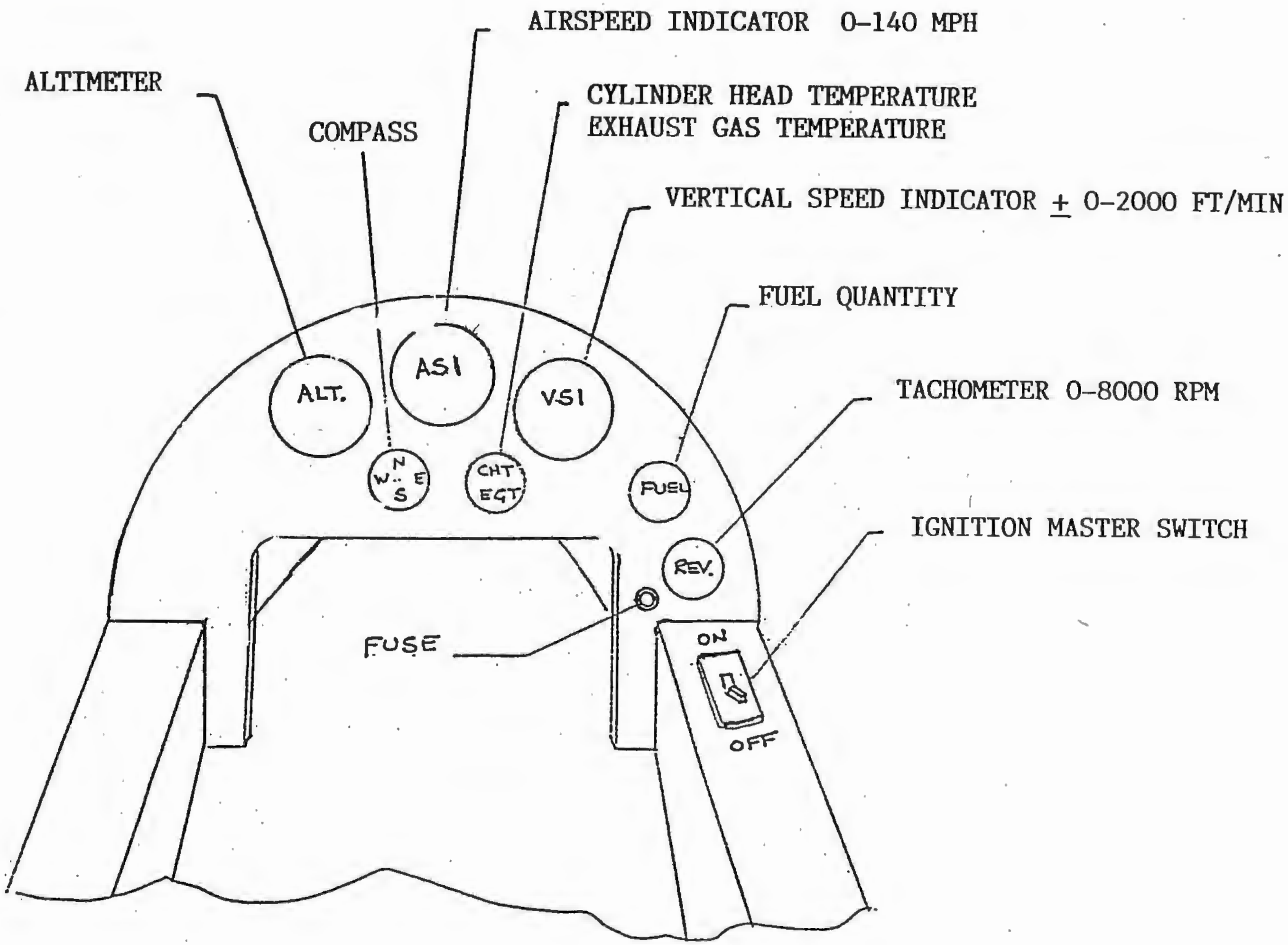
SERIES B

ITEMS NOT CONTAINED IN KIT

SERIAL	ITEM	QTY	PURPOSE	RECOMMENDED SUPPLIER
1	EPOXY RESIN	6 kgs	FIBREGLASSING	SAFE-T-POXY) ex MATL. SUPPLY (APCO 2410 RESIN+) SPECIALISTS, 2183 HARDENER) BOOKER AIRFIELD NR. MARLOW, BUCKS SCHERING: EUREDUR and) ex CFM METAL-FAX EUREPOX) LIMITED
2	EPOXY RESIN	3 x 500 g PACKS	BONDING	ARALDITE NO. 2005A & B CIBA GEIGY FROM STRAND GLASS - or generally available
3	ADHESIVE	1 LTR	FABRIC ATTACHMENT	BOSTIK NO. 1 CLEAR - generally available
4	DOPE/LOW TAUTENING	1½ GALL	ALL FABRIC SURFACES - CLEAR ALUMINIUM SURFACER	NEOGENE PAINTS. PRINTA INK and PAINTS LTD. NEOGENE WORKS, 65 ALFRED ROAD, LONDON W2 5H4 TEL. 01-289-2271
5	PAINT	5 LTRS MINIMUM- as reqd.	FINISHING - ALL SURFACES	INTERNATIONAL PAINTS, FLEXIBLE POLYURETHANE 66 FINISHES 'MEDLAB' DERBY LIGHT AERO SPARES, LITTLE EAST BADWORTHY FARM, SHEBBEAR, BEAWORTHY, DEVON EX21 5RQ TEL. 040-928305 & 928610
6	FLIGHT and ENGINE INSTRUMENTS			SEE NEXT PAGE FOR RECOMMENDED PANEL/LAYOUT

NB: Cost of the above materials - £150

<u>NB</u>: Cost of these intruments would be in the region of £450 (incl. VAT) - the ALTIMETER/ASI and VSI being ex RAF reconditioned items.



<u>INSTRUMENT PANEL LAYOUT</u>

<u>NOTE:</u> <u>NEVER FLY WITHOUT AN A.S.I.</u>

THE SHADOW - MK I

SERIES B

KIT PRICE LIST

Single Control (*)	....		£7,020
Dual Control	....		£7,500
* If 'Footwell' required (for rear cockpit)	....		£ 150
Custom Built Trailer/Hangar	....	c	£3,300

EXTRAS - can be purchased individually

Pilot's Note	....	£ 5
Service Manual	....	£ 15
Video - VHS or BETAMAX (PAL system only)	....	£ 10

NOTES

1. All prices are EXCLUSIVE of VAT @ 15%, packaging, freight and insurance.
2. A 20% deposit is required with your order.
3. Cheques to be made payable to 'CFM METAL-FAX LTD.'

JUNE, 1986

N.B.

1. At present the Stage Inspections (1-4) can only be undertaken by CFM METAL-FAX LTD., but both BMAA and PFA Inspectors should be able to assist in the future when they are conversant with the aircraft's construction. Customers may either bring their 'stages' to the Factory or we can visit - (for charges see below).

2. Before the aircraft reaches the final inspection stage, application should be made on FORM CA 1 for Registration letters.

3. The Final Inspection stage must be carried out by CFM METAL-FAX LTD. It is our experience that some work will be required during the course of this check. On completion a FORM CFM 8 will be completed by us and subsequent application made to the CAA (via the BMAA) for a Permit-to-Fly for Test Purposes (PTFFTP).

4. When the PTFFTP is extant, the aircraft can then be check flown by one of the named pilots in our Company Exposition. On completion of the Flight Test Report (FORM CFM 9) application will be made by us on FORM CA 959 for a full term Permit-to-Fly for your aircraft.

SUMMARY OF COSTS

Application for Registration details	....	£ 16
Application for PTFFTP	....	£ 45
For all STAGE inspections a fee of plus 22p per mile	....	£ 25
The Final Inspection (FORM CFM 8) - 22p per mile and an inspection fee of should additional work be necessary this will be charged at £12 per hour	....	£ 25
For FLIGHT TEST prior to the application for the PERMIT-TO-FLY with travel expenses at 22p per mile, overnight charges may be included if unavoidable due to weather or distance.	....	£100

ALL PRICES ARE EXCLUSIVE OF VAT

THE SHADOW

SERIES B

KIT

MINIMUM MANDATORY REQUIREMENT FOR PERIODIC CHECKS/INSPECTION BY QUALIFIED INSPECTOR

STAGE	ITEM	WHEN TO BE INSPECTED	DATE	SIGNATURE OF INSPECTOR	REMARKS
1	FUSELAGE - to include undercarriage	When complete but before the fitting of side panniers or nose cone.			Does not include nosewheel assy. at this stage.
2	BOTH WINGS CENTRE WING SECTION and BOOM	When complete but before any part is covered			
3	TAILPLANE ELEVATOR, FIN POST & RUDDER	When complete but before any part is covered			
4	ENGINE, FUEL TANK AND PROPELLER	When fitted to airframe			
	COMPLETE AIRCRAFT	Fully assembled. Covered and rigged.			CFM FORM 8 to be completed

New rôle for Shadow

BIGGIN HILL & LEISTON

An attempt to fly from England to Australia in a tiny Shadow light aircraft got off the ground last week as 28-year-old Eve Jackson took off from Biggin Hill on the first leg of her 12,500-mile journey.

But though the small aircraft, officially classed as a microlight, finds a home with private pilots, the Shadow has other uses, too. One is to photograph Indian cities as part of a survey sponsored by the Dutch International Institute for Aerospace and Earth Sciences. A Shadow, which weighs 331lb empty, is being air-freighted to Hyderabad from Suffolk-based manufacturer CFM Metal-Fax to begin its mission. Some 17 have been built and 34 are on order, writes **J. M. Ramsden.**

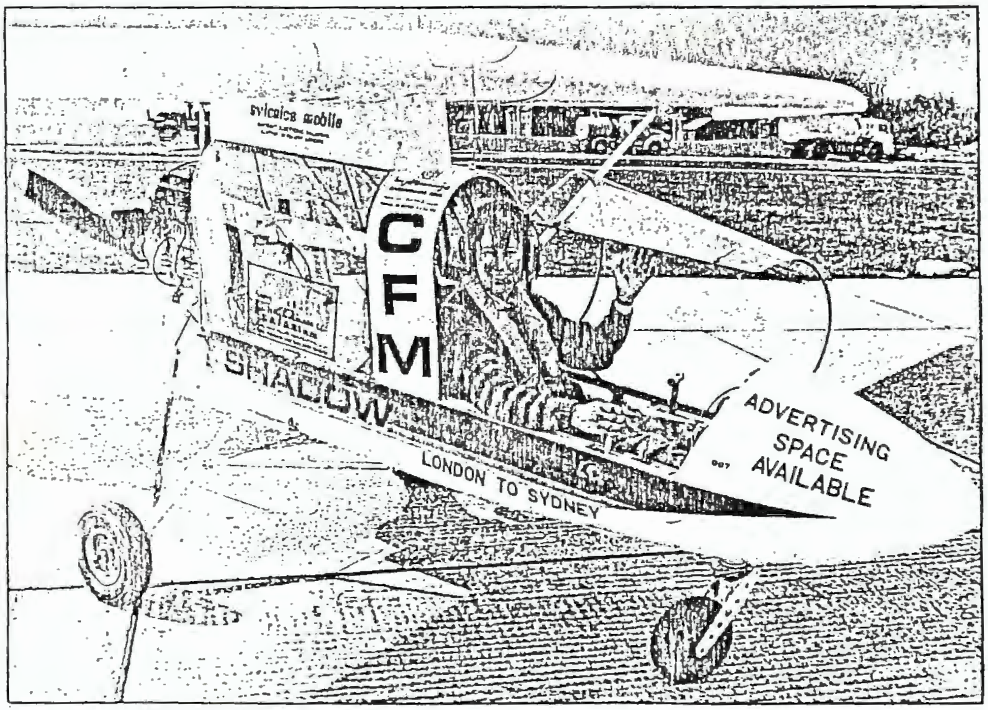
Costing less than £11,000 (plus trailer-box), the two-seat 40 h.p. Shadow has a speed range of 38-95 m.p.h., endurance (with an extra tank) of nearly 8hr, and a claimed inability to stall or spin. Aerial photography with the Shadow costs just 5 per cent of that carried out with a Piper Navajo, says CFM.

Co-directors David Cook and Mike Plewman foresee an aerial-work market for up to 50 Shadows a year. The aircraft can be delivered as a kit (at £6,900), or completed with a CAA permit to fly in the microlight category. CFM prefers to describe the Shadow as a "mini aircraft" with the certification advantages of microlight. Fuel consumption is given as 2½gal/hr, and take-off and landing distances are described as "playing-field". The structure is tested to +6*g* and −3*g*. Controls are normal three-axes stick and rudder, throttle, two-position flaps, and differential wheelbrakes. Structural materials are aluminium, wood, and Ciba-Geigy Fibrelam.

The Chinese Government is said to be showing an interest in the Shadow for aerial mapping, a major avionics company has been testing a surveillance pod on the aircraft, a crop-spraying version using the electrodyne technique to reduce fluid weight and volume is to be tested, and a float plane version has been flown.

Complete aircraft can be delivered in August or mid-September. Details from CFM (Eastlands Industrial Estate, Leiston, Suffolk IP16 4LL, England; tel 0728 832353).

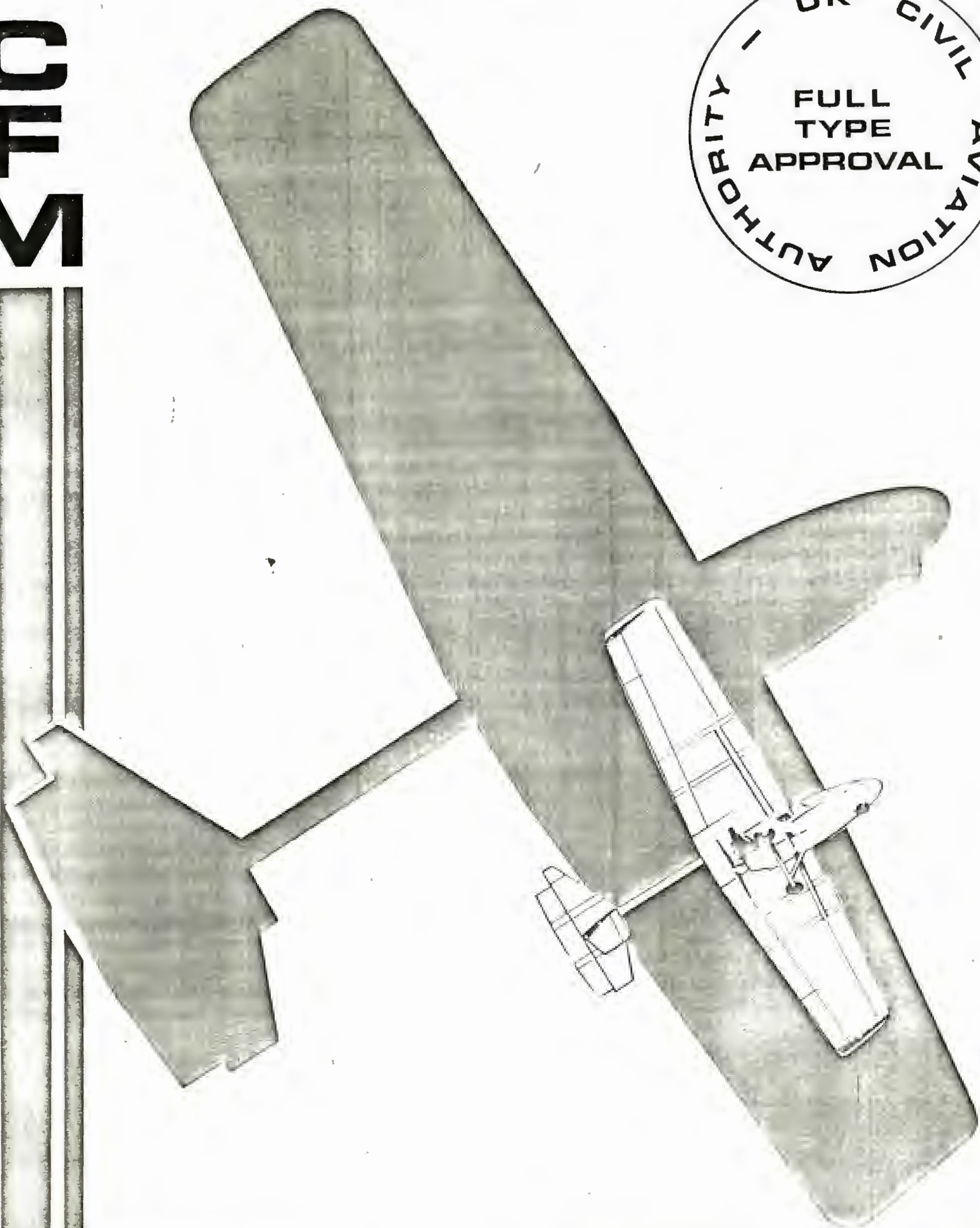
Eve Jackson prepares to leave Biggin Hill for Australia in a Shadow. An auxiliary tank gives a 500-mile range



UK CIVIL AVIATION AUTHORITY —

FULL TYPE APPROVAL

CFM

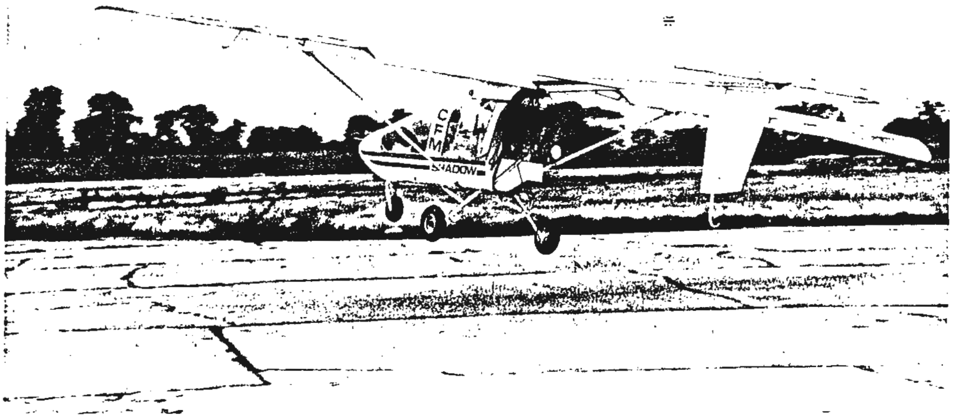


THE SHADOW

THE SHADOW

A 3-AXIS
HIGH WING MONOPLANE

"Produced for the top tiers of the mini-aircraft market and encroaching on the lower end of the general aviation spectrum."



DESIGNED by DAVID·G·COOK

David Cook is the founder member and Managing Director of Metal-Fax Ltd.

During the years 1964-1980 he was the Chief Designer of Richard Garrett Engineering Ltd.

Through his long association with flying he has become an Instructor and Examiner for the Civil Aviation Authority.

David's initial designs were of the rigid hang-glider type for use in competitions.

In 1978 the Princé of Wales presented him with the Royal Aero Club Bronze Medal for Aviation Achievement for designing and piloting the first crossing of the English Channel using a powered hang-glider.

Since 1980 he has devoted his energies and expertise to the very successful development of.....

THE SHADOW

METAL-FAX LIMITED
Unit 2D, Eastlands Industrial Estate, Leiston, Suffolk IP16 4LL
Telephone (0728) 832353 Telex 987703 CHACOM G

9 JUN 86

CAA APPROVED AI AIRCRAFT MANUFACTURER - DAI/8919/84

Dear Mr Dhawan,

We have pleasure in enclosing details of our exciting SHADOW SERIES B - MK I aircraft which has created so much interest and favourable comment. It is the first two-seat, 3 axis microlight in the world to be granted full 'Type Approval' by the UK Civil Aviation Authority in May, 1985.

The SHADOW is significantly different from most other microlight aircraft available today. It has been professionally designed to be an aircraft, in the true sense of the word, falling within the microlight category so retaining all of the concessions afforded to this type. By careful development over a two year period and by the use of advanced materials/construction techniques, the SHADOW has emerged as a definite innovation in the world of light aviation.

As the owner of a SHADOW you will enjoy the outstanding performance and precise control of a refined aircraft at an operational cost which is well within the reach of the average enthusiast. In addition, you may be in a position to consider more practical uses of your machine, in particular, aerial surveillance, photography, crop spraying and float flying. In 1985 a SHADOW came 4th overall in the World Championships at MILLAU in France (it was also classed as both the fastest and the slowest aircraft in the competition) and two more took 1st and 2nd places in the Norwich Air Race; one of these was carrying a passenger and the other was an aircraft straight off the production line!

Although primarily designed as a two-seat or load carrying aircraft the SHADOW also offers exhilarating solo flying. Here then, at last, is a low cost and durable aircraft with not only superb sports flying, but the potential to fulfil a variety of practical roles, bringing an entirely new dimension to the realm of inexpensive private flying. We can also provide a superb custom built trailer which doubles as both hangar and transporter.

This remarkable aeroplane is now available with Dual Controls - providing the opportunity, at last, to train for your PPL Group 'D' on a 3 axis aircraft.

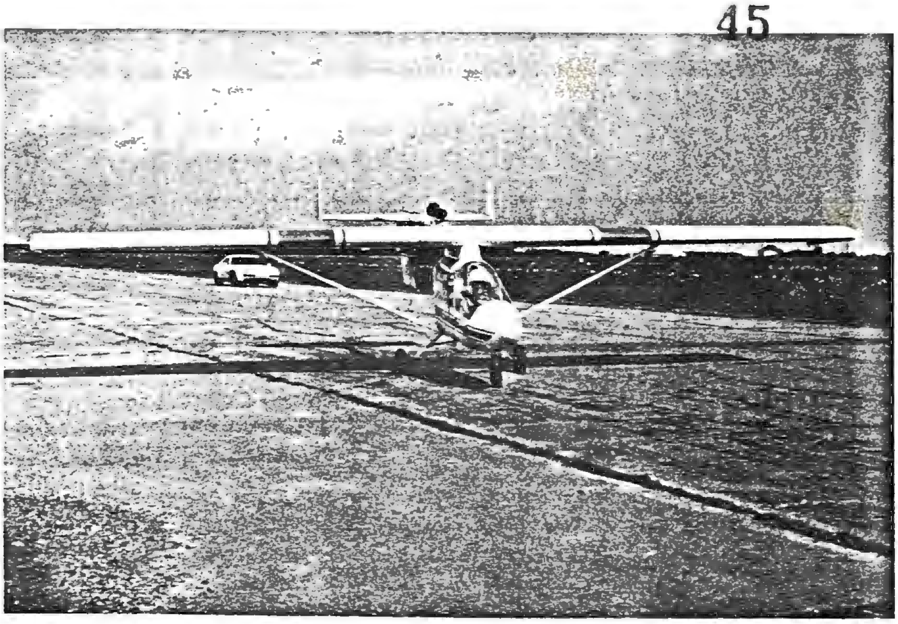
To complement the Factory built SHADOW, the aeroplane is also available in kit form - details of this are contained in the Kit Information Pack. This version also includes the Dual Controls as an optional extra.

We look forward to welcoming you to the ever increasing number of international enthusiasts. There are SHADOWS currently flying in the UK, NORWAY, FRANCE, PORTUGAL, YEMEN, AUSTRALIA, INDIA and in the near future KENYA - with numerous kit versions under construction as far afield as NEW ZEALAND.

Yours sincerely,

T.M. Plewman
Director

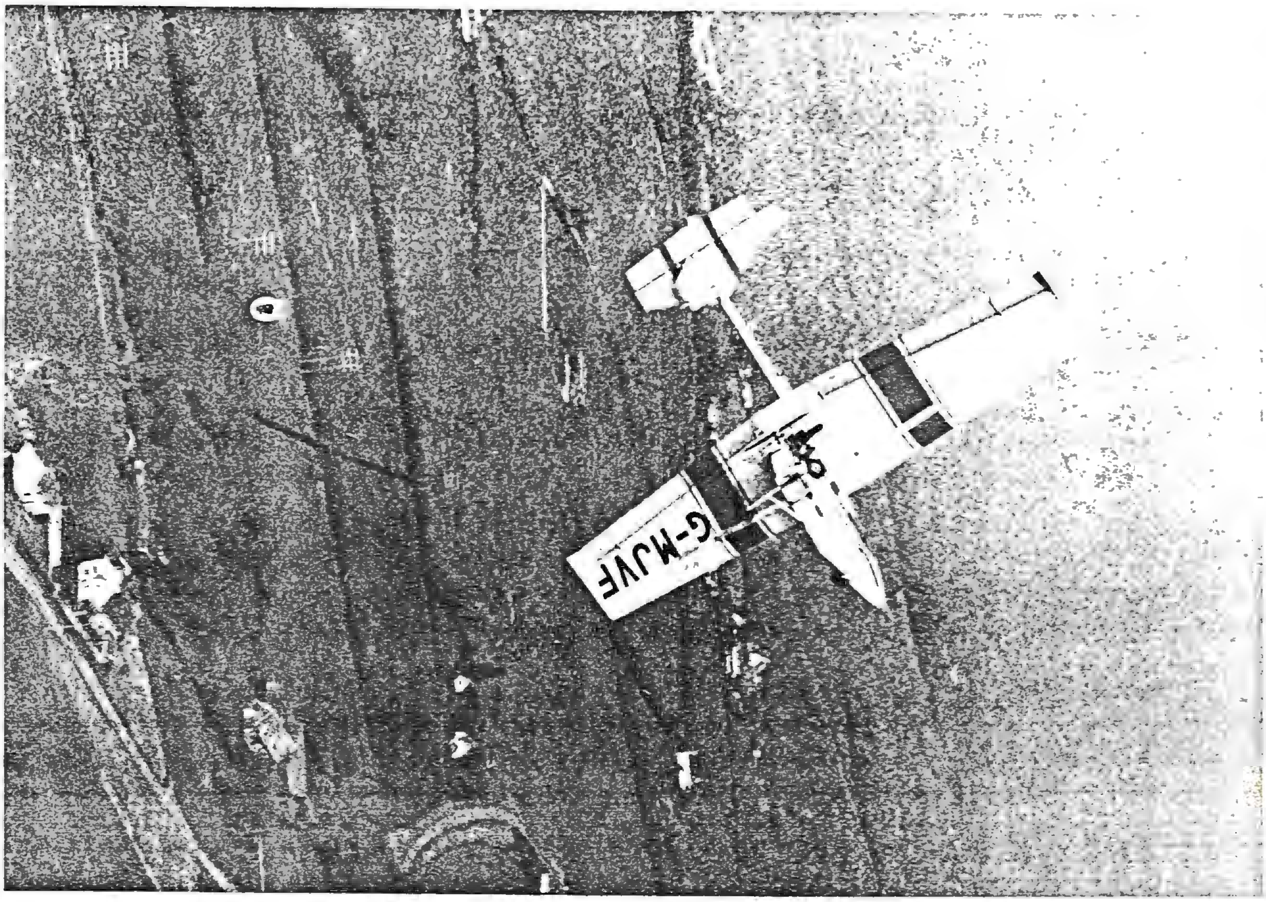
SHADOW MICROLIGHT AIRCRAFT

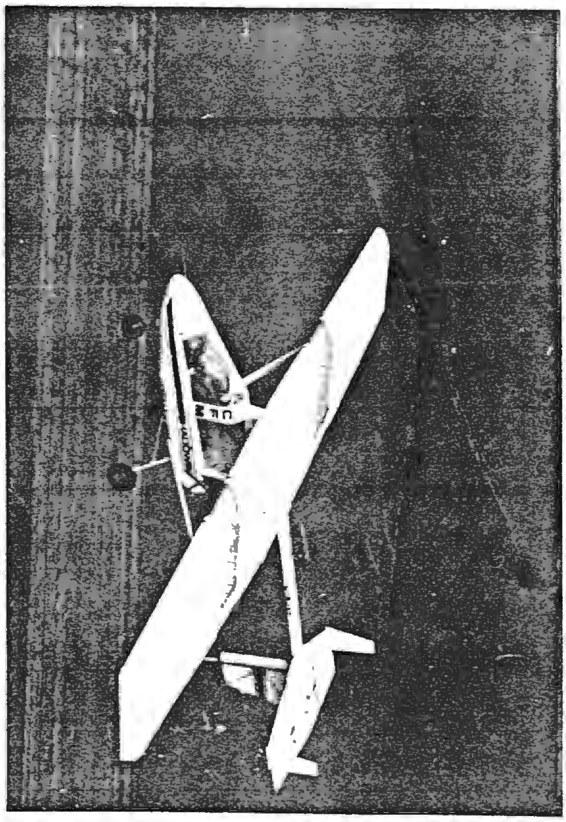


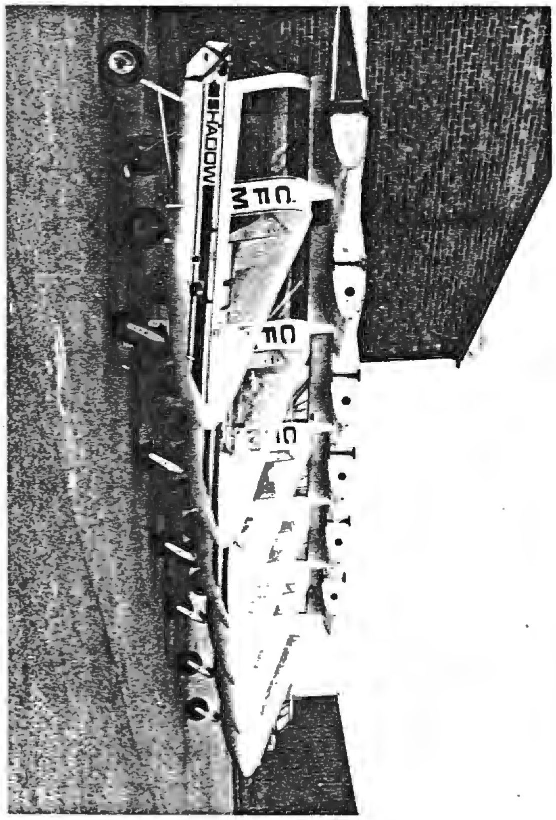
WORLD AIRSPEED RECORD HOLDER
CLASS: C-1-a/o

COOK FLYING MACHINES

Metal-Fax Ltd
Unit 2D
Eastlands Industrial Estate
Leiston, Suffolk IP16 4LL
Tel: 0728 832353







COOK FLYING MACHINES

THE SHADOW

INTRODUCTION

THE CONCEPT

The Shadow has been designed and developed over a two year period to provide the owner with a true "state-of-the-art" light aircraft, having an "air-work" capability yet remaining within the microlight category. In order to produce a two seat aircraft which is both highly durable and of exceptionally light weight, hang glider type construction has been rejected in favour of advanced specification bonded structures. By the use of these materials and careful development of an aerodynamically clean profile all parameters of the original Shadow design philosophy have been achieved. The aircraft is now adding an exciting new dimension to the world of light aviation.

THE DESIGNER

Unlike several designers who have endeavoured to produce commercially viable microlight aircraft over the past few years, David Cook is no newcomer to ultralight aviation. Apart from several years flying in the RAF, David has been associated with light aircraft since the age of 15 and is recognised as one of the pioneers of hang gliding and microlight aviation in Britain. In the early days of hang gliding when most enthusiasts were flying Rogallo-derived flex wings, David instead chose to pursue rigid wing designs and developed a close association with American pioneer Volmer Jensen, whose aircraft he built and flew in this country. It was on one of these, a VJ23, that David became the first powered hang glider pilot to cross the English channel, this being achieved with a 9 h.p. motor and a height gain of only 300 ft over the entire distance! For this success David was awarded the Bronze Medal of Achievement by the Royal Aero Club. It was only when several countries published provisional airworthiness requirements and the future direction of microlight aviation became more clearly defined that David decided to commit himself full time to the development of an advanced and highly sophisticated design. The Shadow therefore is the culmination of years of experience in designing and flying ultralight aircraft and already it has won a major "Best Microlight" award and has established a world airspeed record in its class (79 mph/126.36 kph over a 3 kms course) - truly adequate confirmation of David Cook's design skills.

THE STRUCTURE

In order to achieve the high strength requirements at low weight demanded by microlight airworthiness regulations a variety of materials is used in the Shadow structure. Each component has been tested in compliance with British Airworthiness Requirements and shown to meet fully the criteria set. Although apparently having a strutted wing it is in fact a Cantilever design, the strut having been added principally for "psychological security" and to reduce wing root stress in ground handling. The wing spar employs a unique "I" - beam structure, with a plywood shear web and preformed alloy capping pieces. Foam/fibreglass ribs are attached to the mainspar, the D-tube being of plywood and the rear wing covering being polyester fabric suitably doped. Inboard three position flaps are operated by Teleflex cable and ailerons by push-pull tubes achieving immediate and low friction response. The body is built from Fibrelam board to produce a robust component of exceptional strength, rigidity and light weight. The main suspension is a steel tube and fibreglass rods to which hydraulic differential brakes have been added. Exhaustive inflight and static testing has shown all components to be entirely practical and suitable for their application.

FLYING THE SHADOW

Whilst some microlights can take as long as 40 minutes to assemble, the Shadow can be transported on an open or closed trailer, and can be rigged ready for flight in under 10 minutes. The Rotax motor can be started by a recoil pull cord from the pilot's seat; an alternative electric start system may be available soon.

Since the canopy is hinged along one edge, entry to the pilot's seat is open and unobstructed. Once installed there is an immediate impression of security and of a compact well conceived pilot's aircraft. Due principally to the fuselage D-tube sides and shaped central bulkhead the pilot's seat feels unusually safe and secure for a microlight aircraft. All controls fall readily to hand (or foot) and are light and responsive. A full array of instruments can be accommodated in the front bulkhead and there is even room for a 720 channel VHF radio and other electronic equipment. The field of vision is exceptional and thanks to the "pusher configuration" is similar to that found on a sailplane rather than a light aircraft.

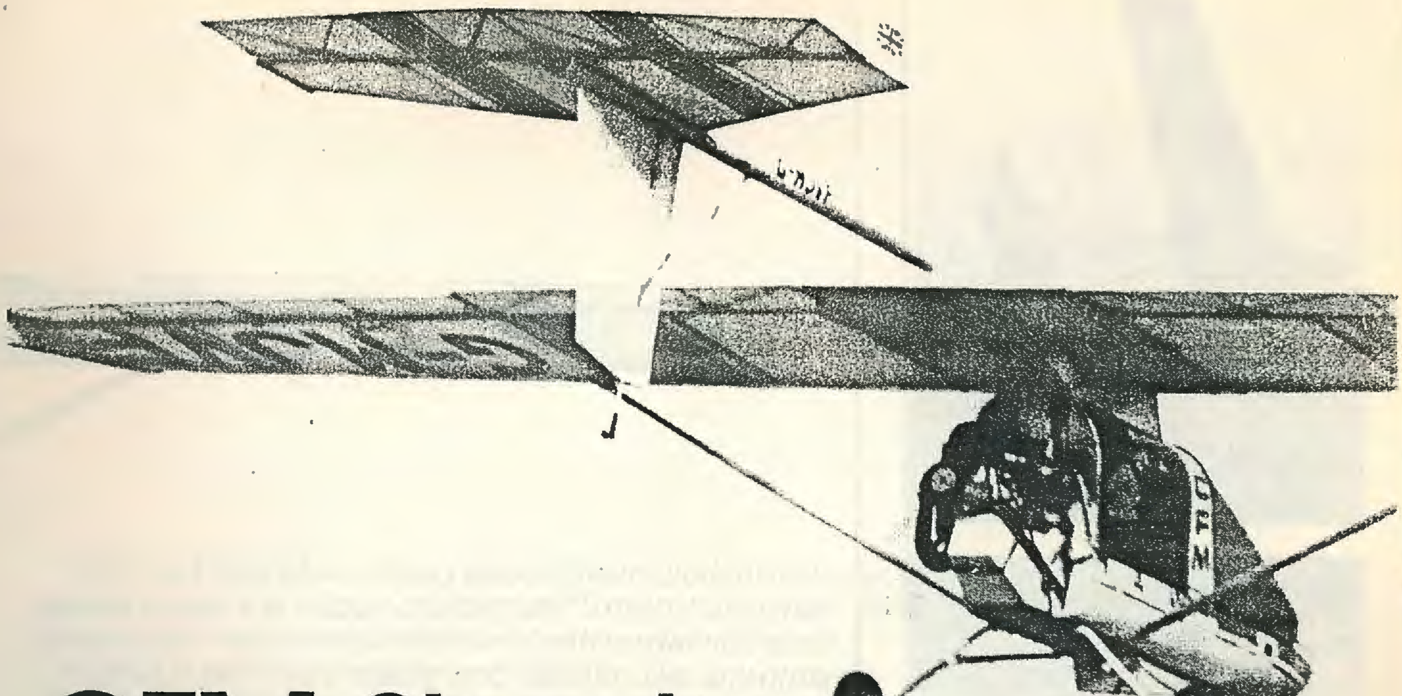
Entry to the rear compartment is somewhat more restricted and demands a feet-first approach. Once installed, however, it is possible to sit quite comfortably with knees half bent. Just how long one could travel in the rear seat is a matter for individual assessment but the rear compartment is by no means uncomfortable! For in-flight training a control stick can be fitted which is adequate for this purpose since the Shadow is distinctly "stick-dominant". Once again visibility is surprisingly good from side to side. Although the forward view is restricted by the pilot's head and part ofthe main bulkhead, vision of the horizon is only partially impaired. Ideally the Shadow should not be considered specifically as a training aircraft, rather it is a 1 + 1 with a second seat flight familiarisation capability. A 16 gallon fuel tank can also be installed in the rear compartment and since this is directly on the centre of gravity of the aircraft no trim changes are required when flown laden or unladen.

The aircraft is fitted with hydraulic differential brakes and a castoring nosewheel, therefore a little practice is required to acquaint oneself with the ground control techniques. Turning on the ground is further aided by the fact that the tail-fin is located below the main boom and directly in the propeller blast. Take-off is perfectly straightforward with an application of full throttle and on tarmac the aircraft becomes airborne in 7-8 seconds after a positive rearwards application of stick. Immediately on flying, the control stick is repositioned to climb-out at 60 mph and depending on the type of propeller fitted and load carried, climb rate is usually between 800 and 1,100 fpm. Once height is achieved, on levelling out, the throttle is reduced to just over 50% and the cruise held at 60-70 mph.

The Shadow has been designed and developed for ease of flying; being quick and responsive to control inputs. The roll rate is 25° per second and in the turn the aircraft "grooves" nicely without any need for corrective yaw input. When needed yaw response is sharp and reassuring and overall only small control movements are necessary to correct attitude changes caused by turbulence. On approach the usual disciplines applicable to aircraft with flap are to be observed, with a progressive reduction in speed and height accompanying an increase in flap deployment. On touch-down the nose-wheel can be held off at speeds as low as 20 mph.

There is little doubt that experienced pilots, particularly those who have flown the faster Service aircraft, will delight in the handling response and performance of the Shadow. Those of limited experience will find the aircraft more "sporty and responsive" than any conventional light aircraft which they have flown, but the handling characteristics are entirely predictable and vice free and pilots quickly adapt to the aircraft with ever increasing confidence.

For the final phase of the test programme an independent test pilot was engaged to analyse the Shadow's flight characteristics and fly the aircraft through radical manoeuvres and "absurd attitudes". This included standing the aircraft on its tail on full power, cutting the throttle in this attitude, repeated attempts to spin from fully vertical power on and off, and loops and past vertical wing overs cutting the power at the critical moment. As a result of these tests the aircraft was shown to have virtually no stall at any power setting or attitude and could not be forced to spin. In addition it could fly exceptionally slowly retaining full aileron control, with two up and engine off, a glide ratio of 13:1 was achieved. In other words, for every 1000' of height one can glide approximately two and a half miles! Some of this flying is contained in the demonstration video (see leaflet enclosed).



CFM Shadow

Nothing makes a new type of aircraft quite so much fun to fly as a really snappy take-off and climb. Sitting in the Shadow and giving it full throttle reminded me of my first jet ride: the acceleration is exhilarating, with the aircraft up to 50 mph within seconds and ready to leap off into a climb that makes most light aircraft feel under-powered.

The Shadow works is CAA-approved and is an airy modern building with jigs and machining facilities which enable them to produce almost every part without outside contracting. At present they are producing and selling one machine and two kits per month. The Shadow has full CAA type certification.

Customers have the choice of buying the kit in stages, so spreading the cost over a period, or of buying the aircraft, test flown and complete with a full Permit to Fly. Already there have been sales of eight kits and seven complete aircraft, and a number of these have gone abroad to Australia, Norway, France, Yemen and Portugal. No real effort has yet been made to sell the machine, which has allowed time and experience to be accumulated to ensure that any possible snags both in the aircraft and the kit have been ironed out over the past three years.

The Shadow is a very light pusher aircraft with a high boom and tricycle landing gear. All the controls are quite conventional. The control stick is mounted on the right side of the cockpit with the throttle and choke on the left-hand side: these fall easily to hand. The rudder pedals have heel-operated levers linked to the mainwheel independent braking system. The nose-wheel is fully castoring to facilitate steering on the ground.

With the last machine off the production line delivered just before my visit, there was only the prototype left for me to fly. This had been used for all the certification tests and development flying and had made over six hundred flights totalling 300 hours. Production machines have a slightly enlarged cockpit to cater for almost any size of pilot, though I found the prototype cockpit very comfortable and at least as roomy as that of many gliders I have flown. Four-point harnesses are standard on the production machines. The canopy is two-dimensionally bent plastic made of polycarbonate and guaranteed unbreakable by the plastics experts; it opens sideways to allow easy access for the pilot.

The rear cockpit is entered by lifting either side panel. Provision is made for full dual controls by the fitting of a stick, throttle and flap lever with rudder pedals mounted in a small bulge in the fuselage floor: this gives more room for the passenger or instructor. The view from the front seat is very similar to that in a modern glider: totally unobscured round to the wing.

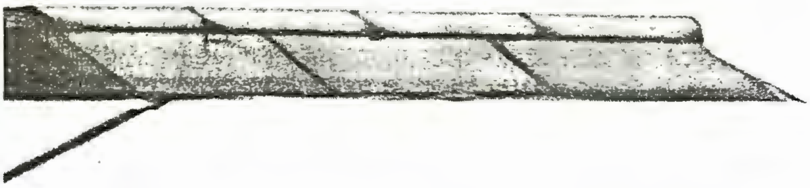
The engine controls consist of a very sturdy throttle lever that would do justice to an F-15, a choke control for very cold weather starting, and the magneto switch. The starting is by the usual mowing-machine type of recoil starter, pulling the rope just above the pilot's head. I was told that it is possible to restart in flight. Normally starting is done from outside the cockpit, standing by the nose where the throttle and switches are within easy reach and where the aircraft cannot move forward without first knocking down the pilot or person starting it. A hand primer is fitted in the fuel line, but neither this nor the choke seemed necessary. In spite of the wintery weather it started hot or cold on all four occasions with a single pull of the toggle — an impressive performance for any engine.

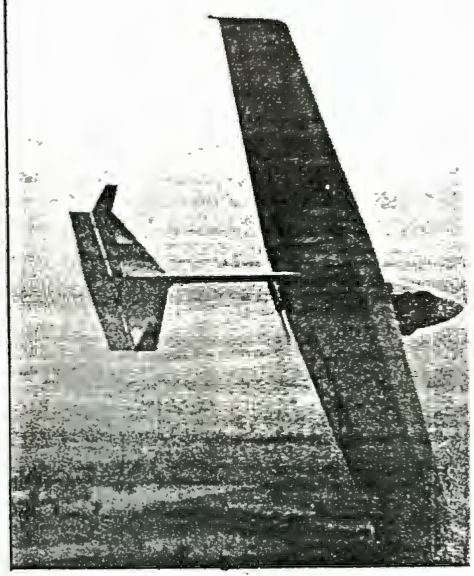
The engine is a Rotax 447 two-cylinder two-stroke producing about 40 hp at 7,000 rpm. The propeller is driven through a 2.58:1 gearing so that it turns over at less than 2,000 rpm in normal flight. An elaborate-looking silencer is standard, and makes the aircraft far quieter than the average light aircraft in flight. Perhaps because of the gearing the engine seems to run more smoothly than most little two-strokes, and it does not seem to worry whether it is running at any speed or idling for fairly long periods. Of course some kind of ear-defenders or radio headset are essential, as the weight limitations do not allow much sound insulation for the cockpits. I wore a normal agricultural pair of ear-muffs, and found the noise level in flight quite acceptable.

The instrument panel has room for more than the essential instruments, and besides the usual ASI, altimeter and vertical speed indicator has a rev counter and a combined cylinder-head temperature and exhaust-gas temperature gauge.

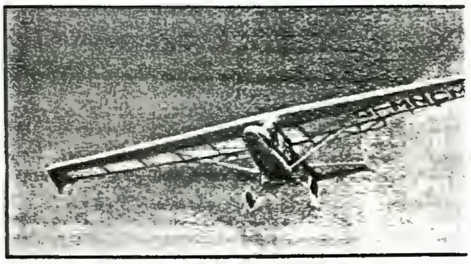
The side stick was a new item for me, but is only of concern for the take-off and the first few seconds of the flight. The only extra problem is in telling when the ailerons are central; this could be made easier with some kind of indent in the middle position when the stick is held right back at the start of the take-off run. Since that position is never used in flight it would be no embarrassment. The rudder is absolutely conventional, although a little lighter than on most aircraft. Taxying in the strong crosswind I had to use wheel brake to stop the weathercocking, which probably would not have been necessary on grass when more power would have been required to keep moving. The aicraft sits firmly on its wheels, and even a rapid swing failed to make it lean even slightly sideways.

I found the wheelbrakes easy to use for taxying, but not so easy after landing in the crosswind, when I anticipated the swing into wind and then suddenly needed the other brake to prevent running off the other way. Flying a new type I normally take extra time to get thoroughly used to the wheelbrakes and steering before trying to fly, as my experience has been that far more





The most impressive thing about this microlight is its speed range: it is happy cruising at 70 mph, has a max speed of 95 mph, and a minimum (with no defined stall) of 38. It is positively stable and handles like any other light aircraft. The view ahead is up to glider standards. Best of all, the Shadow is real fun to fly.
Flight test by Derek Piggott.

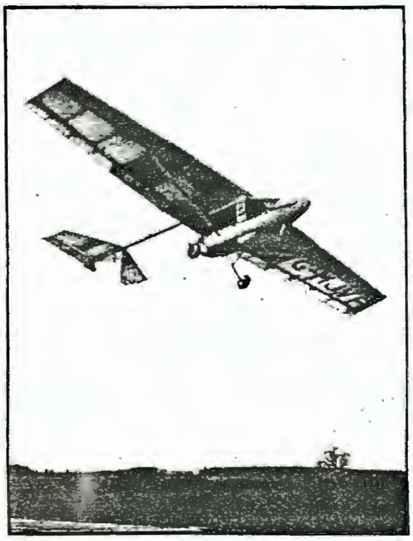


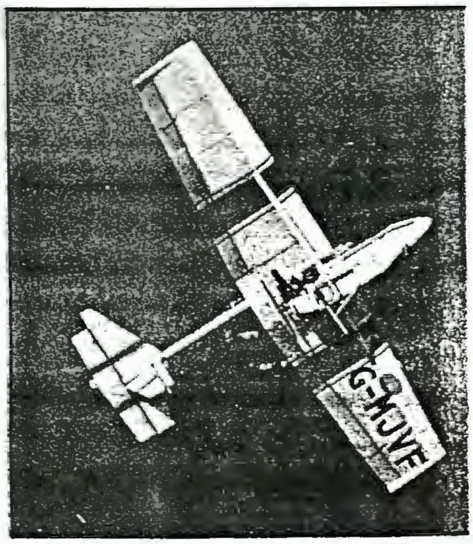
The Shadow is a very light pod-and-boom pusher, with full CAA certification — and conventional three-axis controls via a sidestick controller and rudder petals. It is offered complete, or in kit form. Three a month are being turned out.

machines get damaged by ground-loops and swings on the ground than by bad landings. However with a nose-wheel ground-loops are out of the question.

Worrying somewhat about the rather nasty crosswind (at the time 10 knots or so at right-angles) I did not make a very good job of the first take-off! In spite of the careful briefing I let the stick forward before the nose-wheel had lifted off the ground, and by the time I had eased back again and glanced at the ASI it was showing over 60 mph. The acceleration is certainly impressive! Remembering my briefing, I made a quick turn into wind at fifty feet for noise abatement, and up she went in an exhilarating climb showing almost 1,000 feet per minute. From that moment I knew I was going to enjoy my flight, and seeing a couple of American A-10s flying nearby I could not help feeling tempted to go chase, for this is the kind of feeling I always get zooming up at a steep angle of climb.

Flying solo and well below the maximum permissible weight, the rate of climb was well above the claimed 700 feet per minute. David Cook mentioned that all the quoted brochure figures ➧





are a little below the actual figures and should be achievable by every machine and not just the prototype. A quite definite backward pressure is needed when climbing; I missed a trim control and the pleasure of having the aircraft in trimmed flight all the time. However with that rate of climb I was soon up at 2,000 feet and high enough to try stalking and attempt to make it spin — which I knew had been found impossible by other pilots.

Because of the very short side-stick and high gearing the aileron control seemed a little heavy for the kind of handling tests I was doing, but very reasonable for any normal flying and for flying across-country. The rate of roll from 45 degrees to 45 degrees at about 60 mph was under five seconds, using full aileron and a moderate amount of rudder to prevent any adverse yaw. Using a large amount of aileron with the rudder locked centrally the adverse yaw is much like that in many gliders, and more than in most light aircraft. However quite reasonable turns can be made without co-ordinating properly, and the average Cessna driver would not find any difficulty — although to get the best results some rudder is needed for the entries and recoveries from turns.

But perhaps the most impressive thing about this aircraft is the speed range. It was very happy cruising at 70 mph at 5,000 rpm with the propeller turning over at less than 200 rpm. It was just about trimmed-out hands-off at that speed, and positively stable, needing very little attention and handling like any other light aircraft. The maximum level speed is stated as 95 mph; this very aircraft still holds the world speed record in the C-1-a/o class.

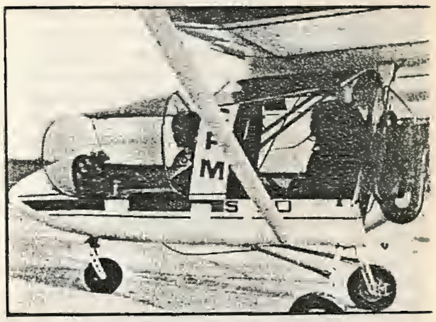
At my cockpit weight of 170 pounds there is no defined stall. This does not seem to be because of lack of elevator authority, as there is ample elevator power for fully held-off landings and for tight turns at any speed. Even when raising the nose fairly rapidly there is no buffet, and the most that can be induced is a very slow gradual drop of the nose by a few degrees and a higher rate of descent. Under power the slow-speed characteristics are even more impressive. The nose can be pulled right up to a sixty-degree angle, and with full power all that happens is again a very gradual lowering of the nose until a slow climb-away occurs. With full rudder and any position of the ailerons there was still no tendency to drop a wing, and so no possibility of making it spin, a truly unusual performance with-positive aileron and rudder control throughout. Flying in this extreme nose-high attitude facing into the wind brought the ground speed down to only a few miles per hour, and with the superb downward view I couldn't help thinking that for use over the countryside the police might do better to have a dozen of these rather than one Optica. Not only could they do the same job, but they could operate from any reasonably smooth farmer's field and at only a fraction of the cost.

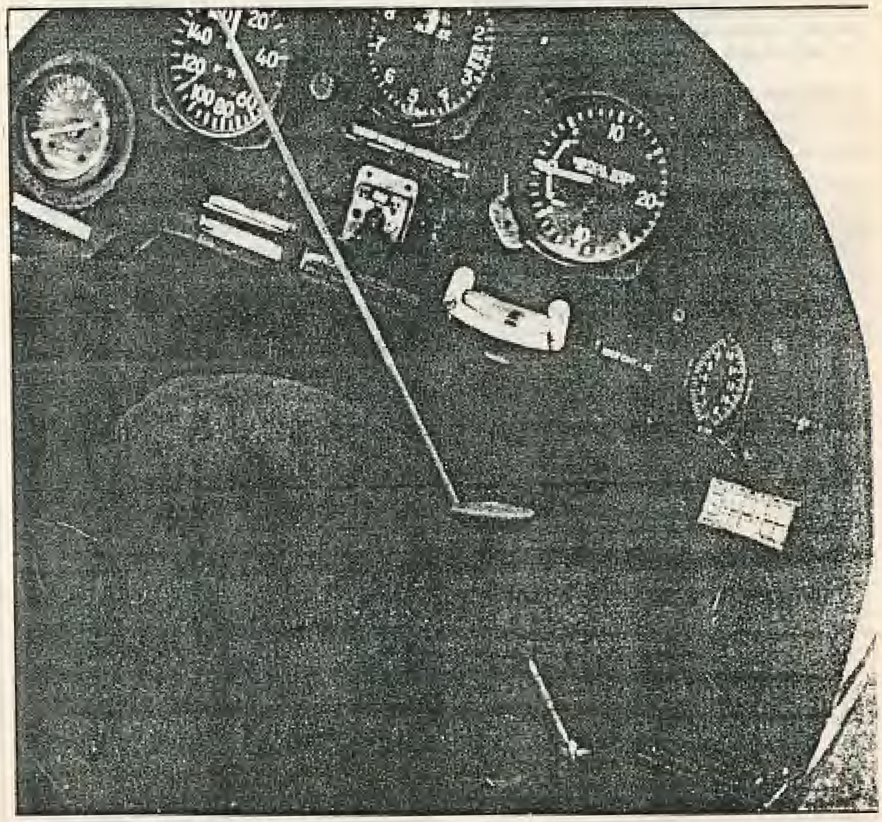
With the flaps lowered the main change is an improvement in the aileron response and a steepening of the approach. I didn't bother with them much on my flight, as there was a stiff crosswind by then and I preferred to limit the drift by having a little higher touchdown speed. The approach seemed typical of any light aircraft but with a far better view ahead. The side-slipping characteristics had been perfectly normal, so I elected to use a wing-down approach at 60 mph. At this speed it was easy to make a well held-off float and a very light touchdown on the main wheels. Opening the throttle again to go around the Shadow leapt off again, and within a few seconds I was up high enough for a low circuit and a second try. This was real fun-flying with no worries about those fiends who insist on making Transport Command circuits, or air traffickers who want radio calls to let them know exactly where you are on the circuit.

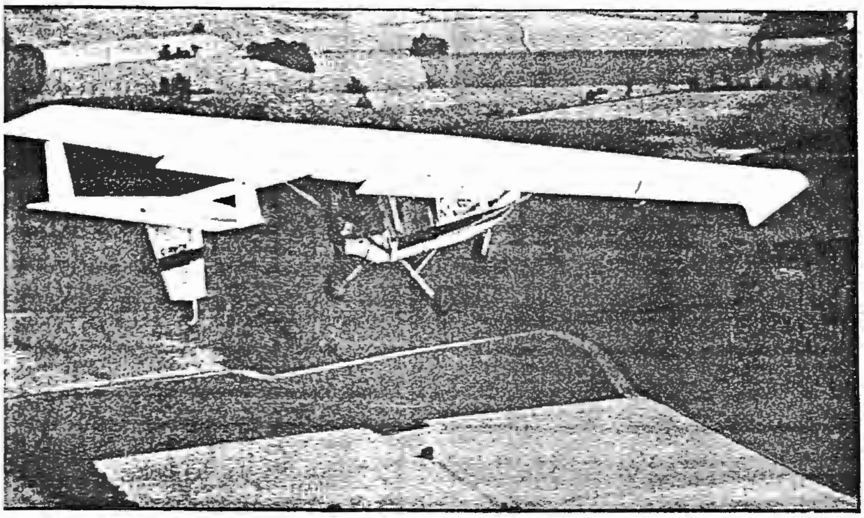
One more landing and my treat was over. I taxied in to park near the trailer/hangar and switched off to chat to the designer and originator David Cook.

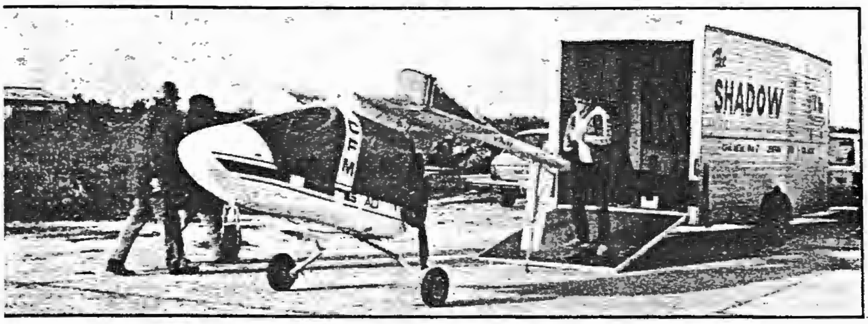
The Shadow owes many of its aerodynamic features — including the wing aerofoil — to the very successful Volmer Jensen VJ-23 Swingwing rigid-wing hang-glider. It was with one of these machines fitted with a little two-stroke engine that David Cook became the first person to fly a powered hang-glider across the English Channel, for which he was awarded the Royal Aero Club Bronze Medal for Aviation Achievement. He has had many years experience as chief designer of Richard Garrett Engineering Ltd., as well as much experience in instructing and flying many types of microlight aircraft. Since 1980 he has concentrated all his energies to developing and building the Shadow. In its construction he has used what he considered to be the most appropriate material for the part concerned. Extensive use is made in the main fuselage of fibrelam, a glass and honeycomb sandwich board used for floorboards in many airliners. In the kit this comes computer-cut to shape and ready to glue together. The wing spar is an I-beam using preformed alloy spar caps and a ply web. The whole D-box including the finished spar and fittings comes complete ready to attach the foam ribs. The rear fuselage or boom is a standard alloy tube, and is also finished and jig-drilled at the works. Apparently if you order a completed machine they simply take the next kit out of stores and assemble it!

It would take you approximately 300 man hours to complete the kit version; no special tools or experience is required. Detailed con-

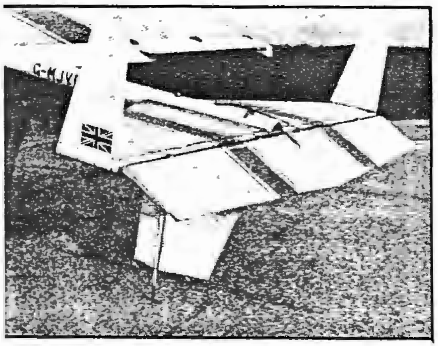


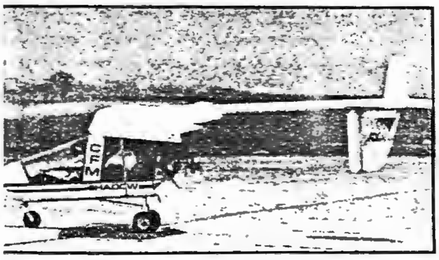






Much of the Shadow's aerodynamics derive from Volmer Jensen's VJ-23 Swingwing, with which Shadow designer David Cook became the first man to fly a powered hang-glider across the Channel. The Shadow's structure is a mix of metal and composites; kit assembly time is estimated at 300 hours. Options include floats, and a trailer-hangar — rigging takes two people about ten minutes.

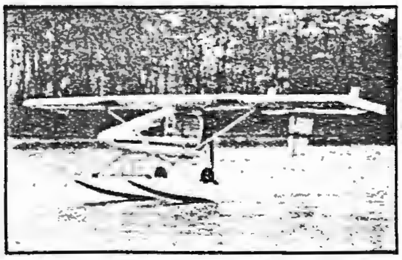




struction manuals are provided with a photo supplement to help the builder.

You may ask why pay all this money for an aircraft when you could buy a second-hand light aircraft for the same amount? Well, there seem to be various advantages. First, you get a new machine and not a clapped-out fatigued one. It can live in its own trailer/hangar ready to drive out to the airfield — or indeed, any farmer's field which is suitable. Any unobstructed area of about 150 metres would be sufficient once you have become really familiar with the machine. So no hangarage fees and possibly no landing fees are payable — apart from the odd bottle of whisky for the farmer. It can be taken out of the trailer and rigged by two people, and it only takes about ten minutes. The fuselage is just rolled out ready to attach the wings and tail. The wings are very lightweight and not unreasonable for the girl-friend to handle. (Anyway she can have a ride for her trouble!) Any servicing can be done by the pilot, who if he has built the machine already knows every nut and bolt. Similarly with minor repairs, so that running costs come out at about £5 to £10 per hour all in!

The engine life is about 400–600 hours before



a complete overhaul, or if preferred a new engine can be bought for about £750.

Looking at the kit of parts one is reminded of a modern model kit. Most of the major parts are semi-finished and there is only glueing, some fibre-glassing and the covering to do.

During the assembly the work has to be inspected and signed off at four stages by either a PFA or BMAA inspector or by the factory. Help is available if there are any troubles, or of course for an extra £3,850 you can have a completed aircraft.

So what did I *not* like about the aircraft? Well, I would certainly want to build my own rather than buy it assembled so that I knew all about the structure and could confidently service it. The ailerons are just a little heavy to my taste, but I expect most other pilots would be very happy with them. I did not like the canopy catches: they are better on production aircraft, and now lock the canopy against any push up from inside. It would be nice to have even a crude form of elevator trim, but otherwise it was fine from the flying point of view.

What can you do with the aircraft? Well, it was fitted with crop-spraying equipment and tested by the ICAP at Cranfield for ULV applications. It is obviously suitable for observation and surveillance purposes, and at least one farmer has bought one for rounding-up cattle on his ranch. It can be fitted with floats, and has a good performance flying from calm water sites such as lakes and other inland waters.

But perhaps best of all, it is real fun to fly. All aircraft bite fools, but this one is safer from the risks of stalling and spinning than any other light aircraft I have known. It is just what the doctor ordered to revive the light aeroplane movement!

It would be perfectly safe to do initial training on such a forgiving machine, but for a pilot who is going to fly other types more experience of stalling and spinning would be essential. I would like to teach in it to see just how quickly a student would master it: my guess is that it would not take long.

By the way, it is categorised as a microlight, a dirty word to many pilots. Better to call it a mini light aircraft, for that is what it really is.

CFM Shadow

Specifications	
Wing span	33 feet
Wing area	162 sq ft
Weight empty	331 lbs
Maximum AuW	767 lbs
cockpit loads:	
front	121 to 198 lbs
rear	0 to 198lbs
Fuel capacity	5 imp gals
Performance	
Never-exceed speed	108 mph
Max cruise	75 mph
Econcruise	65 mph
Min speed (no defined stall)	38 mph
Rate of climb	700 fpm
Take-off run	295 feet
Range at econ cruise	130 miles
Endurance at econ cruise	2 hrs

Engine: 40hp Rotax 447 two-cylinder two-stroke.
Price: kit (in four stages) £6,900 plus VAT. Dual control version is £7,300 in kit form, or £11,275 complete. Information pack: £2. Video: £10. Ready to fly: £10,750 plus VAT.
Extras: custom-built hangar/trailer, long-range tank, floats, crop-spray system, airframe recovery parachute system.
Manufacturer: CFM Metal-Fax Ltd., Unit 2D, Eastlands Industrial Estate, Leiston, Suffolk, IP16 4LL. Tel: (0728) 832353.

UTILISATION

PRACTICAL APPLICATIONS

In view of its superior performance the Shadow is quite capable of handling various work loads and it is in this area that the aircraft becomes highly cost effective. When flown solo with the additional fuel tank the aircraft can cruise for 400 miles without refuelling, thus offering incredible cross-country potential. In addition, being a high wing machine, the pilot has an almost uninterrupted 360° arc of vision. The aircraft can fly slowly (40 mph), is extremely manoeuvrable, yet provides a stable platform for ancillary equipment. Its short take off and landing ability and ease of transportation (in a custom-built trailer which doubles as a hangar) makes it versatile and flexible to operational requirements. Two people can assemble the aircraft in 10-15 minutes.

AERIAL SURVEILLANCE

The aircraft with single pilot operation is ideal for prolonged observation. Search operations, traffic control and reporting, forestry fire watch, pipe-line/power cable monitoring, land and livestock management, fence and border patrols are some of the more obvious applications. It is possible to install a TV and video camera with a microwave transmitter to a ground command station/vehicle.

FLOAT FLYING

The Shadow can be fitted with floats and is capable of calm water operation from sheltered sites. There is excellent rudder response on the water and there is no difference to in-flight handling characteristics at normal speeds (up to 80 mph). Take off distances are in the region of 600 ft. The changeover from floats to wheels is both simple and quick.

CROP SPRAYING

Trials have proved that the spray equipment fitted to the Shadow has considerable potential - especially abroad for crop improvement, defoliation and pest control. An 'in-cockpit' monitoring device enables the pilot to deliver the correct flow rate relative to his airspeed. It is also adjustable for various droplet sizes demanded for differing applications. The system is most effective and comparatively very cheap.

LEISURE/PLEASURE

For the equivalent cost of a high performance car the Shadow provides fun and sport flying at a cost of under £5 per hour. It is exhilarating to fly and can be likened to a "Formula-Car" in the sky!

SPECIFICATION

ENGINE

The following power plant is fitted as standard to production aircraft. It has an integral reduction drive (2.58:1) to a two blade wooden pusher propeller.

BOMBARDIER ROTAX 447 - two cylinder - two stroke - 436 cc
approximately 40 BHP

FUEL CAPACITY - ENDURANCE

With standard tank	- 5 Imp Galls (22.7 litres) -	1¾ hrs with small reserve
With additional tank	- 16 Imp Galls (72.6 litres) -	8 hrs with small reserve

(N.B. These figures based on the maximum cruising speed of 75 mph/ 65 knots at AUW).

At a 'Loiter' speed of 75 mph/65 knots with Pilot only (73 kgs/ 161 lbs) a fuel consumption of only 2 galls (9.08 litres) per hour can be expected.

DIMENSIONS

Wing Span	10.03m	(32ft 11in)
Wing area, gross	15.00m^2	(162sq ft)
Wing aspect ratio	6.58	
Length overall	6.40m	(21ft 0in)
Height overall	1.73m	(5ft 8in)
Propeller diameter	1.30m	(4ft 3in)

WEIGHT AND LOADINGS

Aircraft Empty Weight	150 kgs	(331 lbs)
Maximum Take-off weight -AUW	348 kgs	(767 lbs)
G rating (Ultimate)	+6.0/-3.0	

FRONT COCKPIT LIMITS

Pilot - Weight range: MIN: 54.5 kgs (121 lbs) MAX: 90 Kgs (198 lbs)

REAR COCKPIT LIMITS

Passenger/Freight - Weight range:
MIN: 0 kgs (0 lbs) MAX: 90 kgs (198 lbs)

PERFORMANCE

AT MAX AUW

Never exceed speed	94 knots	(173 kph : 108 mph)
Max. level speed	83 knots	(152 kph : 95 mph)
Max. cruising speed	65 knots	(121 kph : 75 mph)
Econ. cruising speed	57 knots	(105 kph : 65 mph)
Min. Flying speed (no defined stall)	33 knots	(62 kph : 38 mph)
Max. rate of climb (S/L)	3,6 m/s	(700 fpm)
* T-O run from metalled surface	90 m	(295 ft)
* T-O run from prepared grass surface	100 m	(328 ft)
* Landing run (with some use of brakes)	75 m	(246 ft)
Ceiling	3048 m	(10,000 ft - without oxygen)

* No wind

WITH PILOT ONLY - AVERAGE WEIGHT (73 kgs/161 lbs)

Max. rate of climb (S/L)	4,5 m/s	(900 fpm)
* T-O run from metalled surface	35 m	(115 ft)
* T-O run from prepared grass surface	40 m	(131 ft)
* Landing run (with some use of brakes)	45 m	(148 ft)

* No wind

RANGE - (assuming max. cruising speed 65 knots/75 mph - allowing small reserve)

With standard Fuel Tank	approximately 208 kms/130 miles
With additional Fuel Tank	approximately 960 kms/600 miles

GOSPRAY SYSTEMS

'The SHADOW has demonstrated that it could become an effective tool in agriculture'

We have produced a lightweight and efficient aerial crop spraying unit to complement the full Type Certification of the SHADOW by the UK Civil Aviation Authority. Considerable research and development has gone into this system to provide the optimum Ultra Low Volume capability. The concept incorporates the latest technology with a modular design for quick and easy service, assembly and removal.

Preliminary ULV/LV trials using water sensitive paper were most encouraging. The SHADOW aircraft proved that it was more than capable of meeting the required demands in respect of take off, landing, payload and most importantly the in flight handling. Consequently, it was arranged that the whole 'package' should be evaluated by the International Centre for the Application of Pesticides (ICAP) at the Cranfield Institute of Technology. The aim of this exercise was to obtain an objective assessment with detailed results from the most experienced and independent authority available.

The SHADOW is a high wing monoplane, with a strutted cantilever wing and conventional 3 axis control. For transportation the wings and tailplane are easy to dismantle and assemble (within 10 minutes). In addition to the pilot a 90 litre/16 gallon 'hopper' with a 'dump' facility can be carried in the rear seat compartment.

The aircraft is simple to fly, very stable and has exceptional anti-stall and spin characteristics. Combined with an excellent speed range of 25 - 95 mph and ease of ground handling, the SHADOW with its associated GOSPRAY system has 'a natural role in agriculture'.

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THE SHADOW - MK I

SERIES B

PRICE LIST

SHADOW aircraft Factory completed and supplied with the following instruments:

Air Speed Indicator, Altimeter, Fuel Gauge, Tachometer and EGT

* Single Controls	£10,870
Dual Controls	£11,750
* A 'Footwell' can be fitted to the rear cockpit - extra	£ 195

OVERSEAS OPTIONS

BRS - Airframe Recovery Parachute System (includes fitting)		£ 995
Floats with fittings		£ 1,150
Long Range Additional Fuel Tank		£ 225
Trailer/Hangar - all aluminium, custom built, double skinned	c	£ 3,300

DOCUMENTATION

Factory completed aircraft will be delivered with	
CERTIFICATE OF REGISTRATION (with letters affixed)	£ 35
PERMIT TO FLY	£ 150

KIT

* Single Control	£ 7,020
Dual Controls	£ 7,500
* A 'footwell' can be fitted to the rear cockpit - extra	£ 150

EXTRAS - can be purchased individually

Pilot's Notes	£ 5
Service Manual	£ 15
Video - VHS or BETAMAX - (PAL system only)	£ 10

NOTES

1. All prices are EXCLUSIVE OF VAT at 15%, packaging, freight and insurance.
2. A 20% Deposit is required with your order.
3. Cheques to be made payable to CFM METAL-FAX LTD.

JUNE, 1986

VIDEO ORDER FORM

TO: COOK FLYING MACHINES (METAL-FAX LTD) UNIT 2D EASTLANDS INDUSTRIAL ESTATE LEISTON SUFFOLK IP164LL TEL: LEISTON (0728) 832353	FROM: ______________ ______________ ______________ ______________ ______________ TEL : ______________

TICK

☐ Please forward Video Tape (£10.00 enclosed) - I understand this remains my property. Please make your cheque payable to CFM Metal-Fax Ltd.

☐ I am interested in purchasing a Shadow, please forward official order form.

☐ I am interested in The Shadow in easy-build kit form.

COMMENTS

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Human-powered Watercraft

In striving for ever higher speeds the familiar racing shells propelled by eight oarsmen may have to give way to unconventional watercraft. Such a record-setting vehicle was designed and built by the authors

by Alec N. Brooks, Allan V. Abbott and David Gordon Wilson

Until recently the slender shells, or racing rowboats, made familiar by the Olympic Games, the races on the Thames River in England and other rowing regattas held throughout the world, were the fastest human-powered watercraft. The fastest of these, powered by a crew of eight oarsmen, achieve speeds of 12 knots over a standard 2,000-meter course. (One knot is equal to about half a meter per second.) Human-powered watercraft that are not bound by the arbitrary restrictions of officially sanctioned rowing events are likely to equal or surpass this level of performance. Designers of these unconventional craft are dispensing with oars and taking full advantage of modern high-efficiency propellers. They are even dispensing with hulls as they explore innovative ways to reduce the resistance against motion, called drag, that water exerts on a moving boat.

Indeed, two of us (Brooks and Abbott) have developed just such a record-setting human-powered watercraft. The craft, *Flying Fish II*, is ridden like a bicycle. It has a pair of hydrofoils, or underwater wings, and a high-efficiency propeller. It enables a single rider to complete a 2,000-meter course significantly faster than a single rower in a shell can, and it has attained a maximum speed of 13 knots over short distances.

Regardless of its design—whether it is a crude flotation device propelled by underwater kicking, a wood raft pushed along by poles, a dugout canoe powered by paddles or a dinghy moved forward by sweeping oars—every watercraft must contend with four basic forces: weight, lift, thrust and drag. Weight and lift are the simplest forces to understand. Weight is simply the gravitational force pulling down on the craft and its occupants; lift is the force that acts upward, counteracting the weight. As long as a boat does not experience any vertical acceleration, lift is equal to weight.

For most watercraft lift is generated by buoyancy: the displacement of water by the craft's hull. The lift is equal to the weight of the water displaced, and it operates even in the absence of motion. In addition many high-speed boats take advantage of dynamic lift, which is produced as the boat moves through water. A common example of dynamic lift is planing: when the bottom of the hull continuously deflects water downward so that lift is produced as a reaction force. A boat that relies on planing for most of its lift rides higher in the water—often right at the surface—and requires less buoyancy. Until recently designers of human-powered watercraft had not been able to successfully incorporate dynamic lift into their vehicles.

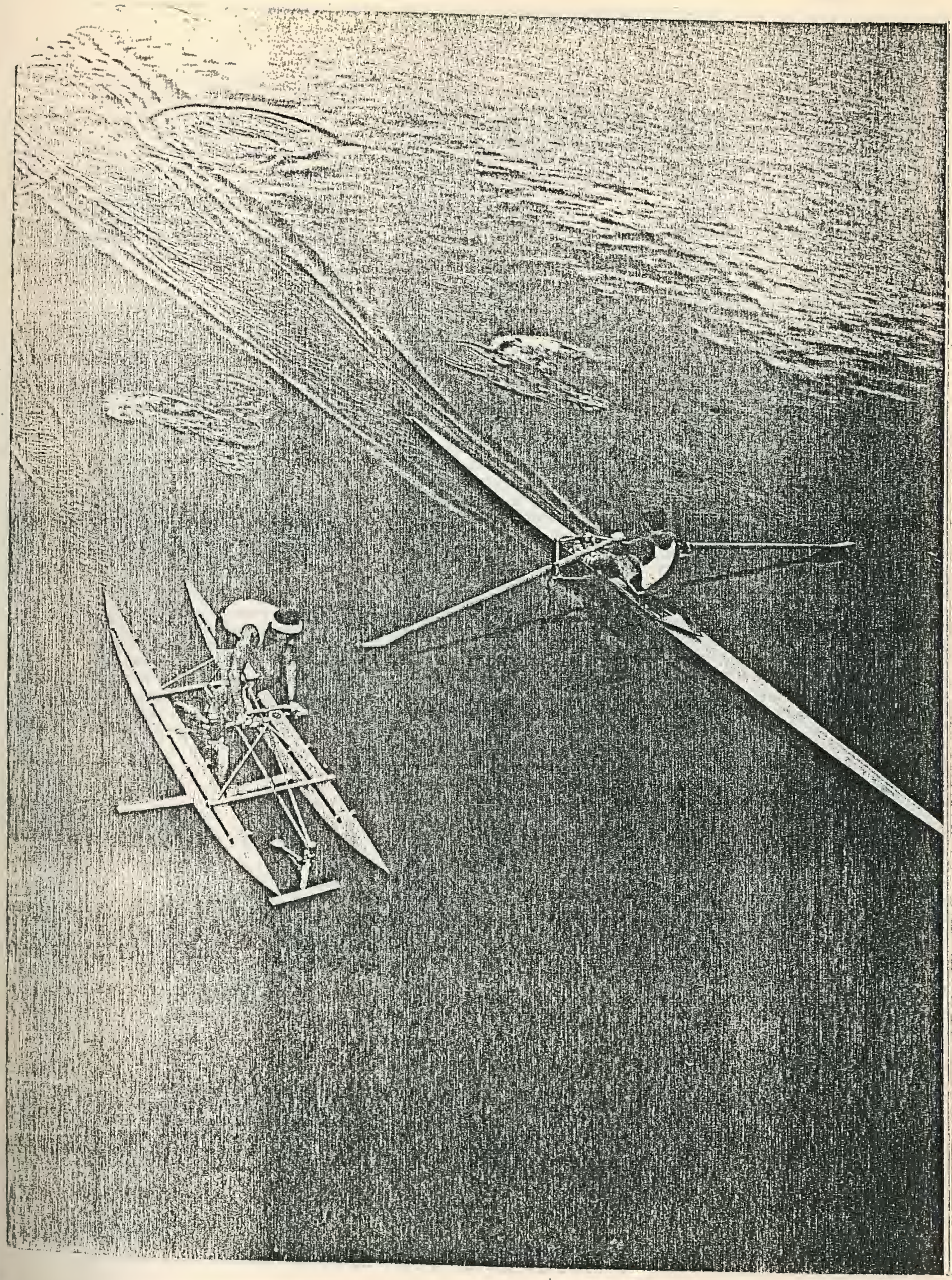
Thrust is the force (produced by the actions of the operator in the case of human-powered watercraft) that propels the craft. Drag is the force that by definition acts in the direction opposite to the direction of the craft's motion. If a boat is moving at a steady speed, the thrust is equal to the drag. In summary, at constant speed lift balances weight and thrust balances drag.

In order to translate efficiently a given human power input into speed the most important objective is to minimize drag. One obvious way to lessen drag is to reduce the weight of the boat. Once a boat begins to move, its source of lift almost always exacts a drag penalty. By minimizing the weight of the boat the required lift is reduced, and hence the drag associated with the lift is lessened. Since the craft's operators are not likely to be overweight (assuming they are healthy, athletic individuals to begin with), the weight reduction must apply primarily to the vehicle itself.

Efforts to this end have led to racing shells that weigh only a small fraction of the operator's weight—a relation similar to that of a modern racing bicycle and its rider. In the past shells were generally made of cedar, spruce and mahogany, and they were made lighter by thinning their hulls. (Indeed, the term "shell" arose because a careless finger could easily puncture a wood hull.) In the 1950's experimental shells that had a skin of glass-fiber-reinforced plastic were tried, and by the end of the 1960's commercially available composite-based boats had challenged the dominant position of wood boats in rowing circles. Today the wood shell is becoming a rarity. Sophisticated composite materials consisting of a resin matrix interlaced with fibers of a polymer or graphite have brought down the weight of the lightest single-person shell to less than 10 kilograms.

Assuming that the weight of the racing shell has been reduced to its practical minimum, a designer's attention must turn to other ways of minimizing drag. Shells have what are called displacement hulls: virtually all their lift is produced by the buoyancy of the hull. Displacement hulls have the unique property that their drag approaches zero as their speed through the water approaches zero. Hence at very low speeds displacement-hull vehicles have extremely low drag and

AMONG THE FASTEST human-powered watercraft are conventional racing shells and the authors' unconventional vehicle, *Flying Fish II*. The shell, shown here being rowed by four-time Olympian John Van Blom, was built by Alfred Stämpfli AG of Switzerland. *Flying Fish II*, ridden by one of the authors (Abbott), is powered by a pedal-driven propeller and supported by two hydrofoils, or underwater wings, while racing. The floats are actually above the water surface and are meant to support the craft only at low speeds.



are among the most efficient of all vehicles. Racing shells, however, do not operate at low speeds.

As a shell's speed increases, its drag increases dramatically owing in part to the formation of waves that emanate from the bow and stern. The energy needed to produce these waves is manifested as wave drag. Wave drag increases rapidly with increasing speed but in an uneven fashion because the bow wave can interact constructively with the stern wave (so that the waves are in phase and reinforce one another) or destructively (so that the waves are out of phase and tend to cancel one another) as the craft picks up speed. At a speed called hull speed the bow is at the crest and the stern is at the trough of a single wave; in its passage through the water the hull has literally created a hill of water through which the boat must push. At this point a great expenditure of power is needed to increase the boat's speed. The human power plant cannot supply the required effort, and so hull speed acts as the effective speed limit of a human-powered displacement-hull vehicle.

Hull speed is proportional to the square root of the waterline length of a boat. Human-powered watercraft that have long displacement hulls are therefore less hindered by wave drag than boats that have short hulls with the same overall buoyancy. On the other hand, for a given buoyancy long, slender hulls have more wetted surface area than short, wide hulls. The greater the wetted surface area, the greater the drag caused by the friction of the water as it flows past the surface of the hull. This type of drag is known as skin-friction drag. Hence as a boat is made more slender, wave drag diminishes but skin-friction drag then becomes more of a problem.

A hull designed for speedy boats must therefore be shaped to minimize the sum of wave and skin-friction drag. Shells are designed to compete in six-to-seven-minute races at power levels of about half a horsepower per rower. (One horsepower is equal to approximately 750 watts.) The resulting optimal length-to-width ratios of these sleek craft exceed 30. A single-person shell, for example, has a length of between eight and nine meters and a width of no more than 30 centimeters. It turns out that the optimal shell shape results in a skewed distribution of drag at racing speeds: 80 percent of the drag operating on the shell is due to skin friction and 20 percent is due to wave production.

Given that skin friction is the dominant source of drag operating on a shell at racing speed, a substantial reduction in drag is possible if skin friction can be reduced. Skin friction arises from a thin layer of water, known as the boundary layer, that flows past the boat's hull. There are two fundamental types of boundary layer: laminar, in which the flow is smooth and steady, and turbulent, in which the flow is chaotic and unsteady. Laminar boundary layers produce much less skin-friction drag than turbulent boundary layers do. The boundary layer on a shell is laminar at the bow, but only a short distance back from the bow it typically undergoes a transition to turbulent flow. Drag is significantly reduced if the transition is delayed, thereby increasing the area of laminar flow on the hull.

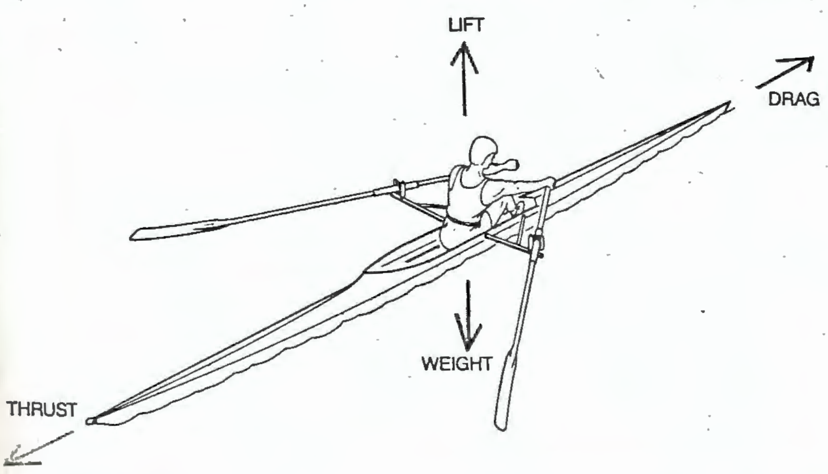
One method of extending the laminar boundary layer that is applied in some specialized underwater vehicles is the injection of long-chain polymers (sometimes referred to as slippery water) into the boundary layer near the front of the craft. Race-sanctioning organizations are not likely to allow this practice in competition, if for no other reason than that it pollutes the water. A similar approach that might be allowed, however, would entail carefully cultivating a layer of naturally slimy algae or some other innocuous microorganisms on the hull.

Boundary-layer suction is another technique that has been applied to stabilize a laminar boundary layer. In this approach fluid in the boundary layer is continuously "sucked" into the boat through pores or small slots in the hull surface. Shells could make use of boundary-layer suction if they were outfitted with a porous hull that would allow water to seep in slowly. A small pump would serve to bail the water out occasionally.

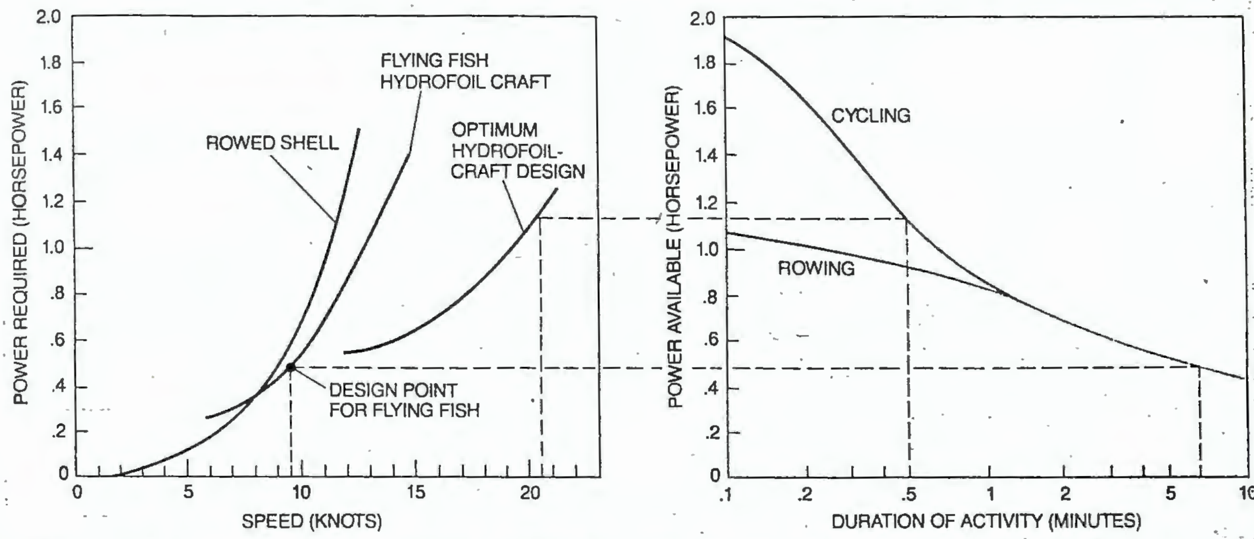
The texture of the wetted hull surface can also play a role in the reduction of skin-friction drag. Investigations under the auspices of the National Aeronautics and Space Administration have shown that a slick waxed surface does not always result in minimal skin-friction drag. Surfaces with very fine grooves running in the flow direction, called riblets, have shown 6 percent less drag than smooth surfaces.

Riblets have been tested on rowed shells by a group from the Flight Research Institute headed by Douglas McLean of the Boeing Company. The group covered a single-person shell with an experimental plastic skin in which grooves had been formed. The spacing between the grooves was three-thousandths of an inch (about 80 micrometers)—finer than the groove spacing on phonograph records. Tests indicated that the shell's maximum speed was increased by 2 percent. Although this may seem like an insignificant amount, it is equivalent to a four-boat-length advantage over a standard 2,000-meter race.

On the basis of such encouraging results the experimental skin was applied to the hull of the U.S. Olympic



FOUR BASIC FORCES must be considered in designing boats such as the racing shell shown here: weight, lift, thrust and drag. Weight is the gravitational force acting on the boat and the operator. Lift is normally generated by buoyancy, the upward force equal to the weight of the water displaced by the boat's hull. Additional lift, called dynamic lift, can be produced by the flow of water under the hull. Thrust, in the case of human-powered water vehicles, is the force produced by the actions of the operator (here seen rowing) that propels the craft forward. Drag is the resistance to the boat's forward motion; it arises in most craft from the creation of a wake (wave drag) and the friction between the hull and the water flowing past it (skin-friction drag). When a boat has a constant speed, lift balances weight and thrust balances drag. The key objective in boat design is to minimize drag at the normal operating speed of the boat. At the speeds necessary for competitive rowing, drag is minimized by making a shell light, long and narrow.



POWER LEVEL necessary for a human-powered watercraft to reach a certain speed for a certain length of time depends on the craft's design. The graph at the left shows the power required for a rowing shell, which relies on the displacement of water by its hull for most of its lift, compared with two other craft designs (one being the authors'), which rely on the dynamic lift produced by hydrofoils. At low speeds displacement-hull craft are more efficient than hydrofoil craft. Actually hydrofoil craft have a minimum speed below which the hydrofoils cannot support the combined weight of the craft and the operator. At higher speeds, however, hydrofoil vessels are more efficient than displacement-hull craft. The graph at the right shows how the power a champion athlete can supply diminishes with the effort's duration. For brief durations the power output generated by the cycling motion is considerably higher than the output generated by the rowing motion. An optimal hydrofoil design could make it possible to reach speeds of more than 20 knots. Such a feat would require power levels that can be achieved only by cycling and only for a few seconds. A craft incorporating such a hydrofoil would be difficult to get started: its "takeoff" speed would be more than 11 knots.

team men's coxed-four rowing shell. (A coxed boat is steered by a coxswain, who does not row but calls out the rowing cadence.) The team made an excellent showing, winning the silver medal in the 1984 summer games.

In addition to low drag, another essential ingredient for a successful racing shell is good propulsive efficiency: as much as possible of the power from humans must be converted into useful thrust. In the case of rowing, two major advances in propulsive efficiency date from the mid-19th century. One was the development of the modern rigger in 1843. The rigger is a tripodlike device attached to the side of the boat. The oarlock, or pivot point for the oar, is located at the apex of the tripod. Since the oarlocks no longer needed to be attached directly to the gunwales, or edges of the sides of the boat, the hull could be narrower (reducing wave drag) and the oars could be longer (enabling rowers to take longer and more efficient strokes).

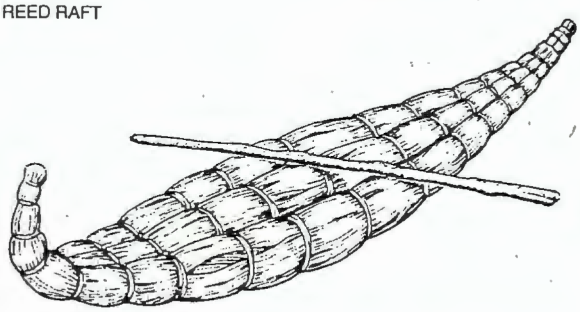
The second advance was made in 1856: the sliding seat. Until that time rowed boats were propelled through the use of the muscles of the arm, shoulders and back, whereas the larger muscles of the legs were used only to brace or support the body. The motion when rowing was one of heavy straining against a slowly moving resistance. The sliding-seat arrangement allows the energy of the leg muscles to be harnessed as the seat moves fore and aft with the bending and straightening of the legs during the rowing cycle. The first sliding seat was a rather crude device consisting of a sheepskin pad sliding on a greased panel. The sliding seat on bearings, still in use today, was invented in the U.S. in 1857.

A shell with a variation of the sliding seat was rowed by Peter Michael Kolbe to win the 1981 world championships in Munich. In contrast to conventional shells, which have sliding seats and fixed riggers and stretchers, or footboards, Kolbe's custom shell was equipped with a fixed seat and a sliding frame that supported the riggers and stretchers. Under this arrangement the rowing motion is the same as the motion for conventional shells, but since most of the rower's mass is on the fixed (rather than sliding) seat, the oscillations of the center of mass (which more or less coincides with the rower) are greatly diminished. This in turn diminishes the oscillations in velocity that a shell is subject to as it travels through the water. (These oscillations are manifested in a conventional shell by its distinctive jerky motion when it is rowed forcefully.)

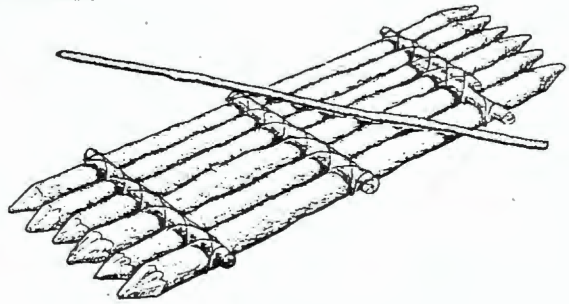
Because skin-friction drag is not a linear function of the velocity of the water in relation to the hull (it is in fact proportional to the square of the velocity), a fluctuating speed always produces more drag than would occur if the boat moved steadily at the average speed. The drag reduction obtained by the sliding-rigger arrangement is only slight, but it is enough to make a significant difference in the racing world. In the 1982 world championships five boats in the men's finals had fixed seats and sliding riggers. In 1983 all six finalists used sliding-rigger boats. After 1983, however, sliding-rigger boats were ruled ineligible for competition.

Although the addition of the rigger and the sliding seat significantly augmented the propulsive efficiency of rowing, rowing nonetheless has a fundamental limitation. Oars and paddles are basically drag devices: they generate thrust by slipping backward through the water. The slippage represents an efficiency loss; it can be reduced by increasing the size of the oar blade, but only to a limited degree because of practical constraints. Moreover, the aerodynamic drag caused by the blades when they are out of the water during the return stroke can be quite significant, particularly under windy conditions.

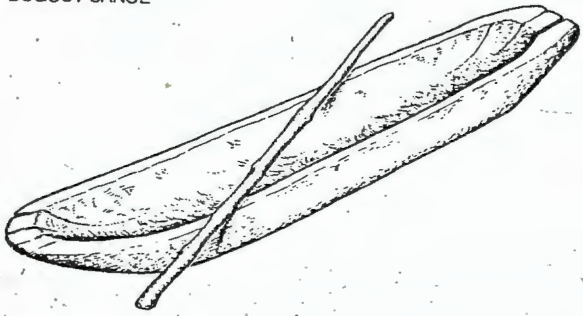
The efficiency of a propulsion system is defined as the ratio of useful power output, which is the product of the average thrust and the velocity, to the human power input. The detailed physics of rowing is not entirely understood but analysis by many investigators has put the propulsive efficiency of rowing at between 65 and 75 percent. Hence about two-thirds of the



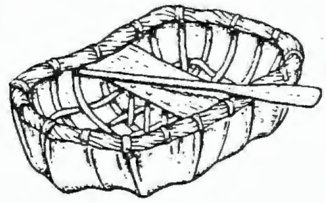
a REED RAFT



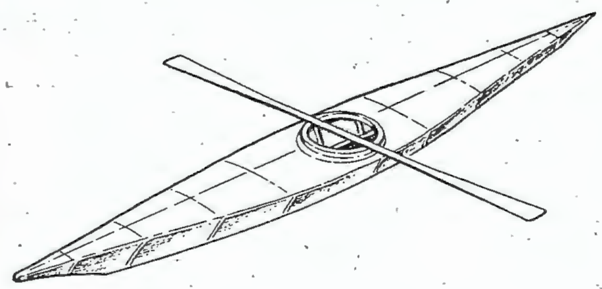
b LOG RAFT



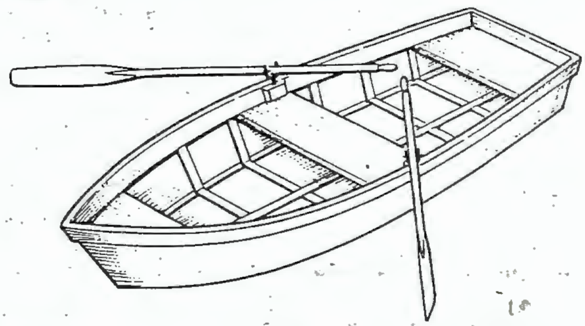
c DUGOUT CANOE



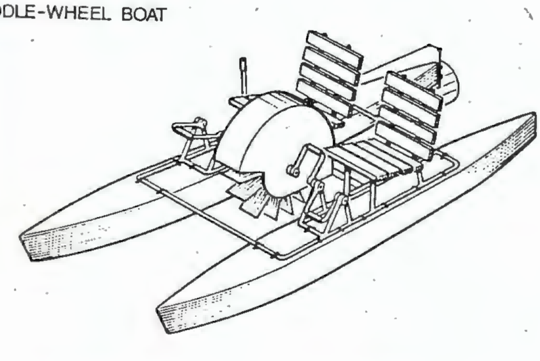
d CORACLE



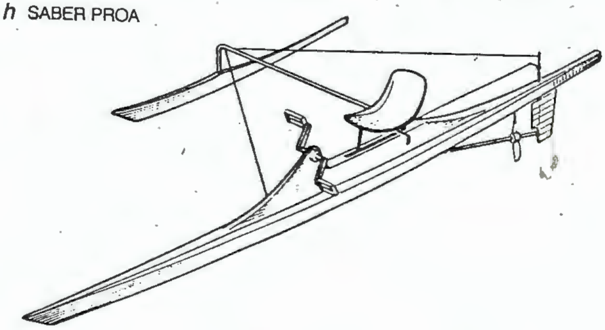
e KAYAK



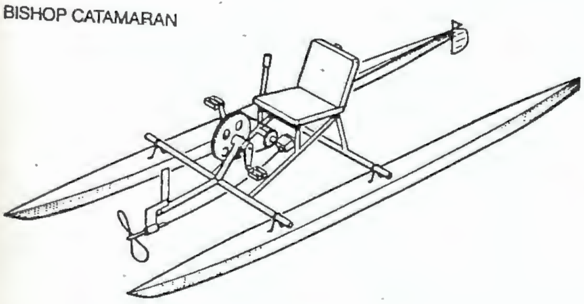
f DINGHY



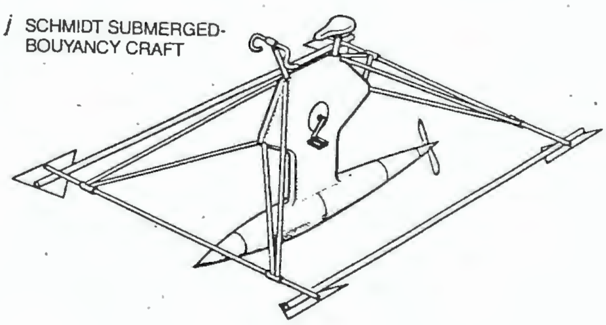
g PADDLE-WHEEL BOAT



h SABER PROA



i BISHOP CATAMARAN



j SCHMIDT SUBMERGED-BOUYANCY CRAFT

rower's power output is delivered to the boat as useful work; the rest goes into creating disturbances in the water and air.

Motorized boats abandoned propulsive drag devices, such as paddle wheels, long ago in favor of propellers. Interestingly, before the development of small gasoline-fueled outboard motors at the turn of the century, human-powered propeller-driven boats were in fact being developed for practical transportation purposes. Such propeller-driven boats proved to be much faster and less tiring than canoes or rowboats. In the 1890's a three-rider propeller-driven catamaran (a twin-hulled boat) was shown to be 13 percent faster than a three-oarsmen shell over a 163-kilometer course on the Thames River.

Some disadvantages of propellers are that they can be fouled with weeds and can strike bottom in shallow water, but otherwise propellers are particularly suited for human-power applications [see "The Screw Propeller," by E. Eugene Larrabee; SCIENTIFIC AMERICAN, July, 1980]. Slender-bladed, high-efficiency propeller designs can be applied, since the power level is quite low. In addition, propeller-tip speeds are low enough so that cavitation is not a problem. (Cavitation, the formation of bubbles of water vapor, arises when the absolute pressure on some part of the rotating propeller is reduced below the water's vapor pressure; it reduces efficiency and can cause excessive wear on the blade surfaces.) Several new human-powered watercraft have been outfitted with propellers whose efficiencies exceed 90 percent.

The rotating motion of propellers also makes it relatively easy to drive them by an arrangement of pedals, sprockets and chains much like that of bicycles. Such an arrangement takes advantage of the rapid and strong movements of the legs. The circular pedaling action in bicycling remains the most efficient practical method of transferring continuous power from a human being to a machine. (It is not coincidence that record-setting human-powered air and land vehicles depend on a bicyclelike drive train.)

A champion cyclist can produce nearly two horsepower for a few seconds of maximum effort. For periods of continuous exertion lasting for six minutes, however, the power output is generally no more than half a horsepower. Various factors affect power production, including pedaling rate, seat height, pedal-crank length and the physical condition and determination of the cyclist. The traditional rowing motion, in which the rower sits still and brings into play only the muscles of his back, shoulders and arms, yields considerably less power than the cycling motion. The addition of the sliding seat, however, increases the power level of rowing to rival that of cycling—at least for periods of more than a few minutes. (The short-period advantage of cycling is lost after about a minute because of the limitations imposed by the human circulatory and respiratory systems.)

The inherent advantage of pedal-driven-propeller boats over rowed boats therefore lies chiefly in the fact that oars are a less efficient mechanism for channeling human energy to the propulsion of the boat. Furthermore, a rowed boat's uneven speed exacts more of a drag penalty than the smooth, continuous speed that can be achieved with a propeller.

Designers of fast human-powered watercraft have also attempted to minimize drag in novel ways. One way to virtually eliminate wave drag and at the same time reduce skin-friction drag is to submerge the hull; the operator would have to be supported above the water by narrow struts extending upward from the hull. The minimal-drag hull in this case is teardrop-shaped, with a length between three and four times its width.

Such a configuration is like that of a unicycle, and balancing would likewise be difficult, if not impossible, for the rider. Theodore Schmidt alleviated this problem somewhat by attaching four small outrigger hydrofoils to an experimental submerged-hull craft of his own design. A tricyclelike arrangement of three smaller submerged-buoyancy hulls would be stabler but not as efficient. Since the ratio of surface area to displacement gets smaller as displacement increases, one big hull has less surface area than three smaller hulls with the same total buoyancy.

The balancing problem of a single underwater hull could be solved by putting the operator in the hull—in effect creating a submarine. But a streamlined hull big enough to enclose a rider displaces much more water and has more surface area than a hull that provides just enough buoyancy to support a person's weight. Although it is not optimal for human-powered transport near the surface of the water, a human-powered submarine could be a great improvement over a skin diver with flippers. In the early 1950's a two-person human-powered submarine called the Mini-Sub, designed by Calvin Gongwer, was produced in limited quantities by the Aerojet-General Corporation. Pushed forward by twin 760-millimeter counterrotating propellers, the Mini-Sub reportedly could achieve speeds of seven knots—about three times the speed at which a diver can swim underwater.

Other designs seek to reduce the second major drag component, skin-friction drag, by employing dynamic lift to raise part of the boat out of the water and thereby reduce the boat's wetted surface area. Although dynamic lift does incur a drag penalty of its own, in many instances the reduction in skin-friction drag more than compensates for the drag generated as a by-product of the dynamic lift.

Human-powered water vehicles that take advantage of the dynamic lift achieved by planing are still in the imagination of designers, but another way to generate dynamic lift has been applied successfully: hydrofoils. Hydrofoils are underwater wings that produce lift in the same way as airplane wings produce lift. The required size of a hydrofoil wing is quite modest compared with airplane wings. For example, at a speed of nine knots something under a tenth of a square meter of foil area is needed to produce enough lift to support a single rider above the water. A hydrofoil designed to produce the same lift at twice the speed would require only a fourth as much area.

Although the small wetted area of hydrofoil wings results in minimal skin-friction drag, hydrofoils do incur a different type of drag. As the hydrofoil travels through the water it leaves behind a vortex wake, just as airplane wings do. The energy expended in generating the vortex wake is manifested as a drag called induced drag. Also, the spray kicked up by the vertical struts supporting the hydrofoil as they cut through the surface of the water results in additional drag.

Another major problem with hu-

HUMAN-POWERED WATERCRAFT display assorted shapes, construction materials and propulsion devices. Relatively primitive craft are poled (*a–c*) or paddled (*d, e*) and are made of such diverse natural materials as reeds, wood and animal skins. More modern craft are made of wood or metal and are rowed (*f*), an action that calls for the use of the arms, shoulders and back, or are paddled with foot pedals, bringing into play the strong leg muscles (*g*). Pedal-driven-propeller boats (*h–j*) have greater propulsive efficiency than either rowboats or paddle-wheel boats. Novel designs and materials have also cut back on the drag such craft encounter. The submerged hull of Theodore Schmidt's experimental craft (*j*), for instance, effectively eliminates the problem of wave drag.

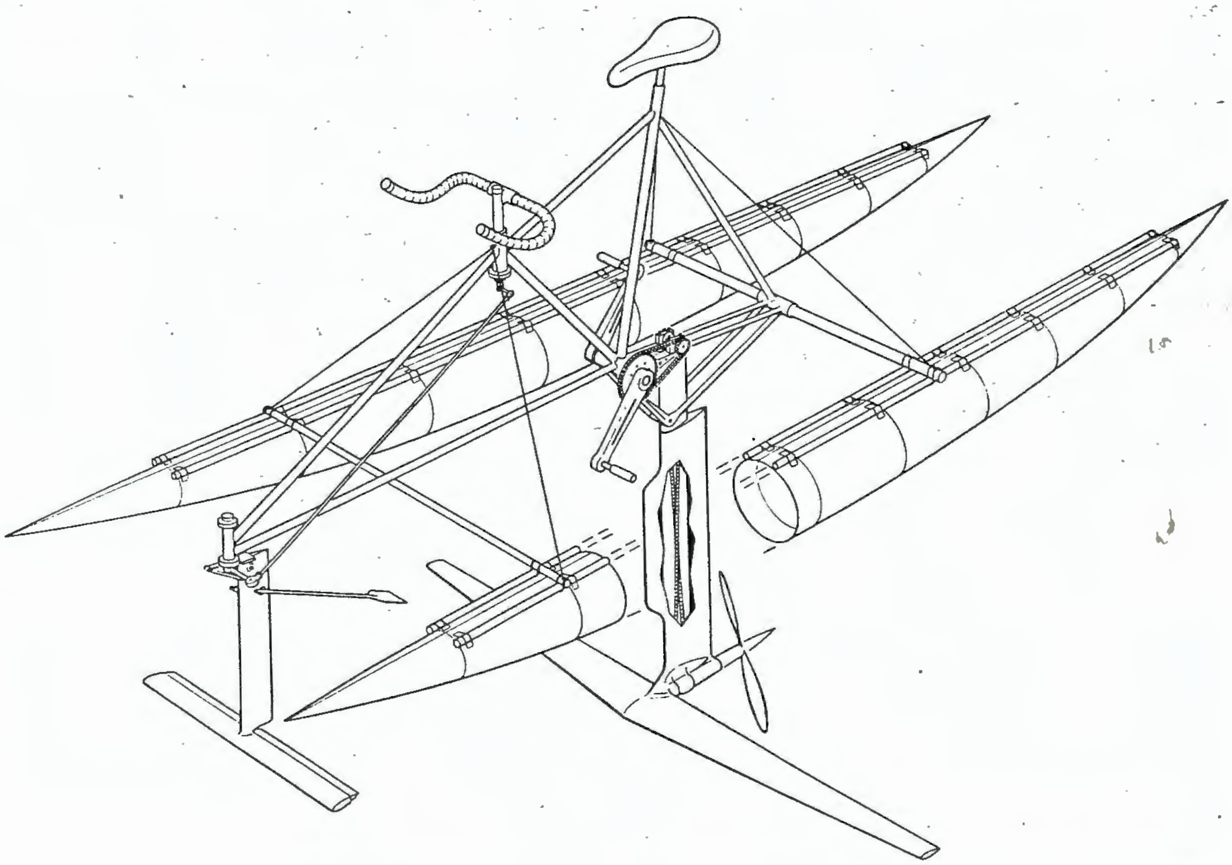
man-powered hydrofoil craft is that they need to reach relatively high water speeds before they can "take off," or lift themselves above the water. Since hydrofoils produce zero lift at zero speed, another support system, such as a displacement hull, is required for the initial and final phases of a "flight." A wing selected for all-out speed may have to be moving through the water at 10 knots before it can generate enough lift to support the craft and rider. This speed may well be impossible to achieve while the craft is still supported on the water by its displacement hull. A larger hydrofoil wing could reduce the takeoff speed, but the drag caused by the increased surface area would not allow the craft to go as fast.

Stacking hydrofoils so that smaller foils are placed below larger ones, as is done on motorized hydrofoil vessels, might circumvent the problem. A craft with such a tapered "ladder" arrangement of hydrofoils could take off at low speed on the large upper foils. Once sufficient speed has been attained so that the lift produced by the lower foil is enough to support the craft, the craft could rise up farther, raising the larger foil out of the water and thereby reducing drag. Because of the inherent difficulties associated with hydrofoils, human-powered hydrofoil craft do not have the same speed potential as human-powered airplanes, which have achieved speeds of more than 25 knots.

Until recently all human-powered water-speed records were held by displacement boats propelled by oars. With the intent of exceeding these speeds, two of us (Brooks and Abbott) in 1984 designed and built *Flying Fish I,* the first hydrofoil capable of sustained flight on human power alone. The sticky problem of initially getting the craft up to takeoff speed, which had plagued earlier designers, was bypassed initially by eliminating the need for a displacement hull. Flying speed was attained by catapulting the craft into the water from a floating ramp, much as jets are launched from aircraft carriers. Using this "flying start" launching method, cyclist Steve Hegg, an Olympic gold medalist, pedaled *Flying Fish I* a distance of 2,000-meters in six minutes 38 seconds, eclipsing the world record for a single rower by 11 seconds. The times, of course, are not directly comparable, because the rowing record was set from a standing start.

Flying Fish I has a high-efficiency, pedal-driven propeller and two slender wings supported by narrow vertical struts. The main wing, which carries 90 percent of the craft's weight, has a large wingspan (1.8 meters) to minimize induced drag and a small chord, or width, to reduce skin-friction drag. The smaller front wing has a configuration much like an inverted T and is lightly loaded; its main purpose is to provide stability and control. To this end it is fitted with a small, spatula-shaped device that automatically controls the depth of the wing. The device skates over the water surface, continuously adjusting a thin flap (analogous to the elevator on an airplane tail) to which it is linked.

The front wing strut doubles as a rudder and is connected to bicycle



FLYING FISH II is a human-powered hydrofoil craft designed and built by two of the authors (Brooks and Abbott). The craft, powered by a pedal-driven, high-efficiency propeller, takes off at six knots and has a top speed of about 14 knots. It is ridden just like a bicycle. The first version of the craft did not have side pontoons and required a catapult-launch ramp to bring it up to takeoff speed. The pontoons on the current version support the craft so that it can now reach takeoff speed from a standstill. The depth at which the hydrofoils "fly" is controlled automatically by a spatula-shaped surface follower linked to a thin flap on the front hydrofoil. The craft has completed a 2,000-meter course approximately 10 seconds faster than the record for a single-rower racing shell.

handlebars for steering. The craft is ridden much as one would ride a racing bicycle. The structure that is normally above the water is, in fact, a modified bicycle frame.

Flying Fish II was developed as a refinement of the first version of our craft. We attached lightweight pontoon floats to it in the hope that an unassisted takeoff could be made from a standstill. This proved to be possible, and with practice acceleration from a standing start to the fully foil-borne mode took only three seconds. The craft also became much more practical because it could now "land" on, as well as take off from, its floats. (The catapult-launched *Flying Fish I* gave the rider a dunking whenever he stopped pedaling.)

Aboard the *Flying Fish II* one of us (Abbott) recorded a time of six minutes 39.44 seconds over a 2,000-meter course from a standing start—about 10 seconds faster than the single-person rowing-shell record. From a flying start the hydrofoil watercraft also was able to sprint 250 meters in 38.46 seconds, reaching a maximum speed of approximately 13 knots.

The time is ripe for a technological revolution in human-powered recreational watercraft. Laser International has just introduced the Mallard, a partially enclosed, seaworthy boat designed by Garry Hoyt. Several new pedaled catamarans and proas (boats that have one main hull and a smaller stabilizing outrigger) offer rough-water seaworthiness and impressive speed. Jon Knapp of Saber Craft has designed and built a propeller-driven proa that is faster than a shell in rough water but, unlike a shell, requires no special skills to operate. The Dorycycle, a propeller-driven single-hulled craft designed by Philip Thiel, provides good load-carrying capacity at speeds twice that of the rowed dory from which it was derived.

Whether or not hydrofoil craft become popular for recreation, there seems to be little doubt that they will figure prominently in the next round of breaking records. The International Human Powered Vehicle Association encourages competition in human-powered vehicles—on land, on sea and in the air—without any arbitrary limits placed on their design. Such competition will push the speed of human-powered hydrofoil craft ever higher. It is not farfetched to envision such craft reaching speeds as high as 20 knots—one and a half times as fast as the speeds attained by *Flying Fish II* and significantly faster than the speeds attained by racing shells powered by eight athletic oarsmen.

Science suffers as Congress cuts spending plans

Helen Gavaghan, Washington DC

NASA last week lost ground in the race to win money from the US's annual budget. The House of Representatives agreed to a budget proposal that increases the agency's spending by only half of what President Reagan had wanted.

The House was voting on its budget committee's detailed plan for the US's Federal spending in the 1989 financial year. If this proposal survives the US's complicated budgetary system, the international space station will be delayed even further and other new programmes, such as a new orbiting telescope to observe the X-ray part of the electromagnetic spectrum, will face severe cuts in funding.

Another casualty of the House's budget proposal is very likely to be the superconducting supercollider, a giant new particle accelerator for research in subatomic physics. It will produce particles 20 times as energetic as any other machine. The plan would, however, grant more to AIDS research than Reagan advocated programmes to combat drug abuse and for assistance for the homeless.

The House's plan is a long way from being the final position on the budget for 1989, but it provides guidelines for committees that authorise programmes and appropriate money for the House, which is the lower tier of the US Congress. Within the next few weeks, the Senate, the upper tier, is expected to complete the same process. The whole budget should be settled by the summer.

The scope for variation has been narrowed by the agreement between Congress and the White House last year to cut the annual deficit. This limited spending on discretionary programmes, which include science and space, as well as some aspects of welfare. This is why the House gave science less of an increase than Reagan requested.

Reagan wanted a large portion of the additional money available to be spent on NASA, the National Science Foundation and the Department of Energy's general science programmes. He requested an increase of 29 per cent for the three, to bring their joint spending to $13·9 billion. The House has cut this to $12·45 billion. NASA loses about $1·1 billion, the NSF about $30 million and the Department of Energy about $300 million.

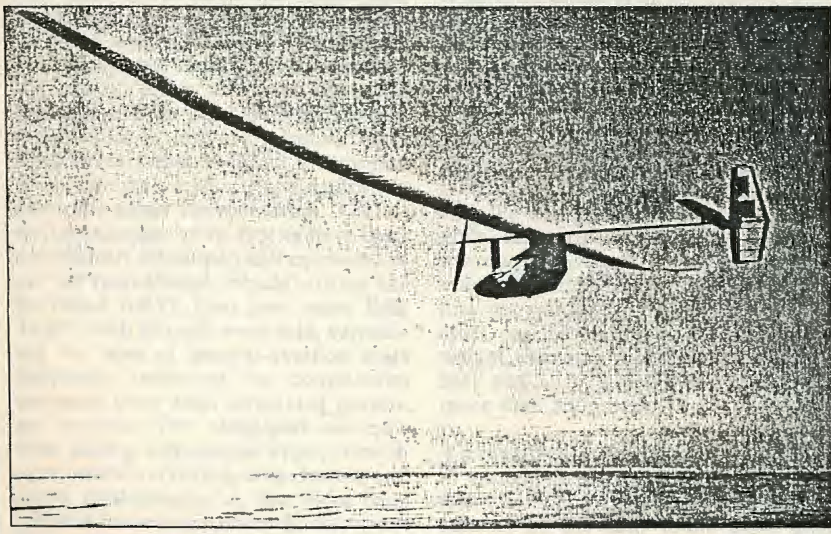
This year for the first time, the budget from the Department of Energy includes a request for money to build the supercollider. President Reagan envisaged a first instalment for the collider of $363 million in 1989. If Congress finally agrees a budget reflecting that proposed by the House, this instalment could disappear, because the collider does not have solid support.

Some scientists fear that the supercollider will take money from other research that is less glamorous. These scientists may well find allies in Congress. When the energy department produced its short list of eight sites, the collider lost the support of other states.

Whether or not the House's suggested figure for NASA's budget holds firm or not Congressional staff believe that the agency will face severe cuts, particularly to the international space station. NASA wants $1 billion for the space station in 1989 compared with the $415 million it received for the project this year.

Like the supercollider, though, the space station has congressional opponents who doubt whether it is the best way to provide experimental facilities for work in low gravity. □

Daedalus still alive and flying



MIT Daedalus Project

A TEAM from the Massachusetts Institute of Technology aims to set a distance record for human-powered flight this spring. The Daedalus Project aims to retrace the flight of the Greek mythological character, Daedalus, who fled on wings of wax and feathers from the Labyrinth of Crete where he had been imprisoned by King Minos. The organisers of the project aim to fly their aircraft for 119 kilometres from Iraklion, the main town on Crete, to the volcanic island of Santorini.

If successful, the flight would eclipse the record for human-powered flight of 58·6 kilometres set by the same team a year ago at the Edwards Air Force Base in California (*New Scientist*, 29 January 1987, p 28).

Last week, the Greek Air Force flew three craft built by the group to Greece. Each plane weighs 32 kilograms and has a wingspan of 34 metres. With one pilot, the planes are designed to cruise 3 to 5 metres above the waves at 24 kilometres per hour. The flight between the Greek islands should take four to five hours.

John Langford, the project manager at MIT, says that the flight crew should be ready this week, and that the flight could be made any time between now and mid-May. Weather will be the key factor in scheduling. Low winds are essential because of the size and weight of the craft. The flight would start at dawn, when the weather normally is calm and cool. □

Japan is 'no octopus'

BRITAIN is hoping to collaborate more closely with Japan on technology research. This week, officials from both countries are holding their annual talks on trade. For the first time, technology research is on the agenda. Delegates from Britain's Department of Trade and Industry (DTI) and from Japan's Ministry of International Trade and Industry (MITI) are discussing joint ventures in superconductivity, optoelectronics and materials research. The talks follow a trip to Japan by a group of industrialists and academics involved in developing new high temperature superconductors.

During the visit, British companies and academic researchers received invitations to join the International Superconductivity Technology Center set up by MITI in Tokyo and sponsored by some 60 Japanese companies.

"The image of Japan as a grabbing technological octopus is one they want to dispel," said Ian Corbett of Rutherford Appleton Laboratory, near Oxford, Britain. "They are extremely keen to collaborate." It seems unlikely that with a joining fee of £500 000, British firms will want to get involved on their own, although some, including Oxford Instruments, already have links with Japanese partners.

British scientists said at the talks that they are impressed by the quality and quantity of Japanese research. Working in teams of up to 50 researchers, the Japanese can call on some £15 million from the MITI this year.

"The investment in Japan in materials science is awe-inspiring," said Gough, who was on the DTI-sponsored trip to Japan. The Japanese were churning out scientific papers at the rate of 30 per month and working with great determination. The British group arrived in Japan the day the Japanese announced the discovery of a new high-temperature superconducting compound that contained bismuth. Over the weekend, all major laboratories had duplicated the results. Two weeks later, when the team left, the compound was available for sale. □

Ultralight Airplanes

The conjunction of the hang glider and the small engine has brought into being the "air recreational vehicle." A typical craft carries 200 pounds and cruises at 50 miles per hour

by Michael A. Markowski

Since the earliest days of aviation a widely sought objective has been an inexpensive airplane that is not unduly difficult to fly. From the time of the Wright brothers, however, the trend has been almost entirely toward bigger and more sophisticated airplanes. Only within the past few years has the conjunction of the hang glider and the small engine (Go-Kart or snowmobile) brought the long-sought objective into being as the ultralight airplane. The numerous models available today range in price from $2,800 to $7,000. For a pilot who has received the proper instruction and is acutely sensitive to the vagaries of the wind the craft are not hard to fly.

Until the ultralight aircraft came on the market most airplanes were designed and built principally to serve a commercial or military purpose. Even light aircraft cost so much to buy and maintain that few people could afford to have one solely for recreation. The ultralight airplane is the first to have been successfully developed and marketed as an "air recreational vehicle" (often abbreviated ARV). Last year more than 10,000 such aircraft were sold, surpassing the sales of general-aviation craft (airplanes employed for commercial purposes other than scheduled passenger service). The ultralights are now even finding commercial application in agricultural surveying, crop dusting and aerial photography. A few have been adapted for military observation service because they have the advantage of presenting virtually no radar image.

Several things besides affordability account for the popularity of the ultralights. One is the sheer pleasure of flying in this way. The pilot of an ultralight is not encapsulated in a cockpit but instead is able to be part of the wind. With the engine off the craft can be soared like a hang glider. At the end of the day the airplane can be folded up and stored at home.

In addition most ultralight airplanes do not have to be registered with the Federal Aviation Administration, nor is the operator required to have a pilot's license. Until recently these exemptions were granted only for craft that could be launched by a person on foot, as a hang glider is. As ultralights evolved, however, their larger engines and higher unloaded weight called for wheeled landing gear. Last fall the FAA set in motion a proceeding intended to establish clearer rules on what type of plane will be exempt. If the recommendations of manufacturers and other leaders in the industry are accepted, the primary criteria will be a maximum empty weight of 220 pounds and a maximum wing loading of three pounds per square foot. With these constraints the exempt craft would have sufficient structural strength and would land at a speed of less than 30 miles per hour, a necessary condition for easy handling.

Most of the models now available have an empty weight of about 200 pounds. The wingspan is 30 feet or more, the cruising speed about 50 m.p.h. and the stalling speed about 25. The glide ratio (the amount of forward movement for each foot of descent) averages 9 : 1 and the rate of climb is 500 feet per minute or more. Most of the craft can lift more than their empty weight, meaning that the pilot and the fuel can have a combined weight of more than 200 pounds.

In retrospect it can be seen that the ultralight airplane has its origins in the first attempts of people to fly. Otto Lilienthal of Germany made more than 2,000 flights during the 1890's in what were essentially hang gliders. Lawrence Hargrave of Australia designed and flew model airplanes powered variously by rubber bands and compressed-air and steam engines. He also invented the box kite, which served as the basis for all the externally braced biplanes made later.

In the U.S., Octave Chanute, who in 1894 had written the aeronautical classic *Progress in Flying Machines,* designed a hang glider based on the box kite and incorporating a Pratt truss, which had been patented in 1844 as a method of bracing railroad bridges. The two wings of Chanute's glider were connected by vertical posts braced by crisscrossing wires in both longitudinal and lateral planes, forming a rigid but lightweight structure that became the choice of the Wrights and all future designers of biplanes. The glider also included an aft tail assembly for stability and a curved-section airfoil for improved lift.

Augustus M. Herring, who had been an assistant to Chanute, was probably the first to fly a powered ultralight aircraft. He built a heavier version of the Chanute biplane hang glider (a glider he had helped Chanute with and had flown for him), mounting a two-cylinder, compressed-air motor ahead of the lower wing to drive two five-foot propellers mounted in tandem, one ahead of the wings and one behind them. On October 11, 1898, Herring made his first powered flight at St. Joseph, Mich., traveling about 267 feet in the air against a head wind approximating 25 m.p.h. He could control the glider only by shifting his weight. A few days later he made another flight. Satisfied that he had proved the feasibility of powered flight, he went on to design a steam engine and a larger aircraft, all of which were destroyed by fire in 1899. Later he organized the Herring-Curtiss Company, the first firm to manufacture airplanes in the U.S.

When the Wright brothers succeeded in piloting their "Flyer" on December 17, 1903, they achieved the first powered flight in which the pilot could control the craft by moving aerodynamic surfaces rather than by shifting his weight. The Flyer was a direct ancestor of today's ultralight airplanes. In succeeding years several other forerunners appeared: the Demoiselle of Alberto Santos-Dumont in 1909, the first truly professional ultralight of D. W. Huntington after World War I, the White Monoplane in 1920, the English Electric Wren in 1923 and the French Pou-du-Ciel in 1935. None of them achieved wide commercial success.

LARGE VARIETY of ultralight airplanes now available is suggested by the 10 versions on the opposite page. Each weighs about 200 pounds and has a wingspan of about 32 feet.

Scientific American July 1982

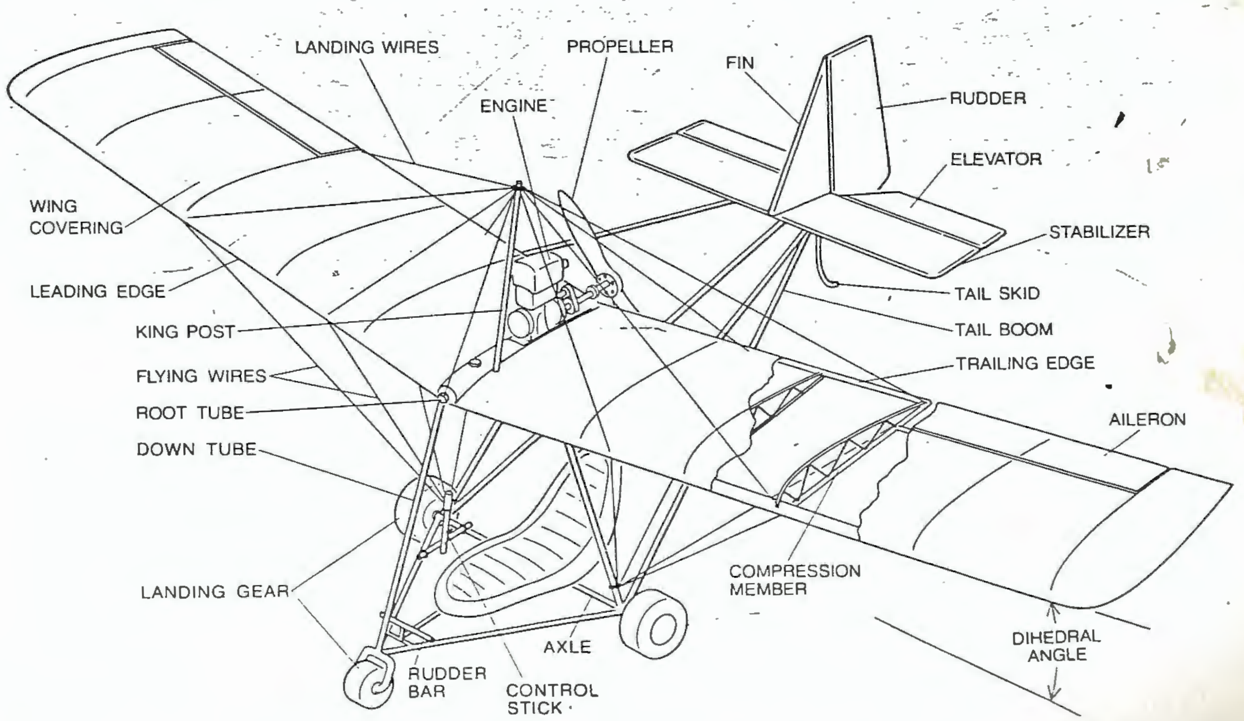
The first modern ultralight airplane was made in Wisconsin in the winter of 1974–75 by John Moody, an electrical engineer and a hang-glider pilot. He mounted a 12-horsepower Go-Kart engine on his Icarus II biplane hang glider. His aim was only to be able to climb to altitudes where he could fly the craft as a hang glider, soaring and gliding with the engine turned off until he needed to climb again. It was not long, however, before a good many of those who followed his lead began to realize that the addition of an engine to a hang glider created a new kind of craft: a small airplane that could be flown independently of the natural lift required for a hang glider alone.

Other hang-glider designs were soon adapted to power. One adventure of this type demonstrated that there is more to making a successful ultralight airplane than just bolting a small engine to a hang glider. It involved the Rogallo wing, a hang glider adapted from a triangular kite patented by Francis M. Rogallo and his wife in 1951. At first the engine was bolted to the king post on Rogallo wings being adapted for power. The high thrust line (the direction of propulsion) of that location proved to be disastrous at times when the force of gravity was not acting on the pilot. In this zero-*g* situation the high thrust line created a nose-down pitching moment the pilot could not counteract. (In normal flight, when the wing is under a positive *g* loading, a shift of the pilot's weight is effective as a control, but in zero *g* the pilot in effect has no weight.) With the nose down the sail began to luff, or flutter, and the glider was forced into either a dive that could not be stopped or an inverted loop that was likely to cause structural failure. Fortunately this dangerous flaw in design was corrected by a lower thrust line before the powered Rogallo wing was put on the market.

The most popular bolt-on engine installation for the Rogallo wing positioned a pusher propeller at the aft end of the keel, which is the center tube of the wing. The rig consisted of a Go-Kart engine mounted above the pilot's head and a long shaft running parallel to the keel. The same unit could be bolted to almost any flexible-wing hang glider. A glider thus fitted out was launched from level ground on foot, that is, by a pilot who held the rig over his head and ran into the wind. Since the thrust line was still higher than the center of gravity, flight in turbulent conditions was not recommended because the craft tended to become longitudinally unstable with the engine running. In calm conditions, however, the arrangement was workable. The rig was employed primarily to gain altitude for soaring rather than to cruise under power.

Until 1977 most ultralight airplanes received their thrust from a Go-Kart engine turning a propeller bolted directly to the engine shaft. The arrangement was simple and mechanically trouble-free, but the engine ran at such a high number of revolutions per minute that the propeller had to be quite small (about 28 inches in diameter) in order to keep the propeller tips from exceeding the speed of sound. As it was, the propeller turned at more than 9,000 r.p.m., quite close to sonic speed, with the result that the propeller noise was extremely loud and the propulsive efficiency was only about 50 percent. The performance of the early powered hang glider was therefore quite marginal. The cruising speed was only slightly higher than the stalling speed, and the rate of climb was a dangerously low 100 feet per minute. Furthermore, the engines themselves were short-lived because they had to run at such high speeds in order to deliver enough power. It seemed clear that the ultralight aircraft would not gain wide acceptance until the level of performance was improved.

An enterprising experimenter, Charles Slusarczyk, approached the thrust problem in a scientific way. Aware that a propeller is most efficient when its tips are moving at a rate well below sonic speed, he devised a reduction-drive system for powered hang gliders; it was patented last year. His idea was to move a large volume of air as slowly as possible through the disk formed by



COMPONENT PARTS of a generalized ultralight airplane are identified. The craft represents the most recent stage of design in that it incorporates an independent three-axis control system: pitch (the up and down movement of the nose) is regulated by moving the control stick back and forth, roll by moving the stick from side to side (making one aileron go up and the other down) and yaw by operating the rudder bar with the feet. An ultralight airplane with this control system is flown in much the same way as a heavier airplane.

the turning propeller while minimizing the drag from compressibility that absorbs a great deal of power near sonic velocity. The result is a vast improvement in thrust and efficiency and a substantial reduction in propeller noise. Nearly all contemporary ultralight aircraft incorporate a reduction-drive propulsion system that gets superior performance out of a small engine. A typical figure for today's reduction-drive transmission is 10 pounds of thrust per horsepower.

Before long the Go-Kart engine was largely replaced by the snowmobile engine, which has a larger displacement and runs at a lower r.p.m. The tuning of the engine is modified from its snowmobile specifications, thereby enhancing its thrust, improving its reliability and increasing its expected service lifetime. Typically the carburetion is reduced or the compression is lowered; sometimes both are done.

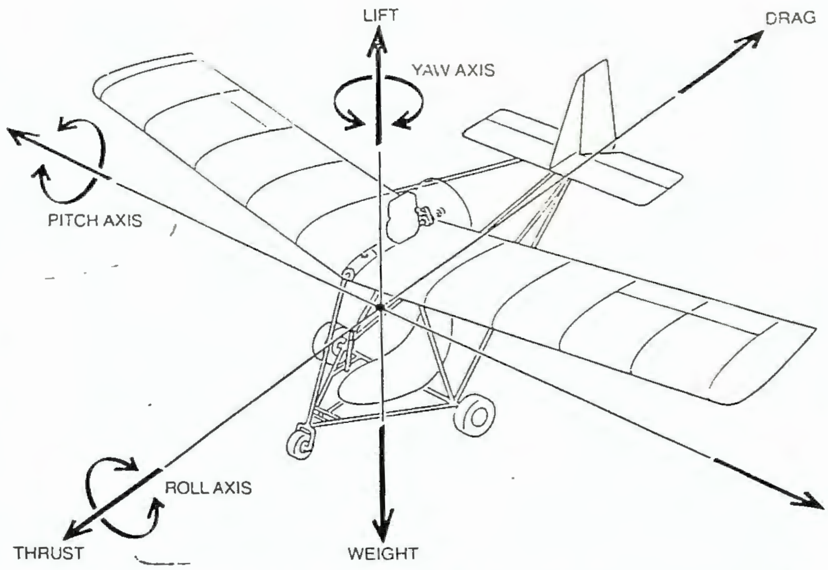
A change resulting from the switch to snowmobile engines was the wheeled landing gear. A hang glider with a direct-drive Go-Kart engine had an empty weight of about 100 pounds and could be launched on foot. The snowmobile engine, the associated reduction-drive components and a strengthening of the frame brought the empty weight to something over 160 pounds and made launching on foot dangerous.

The incorporation of landing gear made for a complete ultralight airplane. Once landing gear was accepted it was possible for engineers to design an ultralight craft around the propulsion system instead of simply bolting an engine to a hang glider. The result was a new generation of designs, most of which moved the new aviation away from its origins in the powered hang glider and toward the "little airplane."

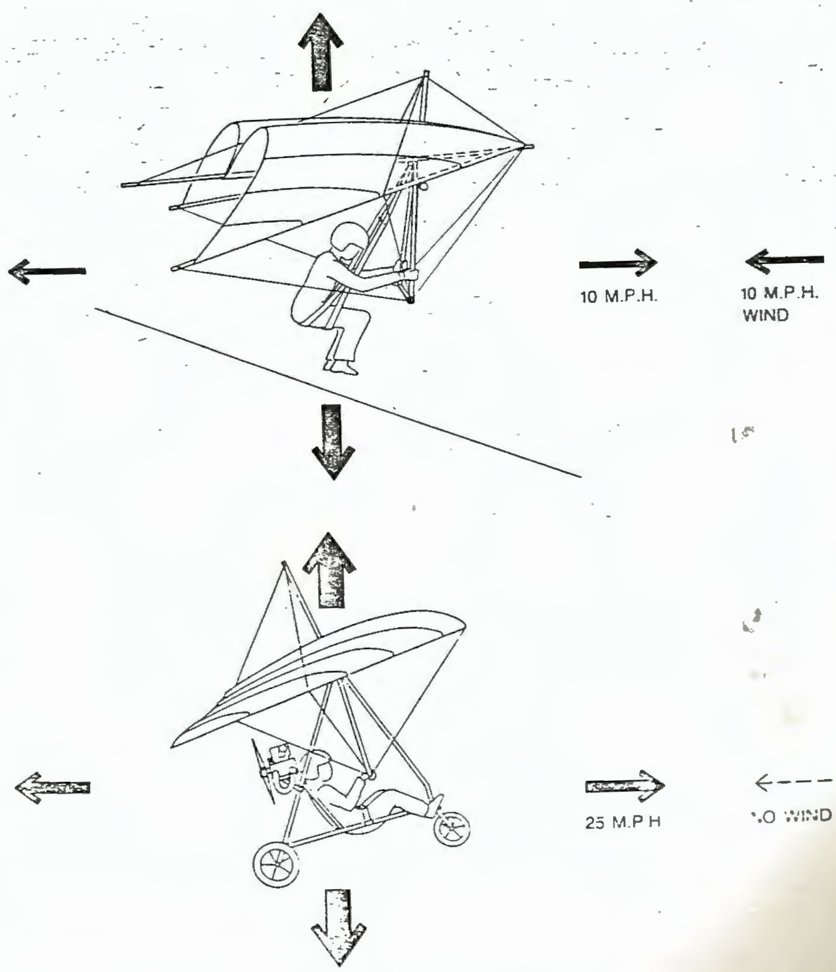
The ultralight aircraft of today can be grouped in four categories, which reflect the basic construction embodied in each design: Rogallo, cable-braced, strut-braced and cantilevered. The order of the grouping also approximates the relative level of performance of each type, particularly with respect to the top speed.

The Rogallo types include not only the foot-launched versions with a bolted-on engine but also the craft known as a trike. A trike (from tricycle) is a pyramidal tubular frame that holds the engine, the pilot's seat and the landing gear. The entire unit is bolted onto a Rogallo-wing hang glider. As a result of this arrangement the owner has in effect two aircraft: a hang glider and an ultralight airplane. In either form the method of flying is the same: the pilot pushes and pulls on a control bar for pitch and shifts his weight to one side or the other to make the craft bank.

One current ultralight airplane, the Eagle, incorporates a hybrid Rogallo wing plus a canard. The main wing is a



FOUR FORCES that act on an aircraft in flight are lift, weight, thrust and drag. Lift is provided by the pressure difference of the air around the wings developed by the flow of air over them. Weight is a reflection of gravity. Thrust is provided by the propeller. Drag results from a variety of forces that tend to hold the airplane back. Pitch, roll and yaw axes are also shown.



FORCES ON TAKEOFF are indicated for a hang glider (*top*) of the Rogallo-wing type and an ultralight airplane (*bottom*) also incorporating a Rogallo wing. The hang-glider pilot takes off by lifting the glider over his head and running downhill into a fairly brisk head wind. The lift and thrust are much weaker on the hang glider than they are on the ultralight airplane.

Rogallo wing that has been modified by the insertion of ribs into the sail and the addition of drooped "tip draggers," or rudders, at the wing tips. The canard is an inflexible wing with an elevator (a movable flap) that serves to control pitch. Pitch control is augmented by the ability of the pilot to shift his body fore and aft.

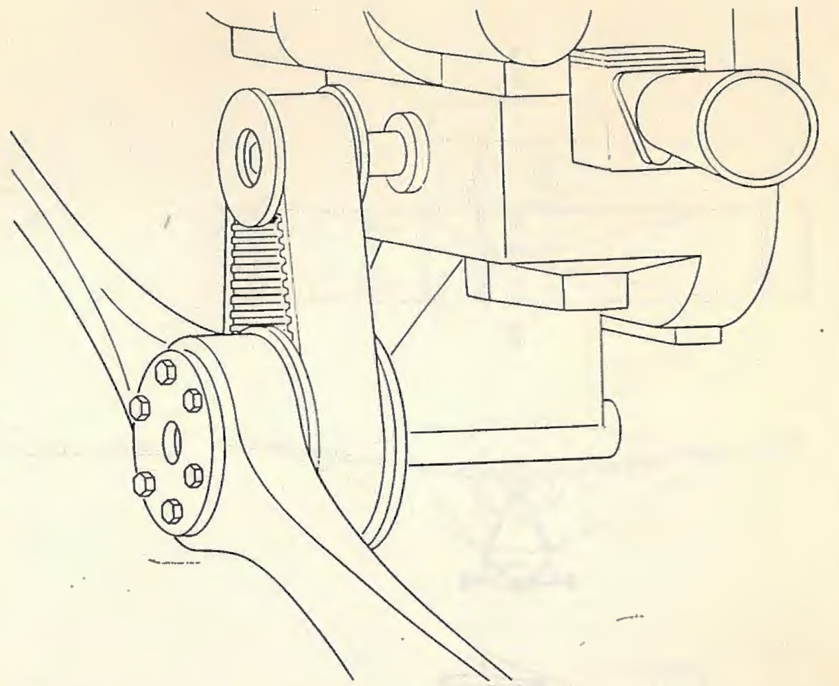
Most contemporary ultralight airplanes are in the cable-braced category. A typical arrangement consists of a pyramidal tubular frame surrounding the pilot and a tricycle landing gear attached to the frame. A ladder-frame wing is connected by a pin to the top of the pyramid and braced by cable to the bottom of the pyramid and to a king post above it. Another tube arrangement runs aft of the wing and holds the tail, which is also braced by cable to the pyramid, the king post and the wing.

The engine is usually mounted in the center section of the wing. A reduction-drive transmission conveys the power to a pusher propeller. Envelopes of presewn Dacron slip on over the framework of the wing to create the surface that provides lift. On the upper surface of the wing preformed aluminum ribs are inserted into pockets to create an airfoil of curved shape, which enhances lift. The lower surface is flat or slightly cambered to compensate for the fact that in flight the air tends to push the surface upward. On some designs only the upper side of the wing has a Dacron "skin." Such a craft is slower than one with a double-surface wing.

The strut-braced construction is gaining in popularity as designers move to improve the aerodynamics of the ultralight airplane. The group includes a fairly wide variety of wing structures. In the simplest designs a basic ladder-frame wing is covered with a presewn Dacron envelope and ribs are slipped into the upper surface. The most advanced designs incorporate a main spar, made of aluminum tubing with a *D*-shaped cross section, that also serves as the leading edge of the wing. The ribs are made of either aluminum or a composite consisting of a foam core and a strong shell of aluminum or fiberglass. Fuselages range from simple tubular pyramids to partly enclosed structures made of foam-and-fiberglass components.

The planes of the fourth group are made in much the same way but have separately cantilevered wings, that is, a wing on each side of the fuselage supported only by its attachment to the fuselage. The cantilever design results in the most streamlined of the ultralight craft and also in the closest resemblance to a conventional light airplane. Another of the virtues of a cantilevered ultralight is that it takes the least time to assemble once it is at its takeoff site.

The controls of ultralight airplanes have also evolved significantly in recent years. When such a craft was made by simply bolting an engine onto a hang glider, control often consisted of nothing more than shifts of the pilot's weight. A few craft had in addition some rudimentary aerodynamic controls, that is, surfaces the pilot could move to affect pitch, yaw and roll. Hang-glider pilots found these familiar arrangements adequate, but to people trained to fly standard airplanes they were strange and confusing. The designers of ultralight aircraft soon recognized the problem and began developing suitable aerodynamic controls. Today it is unusual to find an ultralight airplane that depends in any way on the shifting of weight by the pilot for control.



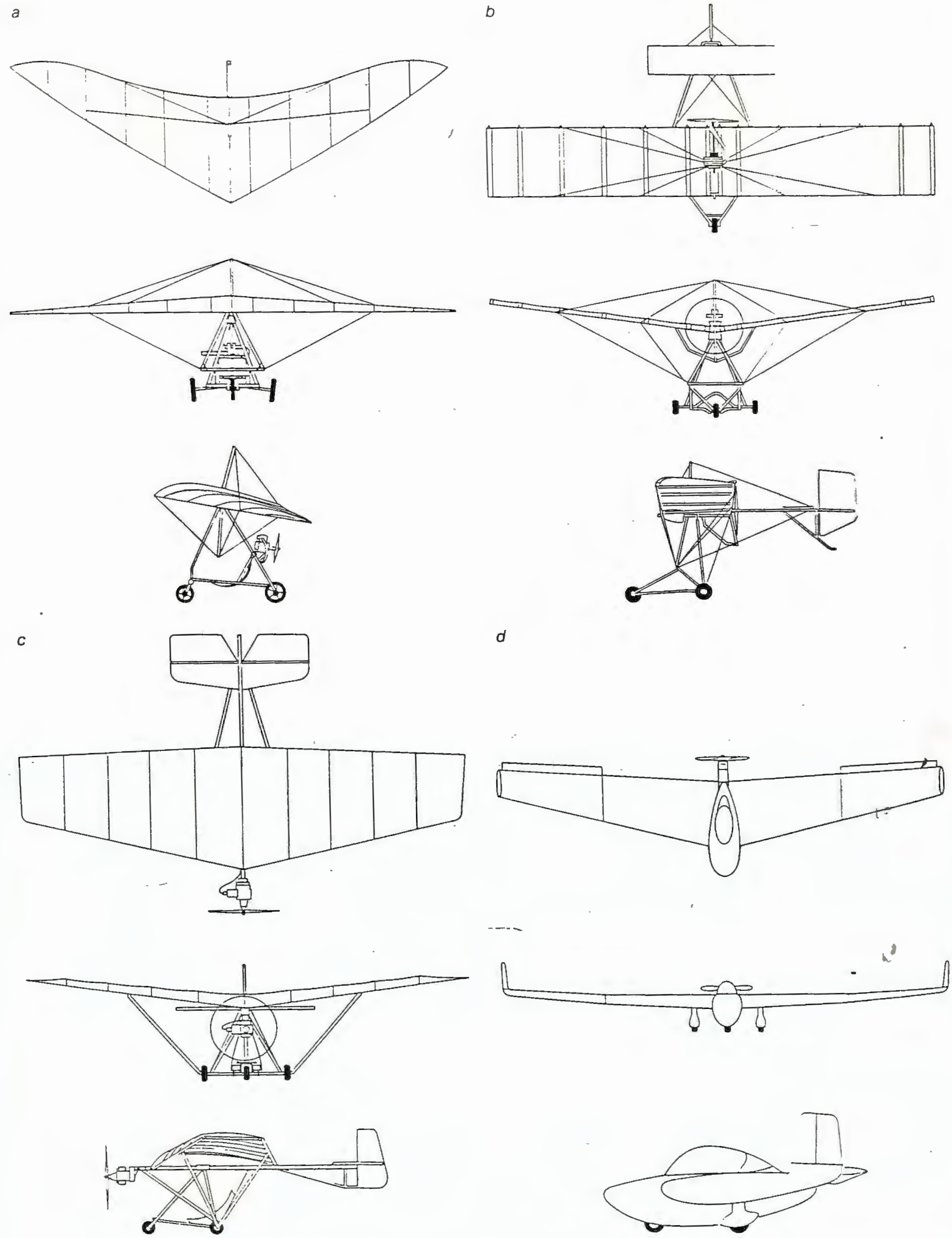
REDUCTION DRIVE, patented last year by Charles Slusarczyk, greatly improved the thrust and efficiency of propellers on ultralight airplanes. A toothed belt transmits power from a small pulley on the drive shaft to a larger pulley on the propeller shaft. A typical reduction-drive transmission of this type provides 10 pounds of thrust per horsepower. With direct drive the propeller tips ran at almost the speed of sound, which was inefficient and extremely noisy.

The first modern ultralight airplane, the powered Icarus II hang glider, had a hybrid control system because that was how the glider was controlled before Moody thought of adding an engine. The pilot, who was suspended prone in a harness, controlled the pitch and therefore the speed by moving forward or backward. He could also move the tip draggers to make the craft yaw and thereby induce a roll. The wings on the inside of a turn lost speed and therefore lift, whereas the outer wings gained speed and lift, generating a net rolling moment and a turn. The simultaneous deflection of both tip draggers increased the aircraft's drag and so served as a means of controlling the glide path.

Another hybrid system was employed in the Quicksilver, which had appeared originally as a hang glider in the early 1970's. The pilot was suspended in a swing and could therefore shift his weight fore and aft and from side to side. To increase the turning capability of the aircraft lines were connected from the harness to the rudder, so that a sideward shift by the pilot deflected the rudder, causing a yaw and thus a roll. The system was workable, but it was still a weight-shift scheme and licensed pilots did not accept it.

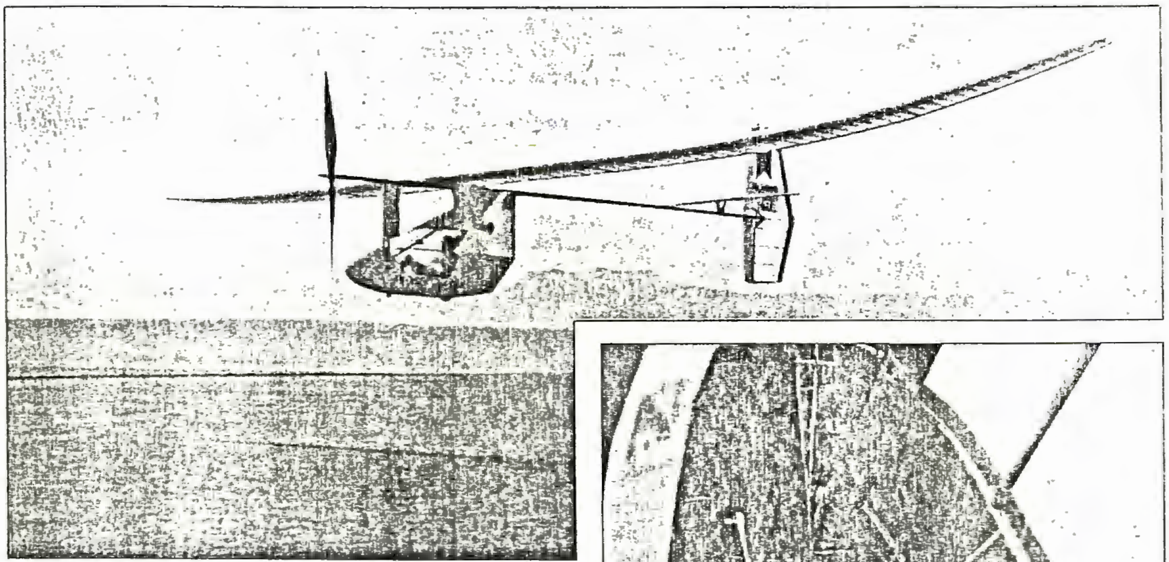
The first major advance in control systems appeared in the first true ultralight aircraft (as distinguished from the powered hang gliders). The new idea was a two-axis control system. The pilot is held in place by a seat belt and cannot effectively shift his weight. Instead he grips a control stick that is connected to the rudder and its associated elevator. The wings have no movable surfaces. The control stick works partly in the conventional way: forward movement pitches the nose down, backward movement pulls it up. Sideward movement of the stick, however, moves the rudder in the same direction, generating yaw and hence roll. (In a conventional stick-controlled airplane a sideward movement of the stick actuates ailerons on the wings to achieve roll.)

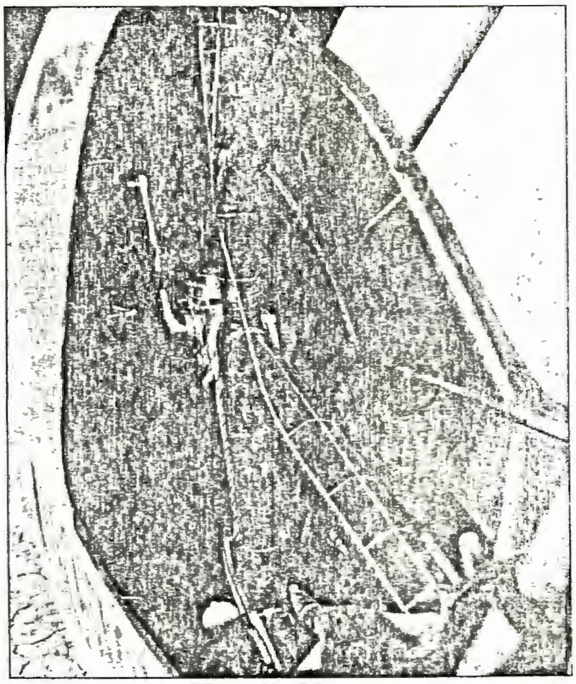
In the two-axis system a deflection of the rudder causes the aircraft to yaw and skid. The velocity of the outside wing increases, generating a rolling moment and its attendant bank. The wings must



FOUR BASIC TYPES of ultralight airplane are the Rogallo (*a*), represented by the Jet Wing; the cable-braced (*b*), represented by the Quicksilver, which is also the airplane shown on the cover of this issue; the strut-braced (*c*), here the Weedhopper, and the cantilevered (*d*), which has a wing on each side of the fuselage supported only by its attachment to the fuselage. The cantilevered craft shown here is a Mitchell U-2. The level of performance of the planes, particularly their top speed, is approximately reflected by the grouping.

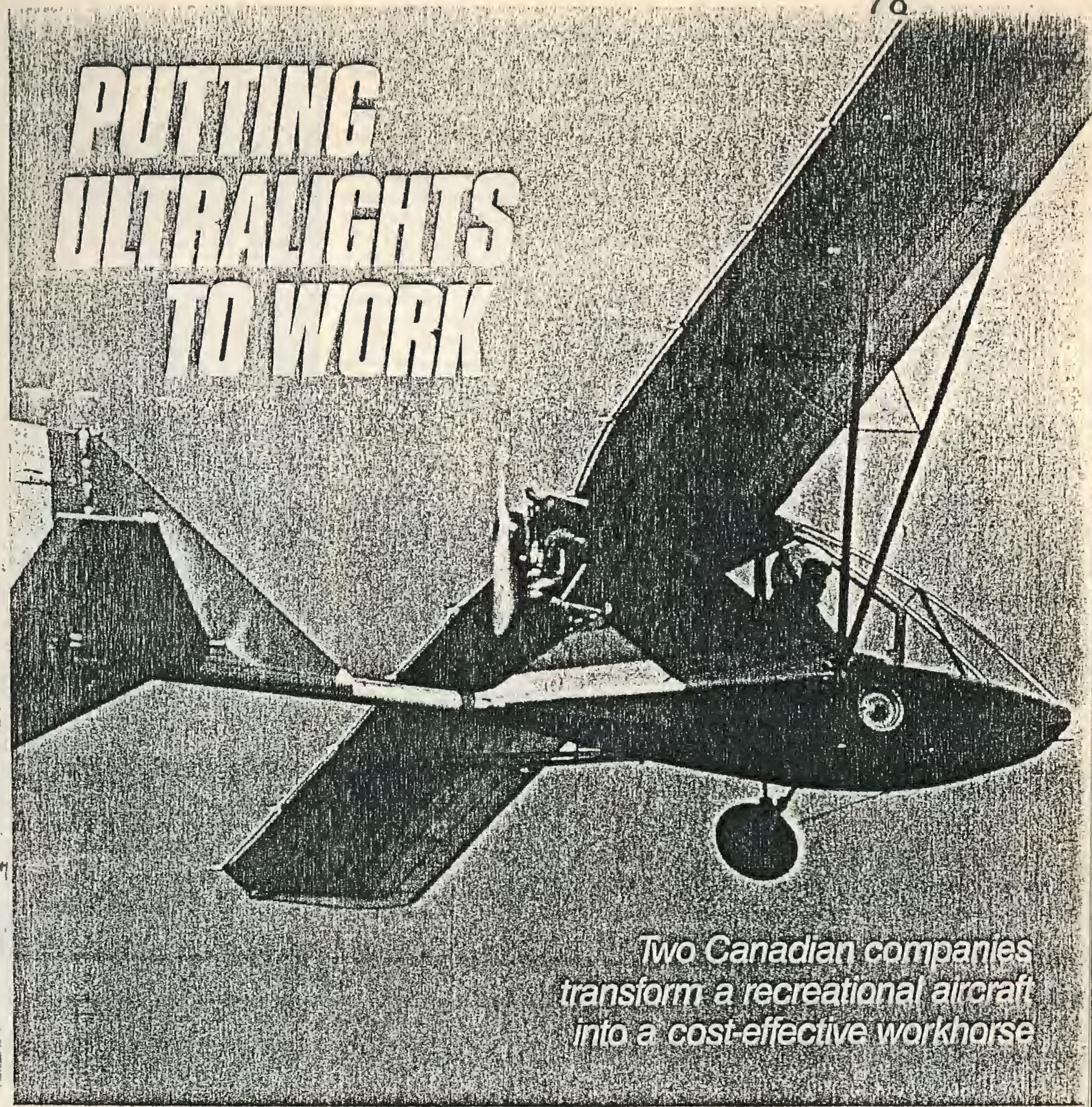
Distance Record Set for Human-Powered Flight





Michelob Light Eagle human-powered airplane set the distance record for its class at 37.3 stat. mi. while undergoing flight testing at Edwards AFB, Calif., on Jan. 22 (photo 1) (AW&ST Jan. 26, p. 30). The airplane—built by the MIT-based Daedalus Project—has a 114-ft. wingspan and 320-sq.-ft. wing area, weighs 91 lb. empty and cruised at 16.6 mph., consuming 0.31 hp. Steering is primarily through an all-flying rudder operated by a right-hand control stick, and roll control is through all-flying wingtips that pivot at the main spar, controlled by the left-hand stick (photo 2). The right-hand stick also controls pitch via an all-flying conventional tail, which project officials said was more efficient than a canard. A carbon-fiber driveshaft connects the pedals to the variable-pitch propeller. Main structural materials are carbon-fiber, Kevlar, polystyrene foam, and .005-in.-thick Mylar skin covering. The project's goal is to recreate Daedalus' mythical flight from Crete to the Greek mainland, a 69-stat.-mi. distance. Next step is to build another aircraft based upon the recent tests and attempt the Crete flight in April, 1988.

PUTTING ULTRALIGHTS TO WORK



Two Canadian companies transform a recreational aircraft into a cost-effective workhorse

by HAWLEY BLACK

It is a perhaps the poorman's perfect aviation package: strong, simple construction, crisp flying characteristics, a reliable virtually maintenance-free power plant, and low purchase and operating costs. That's the promise of two Edmonton-based companies which are fast becoming major exporters of Canadian-designed aircraft.

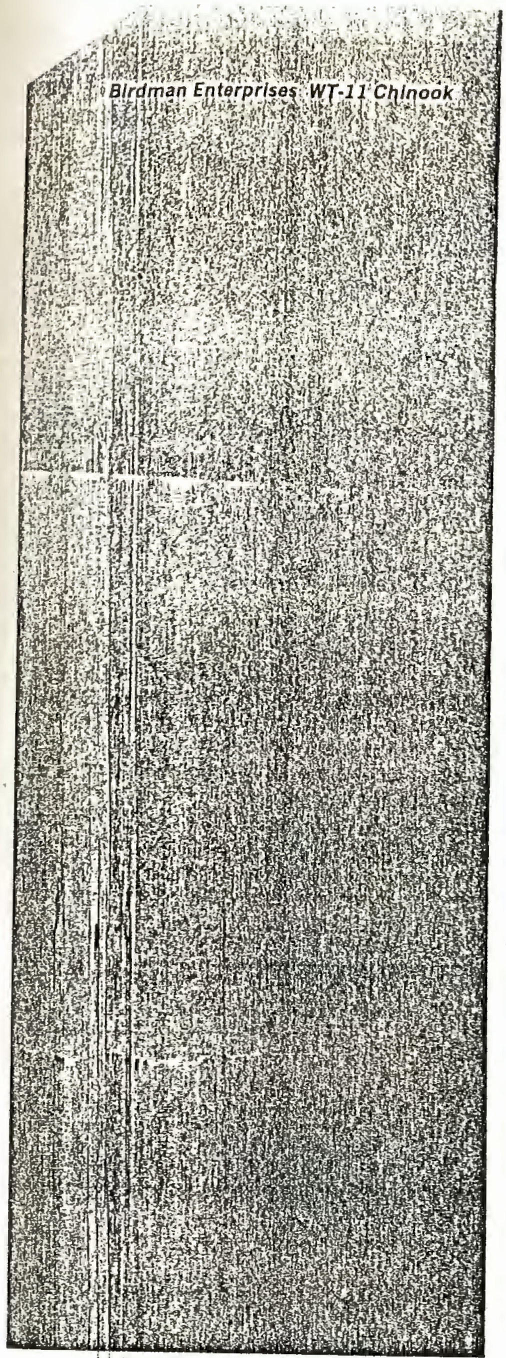
Birdman Enterprises is Canada's longest-established manufacturer of hang gliders and ultralight aircraft, and what it is selling these days is the product of its ten years in this field: the single-place WT-11 Chinook and two-place Chinook 2S ultralights.

Birdman sells its aircraft in Canada and abroad, with exports accounting for 40 percent of its total sales. In 1984, for example, it sold 65 machines in Australia, ten in Japan, five in Israel, and three in Norway, for total export sales of half a million dollars. Indeed, as a result of the work done by this firm, ultralights are moving out of the 'tubes and wire' stage into safe, practical cabin-class flying, says Gerry Vickers, Birdman's marketing manager.

WT Aircraft International is a new company formed by Birdman's former aircraft designer, Wladimir Talanczuk, and a Chinese aerospace firm to manufacture WT-12 Agroplane ultralights in China. The new Canadian-Chinese firm will be building 500 aircraft each year for the next five years, says Andriy Semotiuk, WT's vice-president. Initially, these will be used for agricultural spraying.

Subsequently, the Agroplanes will be available to other countries and for other uses. The project—a joint venture between Wladimir Talanczuk Aircraft Manufacturing Limited and Beijing Chang Feng Aircraft Manufacturing, a leading Chinese aerospace firm—could generate as much as $5 million worth of business over a five-year period for Canadian suppliers, says Semotiuk.

Under the agreement, reached in May 1985, a new firm, WT Aircraft Interna-



Birdman Enterprises WT-11 Chinook

tional, has been formed with an initial capital investment of US $480,000. Of this total, 52.5 percent comes from the Chinese and the rest from Canadian investors. Control will be on an equal basis, although profit will be split according to investment.

The new firm will make the WT-12, the twelfth ultralight designed by Talanczuk, who serves as company president and chief designer. The new machines will be built in Peking using Chinese materials and labour. Talanczuk, who will be based in China for the next year, will oversee the design and quality control of the planes. The new firm also will be responsible for worldwide marketing of the machines.

While conventional spray planes are faster and carry larger payloads, WT Aircraft's WT-12 can land in farmer's field or on dirt roads and can be operated easily for long hours in primitive conditions such as those found in developing countries. Notes Talanczuk: "The WT-12 is capable of flying eight or ten hours a day." The plane can carry the pilot, ten gallons of fuel and 220 pounds of insecticide payload. It also can be quickly converted to other roles such as aerial photography, pipeline and utility corridor maintenance, police work, search and rescue operations, or for livestock or wildlife observation. Combined with low costs, these advantages and its Chinese connection could give the firm an edge in selling to developing nations.

Born in Poland, where he was a Polish air force MiG pilot, Talanczuk came to Canada in 1981, and shortly after joined Birdman Enterprises where he designed the WT-11 and the 2S. Talanczuk studied aeronautical engineering in Poland, and has designed and built almost a dozen new machines.

WT currently is developing and evaluating better spray equipment with the Alberta government. This may be a further spinoff for the firm.

While Birdman has received financial support in marketing abroad under Ottawa's Program for Export Market Development (PEMD), so far WT Aircraft has received no federal or provincial financial help. Notes WT's Semotiuk: "We did it all on our own." Through contacts in New York, Semotiuk met representatives of the China International Trade and Investment Corporation, the Chinese trade promotion agency. In February, 1985, he and Talanczuk flew to Peking at their own expense to meet Chinese aerospace engineers, who in turn visited Edmonton in May to see the prototype.

"We learned that the Chinese work 20-hour days. We'd negotiate non-stop until four in the morning, then at eight they'd be waking us for another round," says Semotiuk.

"The company we have been dealing with employs 10,000 people and makes their rockets and satellites. As far as we know, we are the first Canadian company, and certainly the first small business, to arrange a joint venture with them," says Semotiuk.

Using low cost Chinese labour, the company projects a wholesale price to dealers of $5,000 per machine, from the Chinese export port. This is far below conventional agricultural aircraft which cost between $100,000 and $200,000 and are expensive to operate. Moreover, the machines can be repaired using only simple hand tools, a bonus in Third World countries.

Birdman Enterprises is Canada's largest manufacturer of ultralights. Founded in 1973 to make hang-gliders, the company's MJ-4, MJ-5 and MJ-6 gliders have become a common sight in Canadian skies. Six years later, the introduction of engines turned the hang-gliders into powered machines. In 1979, the company introduced the Altair power package for retrofitting standard kites. The following year it introduced the Atlas, a modified version of the popular Quicksilver design. An Atlas became the first Canadian ultralight to log more than 400 hours.

Since 1983, Birdman has centered its production on the Chinook WT-11 and the Chinook 2S series. Birdman general manager Barry Metcalfe emphasizes that the new machines are not just for weekend hobbyists, but are "serious aerial transportation" that can approach the utility of a light airplane.

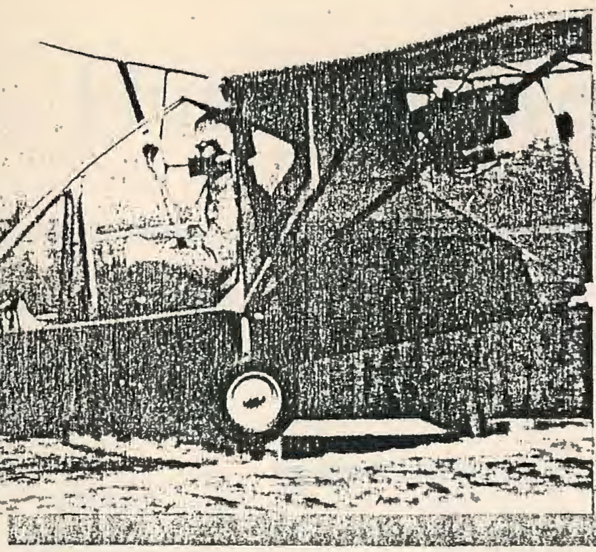
Although most of the aircraft made by Birdman are still used for sport, a growing number are used to perform a variety of tasks. These include surveillance of cattle on the open range, police work, crop dusting, and survey work. The aircraft can be disassembled and readily transported from one site to another. The Chinook's ability to take off and land in short distances and its facility with rough terrain takeoffs and landings also makes it ideal for rural areas with few airstrips. In urban areas, it can use parks, parking lots and even streets.

The Chinook 2S has tandem seating with the pilot and a passenger housed inside a cabin. While this means greater comfort, it also greatly reduces parasitic drag. Designed by Dr. David Marsden of the University of Alberta, the new airfoil designated UA 80/1 (Modified) is especially suitable for ultralights. It is designed to produce high lift and a gentle breakaway at the stall and low drag at the upper end of the speed range. This also means better performance at less power.

The Chinook WT-11 uses 28 horsepower, and the 2S uses 40 horsepower, compared to more powerful engines in other ultralights. This also means gas economy. The single-place WT-11 burns 1.5 gallons per hour. The two-place model burns about two gallons per hour. The plane has a spacious, comfortable cabin, and noise is no problem. Ground-handling is easy, and the takeoff run is 200 feet. Birdman also sells ski and float packages.

The Chinook's wing is a strong two-spar unit with internal lift and drag trussing. It is supported by streamlined lift and jury struts to keep overall height and weight to a minimum. The aileron system is of the gapless or wing wrap type, and an integral part of the outer trailing edge. In the tail, weight has been pared down through the use of a sealed-gap elevator and rudder hinge system.

The aircraft, reports Vickers, can be built in 50 hours from the kit supplied by



Chinook WT 11 277cc Single Place

Specifications

Wing span	35 ft (10.7 m)
Length	17 ft 6 in (5.3 m)
Engine make, model, hp	Rotax 277, 28 hp
Fuel capacity/consumption	5 gal/1.5 gph cruise (22.5 ℓ/6.7 ℓph cruise)
Gross Weight	250 lb (113.5 kg)
Useful load	375 lb (170.3 kg)
Wing loading	3.3 psf
Power/weight ratio	22.3 lb/hp (gross weight)
Design load factors	+6 −3
Price	$7,495 Cdn.

Flight Performance

Cruise speed	50 mph (80.6 km/h)
Stall speed	25-28 mph (40.3-45.1 km/h)
Takeoff run	100-200 ft (30.5-61 m)
Service ceiling	15,000 ft (4,572 m)

Birdman. Once assembled, two people can take it apart in 15 minutes and reassemble it in about the same time. The aircraft can handle cross winds of 20 to 25 miles per hour at 45 degrees and 15 mph at 90 degrees. It starts to stall at 25-27 mph. At 2,500 feet above sea level, it can clear a 50-foot obstacle in 200-300 feet. The two-seat Chinook climbs at 600 feet per minute with two 180 pound individuals on board. It cruises at 55-60 miles per hour. Birdman has specially designed the sturdy undercarriage to handle soft and rough field takeoffs.

Birdman's machines are entirely Canadian made. Its planes are priced in the $7,500 to $8,700 range.

These two Edmonton-based companies, Birdman and WT Aircraft, are making major export sales not only through aggressive marketing but also because they have come up with the next logical step in the ultralight, especially for use in cold climates. Instead of leaving the pilot to freeze in the wind in a cockpit equipped with a seat, controls and little else, they have placed him inside a snug cabin in a style reminiscent of the early postwar Champs and Canucks. And the uses to which these machines may be put also sound a lot like the early days of North American aviation.

HAWLEY L. BLACK is a Calgary-based political/business writer and consultant in business-government relations.

Human-powered Flight

Human-powered aircraft exploit a little-understood flight regime. Aircraft that can negotiate it are fun to fly and may turn out to have uses in reconnaissance and planetary science

by Mark Drela and John S. Langford

During all the centuries in which people dreamed of human flight it was supposed the flier would provide the power, as a bird does. Yet only in the past 25 years—after the development of the propeller-driven airplane and the jet engine as well as the achievement of supersonic flight and space flight—has the human-powered aircraft come into its own. Its arrival is due to the development of a combination of crucial technologies: aerodynamic, propulsive and structural. Equally important was a somewhat earlier achievement: making the craft adequately controllable by a pilot for whom the task of generating a large amount of mechanical power is distracting. The craft have now reached a stage where some applications for the technology can be envisioned.

Human-powered aircraft probably would not have reached this stage without the stimulus supplied by a series of competitions sponsored by a few organizations and individuals. The first one, which took place in France between 1912 and 1922, was a project of the Peugeot company. It resulted in aircraft that were really only jumping bicycles: the operator pedaled hard to get up speed on the ground and then the winged craft would glide through the air for about 12 meters. Once the craft was airborne it had no means of propulsion.

In 1935 the German aircraft *Mufli* went a step further: the pilot was able to drive a propeller after a catapult takeoff. Apparently the power requirement for level flight was more than the designers could achieve. The pilot could produce only enough power for an extended glide, the longest of which was 712 meters. *Mufli* competed for a prize of 5,000 marks offered by a group in Frankfurt for the first human-powered flight around two pylons 500 meters apart. Similar prizes were also offered in Italy and the U.S.S.R.; all went unclaimed.

The most famous competitions, and the ones that have led to genuine technological progress, have been sponsored by Henry Kremer, a British industrialist. In 1959 he offered a prize of £5,000 to the first entrant who could fly an aircraft around a one-mile, figure-eight course under human power alone. Eighteen years had passed and the prize money had increased tenfold when Bryan Allen of the U.S. successfully flew *Gossamer Condor* around such a course.

Kremer subsequently offered the largest prize in the history of aviation: £100,000 for the first human-powered flight across the English Channel. Again the winner was Allen, who pedaled *Gossamer Albatross* across the 21-mile strait between Folkestone and Cape Griz-Nez on June 12, 1979.

Both *Condor* and *Albatross* were large, fragile craft that became unmanageable in all but the gentlest breezes. Their success did not lead to widespread activity in human-powered flight. Four years after the Channel crossing Kremer responded by sponsoring another competition intended to make human-powered aircraft faster and thereby smaller and more practical. This time the goal was to achieve a relatively high speed around a triangular course of 1,500 meters. The prize was £20,000 to the first contestant who could complete the course in less than three minutes—a pace that implied a speed of about 32 kilometers (20 miles) per hour. Frank P. Scarabino of the U.S. won this prize in May, 1984, flying *Monarch*, a craft designed and built at the Massachusetts Institute of Technology. Prizes offered by the Royal Aeronautical Society are now available for flights that better the existing record by at least 5 percent; three such prizes have already been awarded.

Discounting stunts and turn-of-the-century winged bicycles, some 60 human-powered aircraft have been built. Most of them were inspired by the Kremer competitions. The designs can be grouped roughly into three generations, according to characteristic sets of aerodynamic and structural concepts [*see illustration on page 125*]. The

HUMAN-POWERED AIRCRAFT completes a speed trial at Hanscom Field in Massachusetts. The craft is *Monarch B*, designed and built at the Massachusetts Institute of Technology. The pilot is Frank P. Scarabino.

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craft of the first generation were conceptually based on sailplanes (motorless gliders). They could make only straight-line flights, few of which exceeded one kilometer.

The second generation includes the first vehicles capable of sustained and controllable human-powered flight. *Gossamer Condor* is the best-known of them. It was built in California by a team led by Paul MacCready, Jr., and now is on display in the Smithsonian Institution's National Air and Space Museum. A lesser-known but somewhat more rugged craft is *Chrysalis*, a biplane built by students at M.I.T. in 1979. Second-generation craft have unusual configurations because the designers went beyond conventional ideas of what an airplane should look like.

Third-generation aircraft have been built for the speed competition and so are much smaller. Externally they look something like the first-generation craft, but they incorporate modern structural and aerodynamic technology and reflect the experience accumulated through the design and operation of the second-generation machines. Because of a provision in the rules of the speed competition, some of these machines also have an energy-reserve capability. Such a system enables the pilot to store his own energy in the craft for a short time before a flight (usually by pedaling a generator to charge batteries) so that he can draw on it during the flight. The machines are also considerably more sophisticated than their predecessors. For example, the pilot of the M.I.T. *Monarch* can tune the propeller electronically, thereby modifying the requirement for the speed of pedaling or the output of stored energy.

Although the specific tasks have differed in each Kremer competition, the designers of all three generations have faced a common problem: how to reduce the power required by the aircraft to the amount available from a human being. The second major problem of human-powered flight has been stability and control.

The power available from a human differs widely according to the person's age, training and motivation. A well-conditioned athlete can produce up to one kilowatt for short periods of time or a few hundred watts for several hours. Surprisingly in view of the many studies made, little conclusive evidence is available on such basic factors as whether it is better for the pilot to be vertically seated or recumbent. In the absence of sound physiological data the design decision is usually made for reasons of aerodynamics, structure or weight distribution.

The power required by an aircraft is the product of its aerodynamic resistance (drag) and its velocity. Low power can therefore be obtained by building a craft with low drag; flying slowly is also a way of reducing the power requirement.

who in 1984 won with this craft a prize of £20,000 offered by Henry Kremer of the U.K. for completing a 1,500-meter triangular course in less than three minutes. The rules of the Kremer competition and succeeding ones sponsored by the Royal Aeronautical Society stipulate that the craft must be at an altitude of at least two meters at the start and finish; the orange streamer being held by two members of the ground crew is two meters high. The crewman at the right also holds a stopwatch, as does an official judge (appointed by the Royal Aeronautical Society) standing in the near background. In winning the Kremer prize *Monarch B* averaged 21.5 miles per hour.

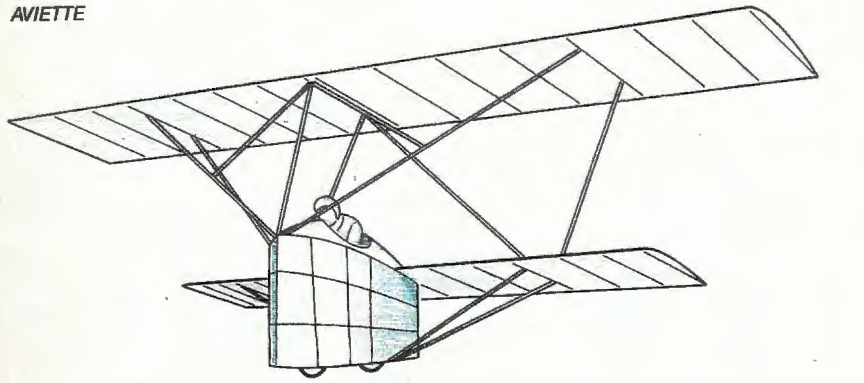
To achieve equilibrium in flight the lift (vertical force) produced by an aircraft's wings must equal the gross weight of the vehicle. Wing area is the most useful variable for the designer. In theory arbitrarily low flight speed and power requirements can be obtained with sufficiently large wings. In practice the wing area is limited by considerations of structural rigidity, weight, sensitivity to wind and the size of the buildings available for storing planes on the ground.

Drag at subsonic speeds has two components of comparable magnitude. One component arises from friction with the air. It is roughly proportional to the exposed area of the plane. The second component is an unavoidable consequence of generating lift and is known as induced drag. Friction drag can be reduced by decreasing the exposed area and employing aerodynamically efficient shapes. Induced drag can be diminished primarily by increasing the wingspan and by flying close to the ground. Both theoretical and practical factors limit the amount of reduction in each case.

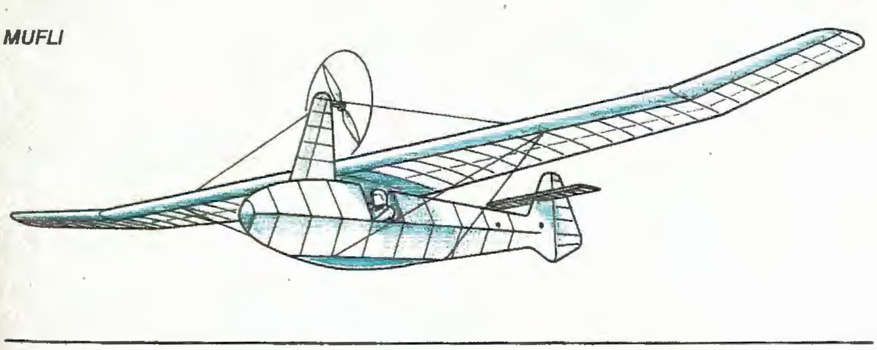
Sailplanes have long represented the epitome of low-drag design, and so it was only natural that the first generation of human-powered aircraft resembled them. Designers essentially sought to reduce the weight of a sailplane by a factor of 10 while adding a propeller and allowing no compromise of aerodynamic principles. All the framework and bracing was internal. One can now see that the task was beyond the capability of the available structural technology. The resulting aircraft were heavy and small compared with the machines of the second generation. The low drag and relatively high flight speed created a power requirement that left the pilot little margin for maneuvering the vehicle.

Second-generation craft embodied the low-speed approach to power reduction. The low-drag advantage of the sailplane was abandoned in favor of external bracing. The resulting increase in drag was offset by substantial increases in wing area and large reductions in weight. A low power requirement was achieved by the resulting low flight speed (approximately 16 kilometers per hour).

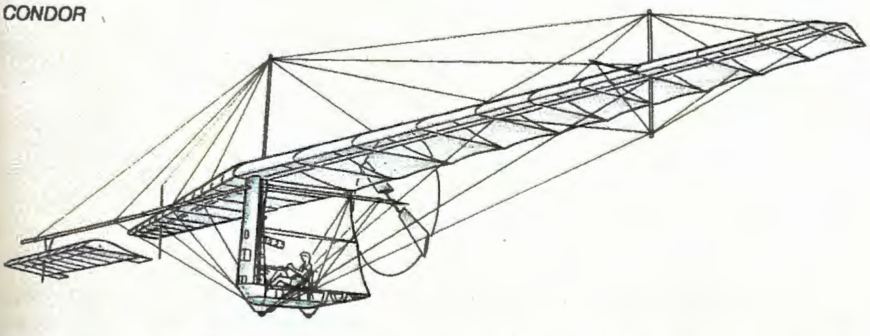
AVIETTE



MUFLI



CONDOR



ADVANCING TECHNOLOGY of human-powered aircraft is marked by *Aviette, Mufli* and *Gossamer Condor. Aviette,* the winner of a competition sponsored by the Peugeot company between 1912 and 1922, was basically a jumping bicycle; it had no source of propulsion after it left the ground and so merely glided for a few meters. *Mufli,* a German craft operated in 1935, had a human-powered propeller, but the pilot could generate only enough power for an extended glide (712 meters was the longest one). *Condor* represents the class of human-powered craft that can fly indefinite distances and are fully controllable. In 1977 *Condor* won the first Kremer competition by completing a one-mile, figure-eight course.

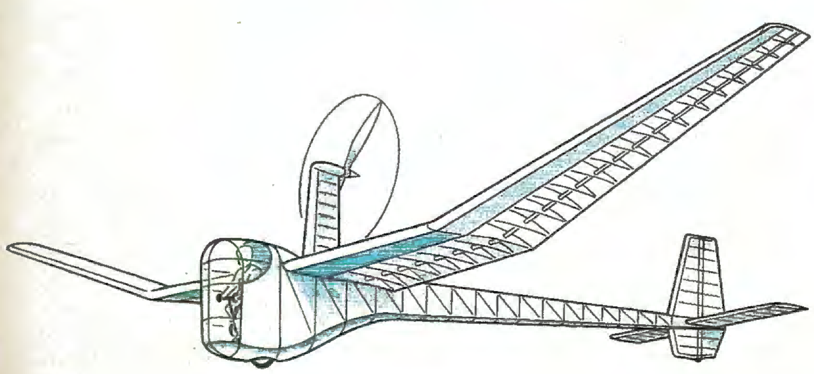
The machines of the second generation also incorporated the first workable solutions to the problem of stability and control. This achievement meant the designers had coped successfully with several effects that are normally not significant in conventional aircraft.

An example is acceleration. To accelerate an aircraft (when, say, it is making a banking turn) some of the surrounding air must also be accelerated. The craft is said to have an "apparent mass" in addition to its own mass. In conventional aircraft this additional component is negligible. In a human-powered aircraft it can be very important. As a result conventional control surfaces cannot generate the forces needed to deal adequately with the apparent mass, and so designers had to take a new approach.

An aircraft must be controlled on three axes: yaw, pitch and roll [*see illustration on page 126*]. Usually a vertical rudder on the tail governs yaw, a horizontal elevator on the tail establishes pitch and horizontal ailerons on the wings determine roll. To begin a turn the pilot rolls the craft by means of the ailerons. This action tilts the lift vector of the wing, providing the side force needed for the turn. The rudder is then employed to "coordinate" the turn, keeping the nose pointed into the airstream. The ailerons control the roll rate, so that they are centered when the turn has been initiated and are used in the opposite direction to roll the aircraft out of the turn.

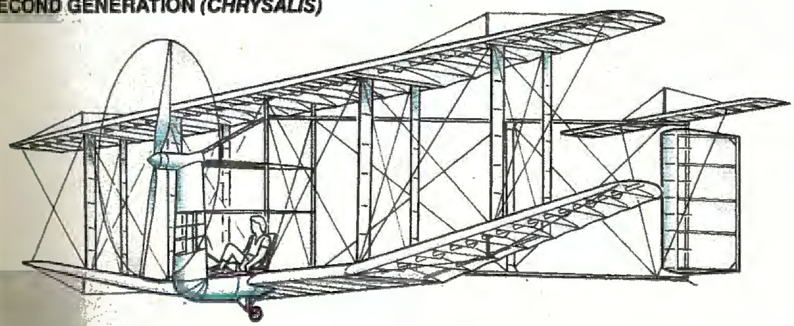
When ailerons are deflected, they impose on the wing a torque that tends to twist it along the axis of the span. The resulting change in the angle of

FIRST GENERATION (*JUPITER*)



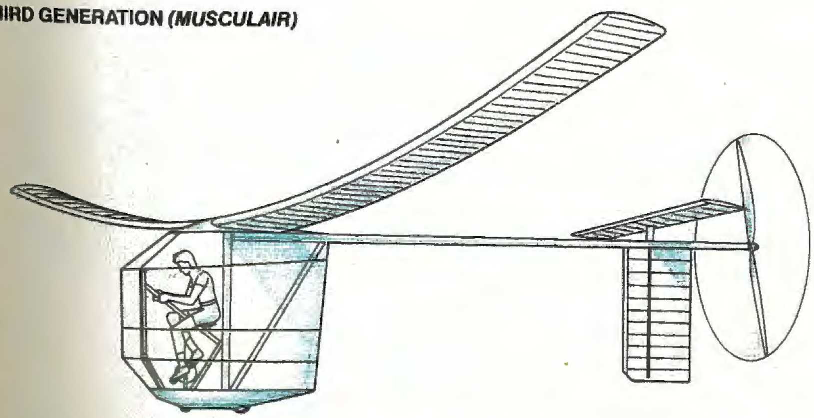
NAME	ORIGIN
MUFLI	GERMANY
PEDALIANTE	ITALY
SUMPAC	U.K.
PUFFIN I	U.K.
McAVOY	U.S.
VINE	S. AFRICA
MAYFLY	U.K.
PUFFIN II	U.K.
LINNET I	JAPAN
RELUCTANT PHOENIX	U.K.
LINNET II	JAPAN
MALLIGA	AUSTRIA
SM-OX	JAPAN
LINNET III	JAPAN
LINNET IV	JAPAN
MERCURY	U.K.
OTTAWA	CANADA
WRIGHT	U.K.
JUPITER	U.K.
TOUCAN I	U.K.
LIVERPUFFIN	U.K.
EGRET I	JAPAN
EGRET II	JAPAN
EGRET III	JAPAN
BURD I	U.S.
AVIETTE	FRANCE
EGRET IV	JAPAN
DEDAL III	POLAND
TOUCAN II	U.K.
STORK I	JAPAN
BURD II	U.S.
BLIESNER	U.S.
OLYMPIAN ZB-1	U.S.
ICARUS	U.S.
SKYCYCLE	U.S.
STORK II	JAPAN
NEWBURY MANFLIER	U.K.
PHOENIX	U.K.
PHILLIPS	U.K.

SECOND GENERATION (*CHRYSALIS*)



GOSSAMER CONDOR	U.S.
CHRYSALIS	U.S.
GOSSAMER ALBATROSS	U.S.
GOSSAMER PENGUIN	U.S.
MILAN '82	JAPAN

THIRD GENERATION (*MUSCULAIR*)



MONARCH	U.S.
HVS	W. GERMANY
BIONIC BAT	U.S.
PELARGOS	SWITZERLAND
MUSCULAIR	W. GERMANY
MONARCH B	U.S.
MAN-EAGLE	U.S.
SWIFT B	JAPAN

GROUPING OF CRAFT into three generations reflects major differences in the technology of human-powered flight. Aircraft of the first generation had internal wood trusswork; they were both heavy and fragile and could make only straight-line flights. Aircraft of the second generation had an aluminum-tube framework and external wires for bracing. These were the first fully controllable craft. Aircraft of the third generation are smaller and speedier. Modern materials such as graphite make cantilevered construction possible.

attack (and hence the lift) at each tip partially negates the effect of the aileron itself. For adequate control of roll the wing must therefore have enough rigidity to resist the twisting torque of the ailerons.

In the first two generations of human-powered aircraft the combination of large apparent mass and torsionally weak wings made ailerons ineffective. The problem was solved for *Gossamer Condor* by means of a canard: a control surface mounted on the fuselage to ride in front of the wing. On *Condor* the canard was tilted, producing a sideward force like that generated by a rudder, thereby achieving the desired yaw. The yawing motion produced a higher airspeed and a higher lift on the outside wingtip and a lower airspeed and lift on the inner one. The lift differential made the craft roll.

To keep the craft from banking too much a pilot flying *Condor* had to pull on the external bracing wires in order to twist the wings, much as the Wright brothers did on their *Flyer* of 1903. The maneuver increased the angle of attack (and hence the lift) on the inner wing and decreased it on the outer one. This action made sustained controlled turns possible.

Because human-powered aircraft of the third generation are smaller, their apparent-mass effects are smaller and the wing can be made considerably more rigid. Ailerons have proved practical for these machines.

We turn now to the three technological developments that have proved crucial to successful human-powered flight. They are high-lift airfoils, efficient propulsion systems and lightweight structures.

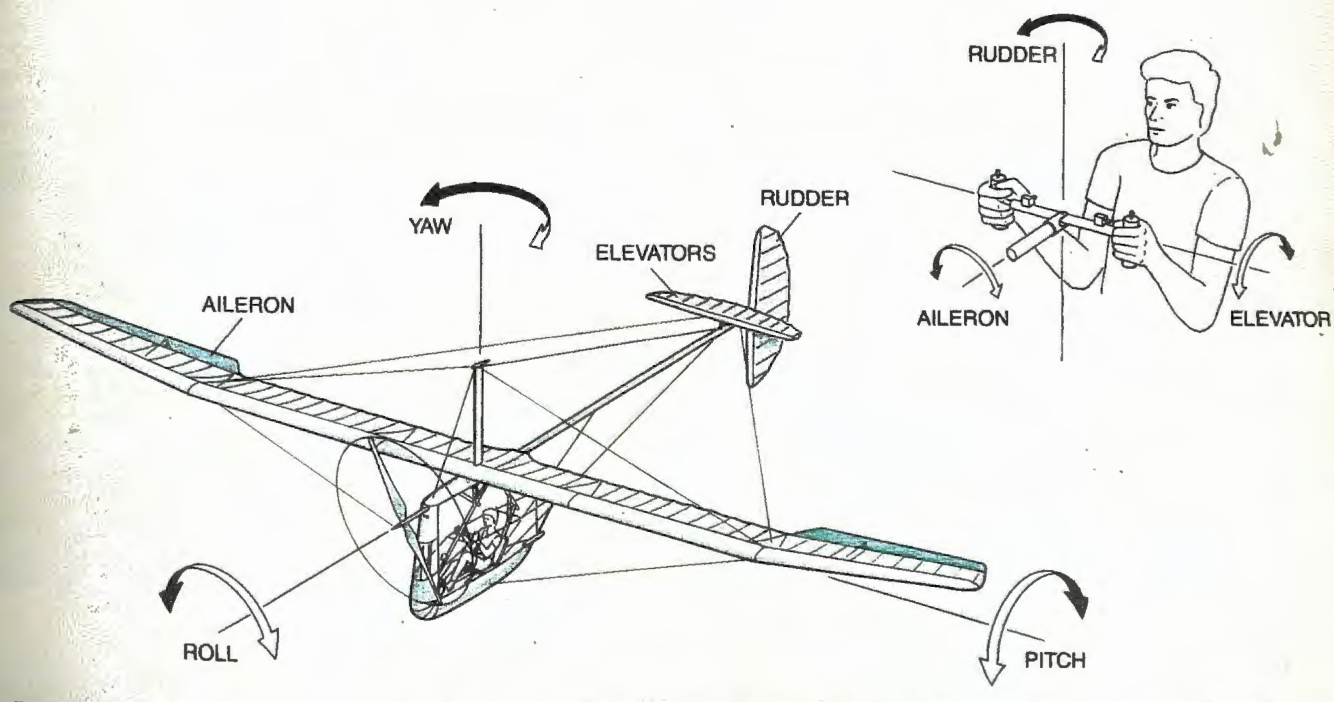
The main aerodynamic surface is the wing. Because it creates most of the drag, its cross-sectional shape (the airfoil) must be as efficient as possible. One measure of an airfoil's efficiency is the ratio of lift to drag ($L:D$). Another performance measure is the "power parameter," which is similar to $L:D$ but gives more emphasis to high lift. The higher the power parameter, the lower the power needed to sustain flight. Because low power is the primary concern in human-powered aircraft, a large power parameter is more important than a large $L:D$. To attain a high power parameter an airfoil must be capable of high lift but must not induce excessive drag.

The airfoil must also have a small pitching moment, meaning that it should tend to remain level along the axis of flight. A large pitching moment generates the same torques about the axis of the wingspan as ailerons do. (This is another reason the wings must be made torsionally stiff.) Higher stiffness invariably adds to the weight of the wing. In addition a high pitching moment destabilizes the aircraft and requires larger tail surfaces, which add weight and drag.

A factor that complicates the design of human-powered aircraft is that they operate in an unusual aerodynamic regime, normally the province of large birds and model airplanes. The regime is formally characterized by its relatively low Reynolds number, a dimensionless figure of merit that takes into account the speed, density and viscosity of the air together with the length of the body aligned with the flow. Typical aircraft operate at Reynolds numbers of between two million and 20 million; a vast store of information on that kind of flight has been built up since World War I. Human-powered aircraft operate at Reynolds numbers of less than one million, a poorly understood region of flight.

The low Reynolds number and the need for high lift, low drag and low pitching moment have required the designers of human-powered aircraft to adapt existing airfoils or to design new ones. The task is to tailor the distribution of pressures on the airfoil's surface. Loosely speaking, two types of airfoil could serve in human-powered aircraft: rear-loaded and front-loaded. The terms reflect the fact that the distribution of pressure on the top and bottom of the wing tends to be uneven, so that most of the load is carried either on the rear of the wing or on the front according to the choice made by the designer.

A typical rear-loaded airfoil offers a large lift-to-drag ratio that prevails through a fairly wide range of speeds and angles of attack. This type works well on sailplanes but not nearly as



THREE-AXIS CONTROL of a typical third-generation craft is achieved solely with the pilot's hands. (His legs are pedaling to provide the power for flight.) He controls roll by means of the ailerons, pitch by means of the elevator and yaw by means of the rudder.

well on human-powered aircraft. Its main disadvantage is its high pitching moment. This disadvantage and others, however, become less severe as the size of the aircraft decreases. The German *Musculair*, a successful third-generation craft, employed a rear-loaded airfoil.

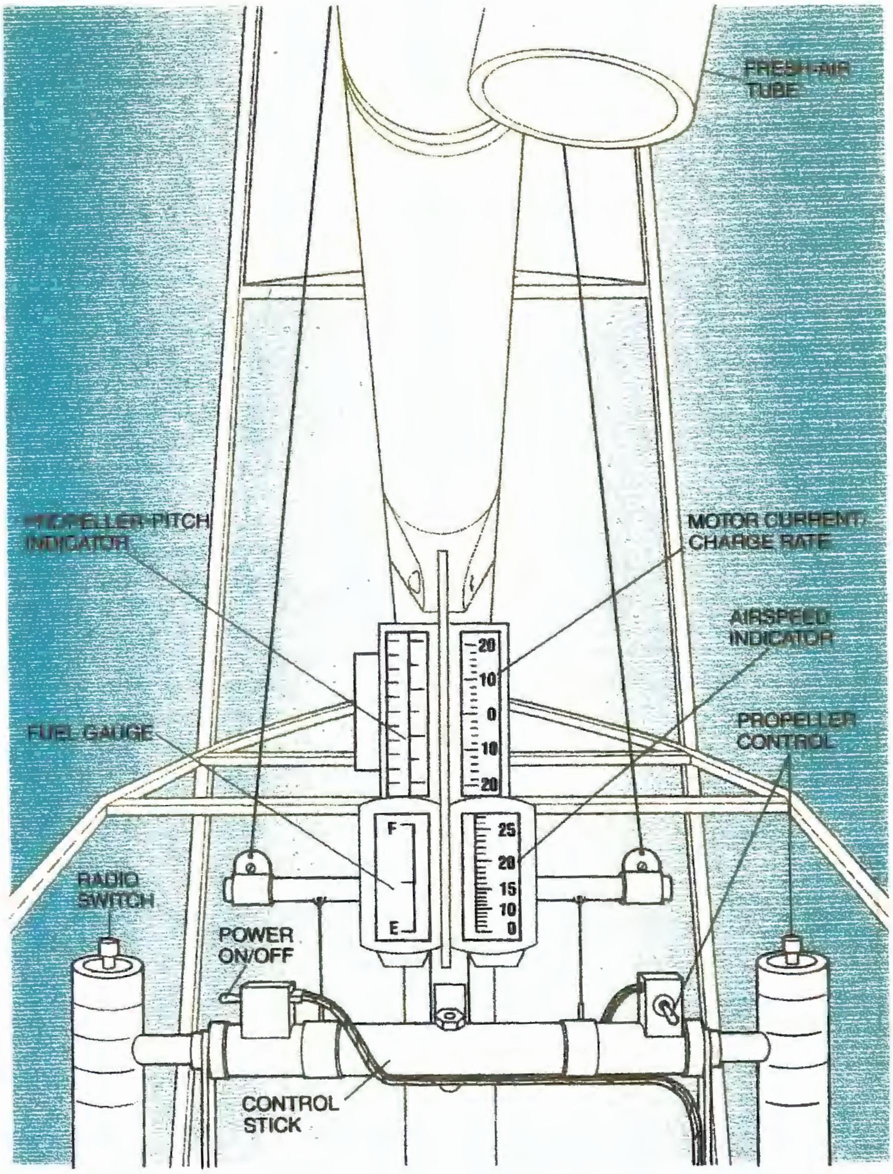
Front-loaded airfoils offer high lift-to-drag ratios and also the highest power parameters, but only over a relatively narrow range of speed and angle of attack. Although those disadvantages make the airfoil unsuitable for sailplanes and most airplanes, it is ideal for human-powered aircraft, which perforce have a narrow speed range because of their limited power. Moreover, the airfoils have low pitching moments; hence a wing with a front-loaded airfoil can be built with a lower structural weight than can a wing with a rear-loaded airfoil.

Propulsion is another area where high efficiency is important in human-powered aircraft. A propeller is by far the most effective means of transforming the mechanical power generated by the pilot's legs into a thrust sufficient to overcome the drag of the machine. One can conceive of other means of propulsion for human-powered aircraft, including flapping wings and jets of compressed air, but they have not yet been successful.

Any propulsive device (with the exception of a rocket) that generates thrust takes in air at flight speed and expels it to the rear at a higher speed as a jet. In the case of a propeller the jet is the slipstream: the air pushed aft of the propeller. A flapping wing pushes back an amorphous mass of air with each stroke.

In every case the jet carries kinetic energy that has been added by the propulsive device and that cannot be recovered; it is eventually dissipated as heat. As the jet velocity increases, the loss from wasted energy goes up faster than the gain in thrust. Thus efficiency dictates a device that takes in a large mass of air and adds to it only a small increment of velocity. This goal calls for a propeller that has a large diameter or for flapping wings that have a large span. (A compressed-air jet is inherently inefficient at the speeds of human-powered aircraft because of its high jet velocity.)

Although the flapping wing can in theory be made quite efficient, it has never been applied successfully to any aircraft powered by a human or carrying human passengers. To achieve high efficiency the wing must be twisted in one direction along the axis of its span on the downstroke and twisted in the other direction on the upstroke. Birds



CONTROL DEVICES of *Monarch B* are shown as the pilot sees them. The current/charge gauge records the rate at which the craft's battery is being charged or discharged; the charging takes place before the flight, when the pilot pedals a generator to store power. In flight he can draw on the stored power by means of the power switch, which actuates an electric motor. The fuel gauge records the amount of charge in the battery. The propeller-pitch indicator reflects the angle of the propeller blades, which the pilot can control by means of the propeller-control switch. By pushing the radio switch the pilot can talk to the ground crew; he can hear the radio at all times. *Monarch's* control stick bears a message of encouragement for the hardworking pilot: "You have great physical powers and an iron constitution."

execute the maneuver quite well, but in a machine the combination of flapping and twisting creates severe mechanical and structural problems that get worse as the size of the craft increases. Hence a propeller is currently the only practical propulsive device for a human-powered aircraft.

The ideal of a large-diameter propeller faces certain constraints in a human-powered aircraft. A large propeller adds weight, which is something the designer is trying to avoid. Beyond a certain size the propeller tips are likely to strike the ground when the aircraft is taking off or landing. Thus the designer cannot achieve maximum efficiency by merely increasing the diameter of the propeller. Instead he must seek to reduce the efficiency-robbing kinetic energy in the slipstream of the propeller by careful attention to the distribution of the load on the blade. Air friction on the blades also influences the design of the propeller. An ample diameter and an optimum design enable a propeller on a human-powered aircraft to attain efficiencies approaching 90 percent.

Structural technology is the feature of human-powered aircraft that has changed the most since the vehicles of the first generation. In those early aircraft intricate trusswork made chiefly of wood provided form and strength. The truss is an efficient structure: it has high ratios of strength to weight and of stiffness to weight. Wood is easily obtainable, easy to work with and relatively inexpensive. Moreover, most of the people who build human-powered aircraft are or were model-airplane enthusiasts, experienced in working with wood.

On the other hand, the wood truss presents several drawbacks. It has so many individual pieces and joints that building one is a labor-intensive project. Mending a broken one is difficult. Moreover, if one truss member fails, the nearby members are put under unusual stress and the entire structure is put in jeopardy. For these reasons the wood truss was abandoned in the second-generation aircraft. Designers relied instead on a primary structure of aluminum tubing that had a large diameter and thin walls; wires provided external bracing.

The tubing was sized primarily to resist compression. External wires took all major bending and torsional loads. (At low flight speeds the drag created by the wires is more than offset by the saving in weight.) The advantage of such a structure is that it has a high ratio of strength to weight and provides excellent rigidity. The absence of wood trusses also made the second-generation craft much easier to repair than their predecessors.

Because third-generation craft are smaller and strong materials such as graphite and graphite-epoxy have become available, designers were able to turn to cantilevered structures that eliminate external wires. Mylar film as a covering skin has also contributed to structural improvement.

The combination of low speed, low altitude and limited power makes piloting a human-powered aircraft a challenging task but one that is within the capability of almost anyone. General-purpose craft such as *Condor* and *Chrysalis* have been flown by men and women ranging in age from the teens to the 60's.

The pilot usually begins by shedding clothes. A jogging outfit and a bicycle helmet constitute the proper attire: extra weight calls for extra power, and sunlight on the transparent covering makes the cockpit uncomfortable when the craft is not moving.

It is hard to get into the aircraft without damaging it. There are few places solid enough to bear one's weight, and so the pilot normally uses stepping platforms and is helped in by members of the ground crew. After running through a preflight checklist the pilot signals to the crew members holding the wingtips and begins to pedal.

The takeoff is surprisingly smooth. Most people flying for the first time are unaware that the craft is airborne until they hear the cheers of the ground crew. The cockpit is noisier than one would expect because of the whirring of the bicycle chain and the cyclic whooshing thump as the blades of the propeller pass the fairing.

In the air the pilot's main task is to concentrate on maintaining a steady attitude and airspeed. If the craft has been correctly trimmed for his weight, only small adjustments of the rudder are necessary. To climb the pilot pedals harder; to come down he or she reduces the pedaling rate.

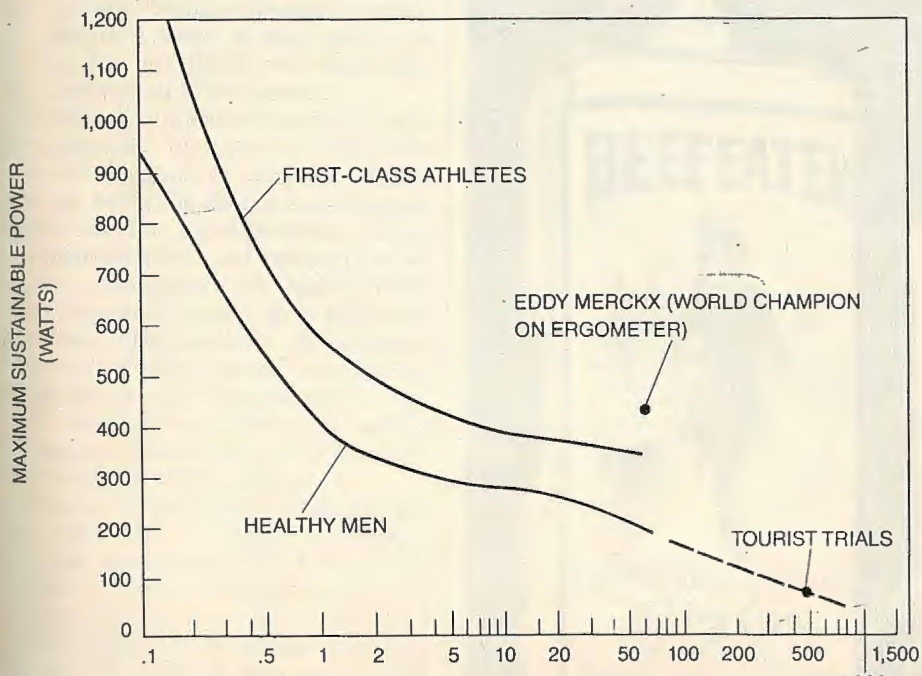
A human-powered aircraft reacts quite slowly to its controls; consequently inexperienced pilots are likely to overcontrol. Even more confusing is the tendency for the aircraft to respond differently on different axes. The pitch response is relatively fast, the roll response agonizingly slow. Making turns around a specific course, as is required in the speed competitions, calls for careful coordination and much practice.

The two primary dangers in flight are stalls and gusts of wind. The craft stalls when the airflow separates from the surface of the wing. The separation usually occurs because the pilot has let the craft's speed fall too low.

The inherently low flight speed makes gusts a special problem. Because the relation between wind speed and the speed of the aircraft is crucial, a gust of only five miles per hour is equivalent to one of 30 miles per hour or more on a small conventional airplane. Striking from the front, such a gust can overload and break the wing; from the rear it can cause a stall. A gust can also change both the flight path and the plane's attitude. Fortunately the low speed and the low altitude combine to make a human-powered aircraft fairly safe; crashes that demolish the airframe usually inflict only cuts and bruises on the pilot.

To land the pilot aligns the craft with the runway and reduces his rate of pedaling. The vehicle glides gently in and touches down softly.

Human-powered flight has been pursued mostly for its own sake, greatly spurred by the incentive of the various competitions. Nevertheless, the technologies that have evolved can be expected to have practical applications in at least three areas: human-powered flight itself, ultralight aircraft and a variety of reconnaissance and observational tasks.



HUMAN POWER varies according to the age, condition and motivation of the person. The range is indicated on this chart. The "tourist trials" line shows values deduced from cross-country bicycle races. One kilowatt (1,000 watts) is the equivalent of 1.3 horsepower. The data are derived from *Bicycling Science*, by Frank Rowland Whitt and David Gordon Wilson.

In human-powered flight the speed competition as it is now set up will continue until 11 more awards of £5,000 each have been won. The result will certainly be faster aircraft, perhaps attaining speeds of as much as 85 kilometers per hour. Such a speed will be difficult to achieve, however, even with highly efficient schemes for storing energy. It remains to be seen whether the proposed prizes will be sufficient to elicit the necessary investment of money and thought.

The Royal Aeronautical Society is examining the possibility of staging additional competitions. They would probably be aimed at making human-powered aircraft more practical and more rugged. At the other end of the spectrum it is now possible (in our view) to build a large, low-power craft that could turn the legend of Daedalus into reality, flying the 96 kilometers from Crete to the Greek mainland at about 22 kilometers per hour.

The relation between human-powered and ultralight aircraft (which are powered by small gasoline engines) is that the former, as they are increasingly designed for speed and utility, become more like the latter. Human-powered aircraft of the third generation cruise on about .5 horsepower and climb splendidly at two horsepower. The engines of today's ultralight aircraft produce from 30 to 50 horsepower. Improvements in the technology of human-powered aircraft can be expected to reduce this gap so that human-powered aircraft can perform some of the tasks now calling for ultralights and ultralights can function at lower power.

The final application has to do with high-altitude operations. High-altitude craft capable of prolonged flights are now being considered as unmanned platforms for reconnaissance, communication relays and sampling work in the stratosphere. A high-altitude craft operates at the low Reynolds numbers characteristic of human-powered aircraft. Hence the technologies developed to increase the structural strength and reduce the weight of human-powered craft will also benefit the high-altitude vehicles.

Eventually these technologies might find application in space. For example, the atmosphere of Mars, even though it is much less dense than the earth's atmosphere, could support winged flight at Reynolds numbers similar to those of human-powered aircraft. A winged, unmanned vehicle (an airborne analogue of *Lunar Rover*) would be an effective platform from which to examine the terrain and sample the atmosphere of Mars.