Evolution of High-Performance Sailplanes

J. Kovács

Presented at the XVI OSTIV Congress, Châteauroux, France (1978)

The purpose of this paper is to outline a quick retrospective on the evolution of high-performance sailplanes and from there attempt to extrapolate the next step that will set the milestone in this today 50-year old evolutionary path. The opportunity is taken to present the suggested formula, which the writer considers to be the next decisive step as far as performance is concerned, represented by the in-flight variable geometry sailplane.

The evolution of the so-called first-line sailplanes from the performance standpoint has not developed at a uniform rate, but has occurred at periodic leaps, induced by technological achievements or by a more intense dedication to this kind of activity.

The most important stages could be classed as follows:

(1) The first impetus could be called the aerodynamic progress stage, marked by the first closed cockpit sailplanes, cantilever wings, fuselage sections composed by conic curves, new (or first) theories to minimize impairing interferences between wing and fuselage (Lippisch, Muttray, etc.), one-piece flying horizontal tail, wing aspect ratio exceeding 20, etc. The maximum expression standing for this leap is the "Fafnir" sailplane (1934), which even at present day seems admirable to me, along with the "Nemere" (1935), "Weihe" (1936) and the superb "Reiher" (1937), most of them produced by the D.F.S. (Deutsches Forschungsinstitut für Segelflug).

(2) The second largest evolutionary leap took place after a rather long interval, taking advantage of the technological progress achieved through the II World War (laminar

Nº	PARAMETER	UNIT	SOURCE (FORMULA)	WITHOUT WATER BALLAST: PIK-20 CLIMB -1-	WITHOUT WATER BALLAST: CHORD RED. GLIDE -2-	WITHOUT WATER BALLAST: SPAN RED. GLIDE -3-	WITHOUT WATER BALLAST: PROPORT. RED. GLIDE -4-	WITH WATER BALLAST (164Kg): PIK-20 CLIMB -5-	WITH WATER BALLAST (164Kg): CHORD RED. GLIDE -6-	WITH WATER BALLAST (164Kg): SPAN RED. GLIDE -7-	WITH WATER BALLAST (164Kg): PROPORT. RED. GLIDE -8-
1	SPAN (b)	m	DESIGN;	15.00	15.00	10.00	12.25	15.00	15.00	10.00	12.25
2	WING AREA (S)	m²	DESIGN;	10.00	6.67	6.67	6.67	10.00	6.67	6.67	6.67
3	ASPECT RATIO (AR)	—	b^2/S; $\textcircled{1}^2/\textcircled{2}$;	22.50	33.75	15.00	22.50	22.50	33.75	15.00	22.50
4	WEIGHT (W_T)	Kgf	DESIGN;	326	326	326	326	490	490	490	490
5	WING LOADING (W_T/S)	Kg/m²	W_T/S; $\textcircled{4}/\textcircled{2}$;	32.60	48.90	48.90	48.90	49.00	73.50	73.50	73.50
6	WING DRAG COEF. (C_{D0W})	—	DESIGN ESTIMATE	0.0060	0.0058	0.0062	0.0060	As per column 1	As per column 2	As per column 3	As per column 4
7	PARASITE DRAG COEF. (C_{Dp})	—	ESTIMATED; $\Sigma S C_{Dp}/S$;	0.0048	0.0070	0.0070	0.0070				
8	ZERO LIFT DRAG COEF. (C_{D0})	—	$C_{D0W} + C_{Dp}$; $\textcircled{6}+\textcircled{7}$;	0.0108	0.0128	0.0132	0.0130				
9	WING EFFICIENCY (e)	—	$-0{,}9615-0{,}00325AR$;	0.8884	0.8518	0.9128	0.8884				
10	MAX. GLIDE LIFT COEF. (C_{Lg})	—	$(C_{D0} \times \pi \times AR \times e)^{0,5}$;	0.8235	1.0752	0.7535	0.9035				
11	MAX. GLIDE DRAG COEF. (C_{Dg})	—	$\sim 2 \times C_{D0}$; $2 \times \textcircled{8}$;	0.0216	0.0256	0,0264	0.0260				
12	MIN. SINKING LIFT COEF. (C_{LS})	—	$(C_{D0} \times \pi \times AR \times e \times 3)^{0,5}$;	*1.3500	*1.40	1.3051	*1.35				
13	MIN. SINKING DRAG COEF. (C_{DS})	—	$\sim 4 \times C_{D0}$; $4 \times \textcircled{8}$;	*0.0398	*0.0345	0.0528	*0.0420				
14	SINKING RATIO $(C_L^3/C_D^2)_{max}$	—	$\textcircled{12}^3/\textcircled{13}^2$;	1,553.23	2,305.40	797.44	1,394.77				
15	MAX. LIFT COEFFICIENT (C_{Lmax})	—	DESIGN ESTIMATE	1.40	1.45	1.35	1.40				
16	MAXIMUM GLIDE $(L/D)_{max}$	—	C_{Lg}/C_{Dg}; $\textcircled{10}/\textcircled{11}$;	38.13	42.00	28.54	34.75	38.13	42.00	28.54	34.75
17	MAX. GLIDE SPEED $(V_g)_0$	Km/h	$14{,}4(W_T/S\ 1/C_{Lg})^{0,5}$;	90.60	97.11	116.00	105.94	111.08	119.06	142.22	129.88
18	MIN. SINKING SPEED $(V_s)_0$	Km/h	$14{,}4(W_T/S\ 1/C_{LS})^{0,5}$;	70.76	85.10	88.14	86.67	86.75	104.34	100.06	106.25
19	STALL SPEED $(V_S)_0$	Km/h	$14{,}4(W_T/S\ 1/C_{Lmax})^{0,5}$;	69.49	83.62	86.67	85.10	85.19	102.52	106.25	104.34
20	MIN. SINKING RATE (s min)	m/s	$4(W_T/S\ 1/(C_L^3/C_D^2)_{max})^{0,5}$;	0.579	0.583	0.991	0.749	0.710	0.714	1.214	0.918
21	MAX. GLIDE SINKING RATE (s_g)	m/s	$V_g\ (m/s)/(L/D)_{max}$; $\textcircled{17}/\textcircled{16}$;	0.660	0.642	1.129	0.847	0.809	0.787	1.384	1.038
22	SINKING RATE AT 100 Km/h	m/sec	$\frac{V_g(m/s)}{2(L/D)}\left[1/V/V_g+(V/V_g)^3\right]$;	0.743	0.679	1.016	0.805	0.745	—	—	—
23	SINKING RATE AT 110 Km/h			0.862	0.769	1.077	0.882	0.802	0.737	1.215	0.928
24	SINKING RATE AT 120 Km/h			1.016	0.887	1.171	0.989	0.885	0.794	1.236	0.971
25	SINKING RATE AT 130 Km/h			1.205	1.035	1.298	1.127	0.994	0.873	1.286	1.039
26	SINKING RATE AT 140 Km/h			1.431	1.214	1.460	1.298	1.131	0.975	1.363	1.132
27	SINKING RATE AT 160 Km/h			2.004	1.671	1.891	1.739	1.490	1.249	1.601	1.392
28	SINKING RATE AT 180 Km/h			2.754	2.272	2.473	2.326	1.971	1.621	1.950	1.756
29	SINKING RATE AT 200 Km/h			3.700	3.033	3.221	3.073	2.586	2.101	2.417	2.233

Table 1

*VALUE LIMITED BY C_L max.

profiles, sophisticated structure of metal or sandwich construction, etc.). Examples of this stage have been sailplanes such as the "Zugvoegel" (1954), the "HKS-1" and "HKS-3" (1953/55), "Breguet 901" (1955), "Meteor" (1955), "Elfe M" (1956), "RJ-5" (1950), "Jaskolka" (1955), "Slingsby Skylark II" (1953), etc.

(3) With the event of the Standard Class (1956) a new leap towards evolution took place, searching new structural and aerodynamic techniques, so that even despite the restrictions imposed by the new class, high-performance could be attained in these sailplanes, to the extent of outmatching that of the open class of the preceding stage. This battle was fought simultaneously with the development of the plastics-reinforced primary structure. Outstanding sailplanes of this stage are the "KA-6" (1955) still within the orthodox philosophy, "Foka" (1958), "Standard Austria" (1960), "Fauvette" (1964), "Vasama" (1966), etc., and Prof. Eppler's "Phoenix" (1957), this latter one technically overlapping the following stage.

(4) The latest stage can also be classed as an aerodynamic stage, as the accelerated development of plastics-reinforced structures (fiberglass or graphite plus epoxy resin) afforded a so far unparalleled surface quality, which in its turn lead towards the development and use of new profiles (Wortmann, Eppler, Strand, Liebeck, etc.), which became usable solely by virtue of the exceptional standard of finish. The technical development of structures together with the development of these low-drag laminar profiles was the background for an enormous leap in performance, surpassing the glide ratio of 1:40 in standard class sailplanes and 1:50 in free-class sailplanes, with a corresponding speed exceeding 100 km/h. Representative members of this stage are sailplanes such as the "Libelle", "Cirrus-Standard", "PIK-20", "Nimbus II", "ASW-17" and "SB-10", the latter being today (1978) the one with probably the highest performance of the World.

I think we are drawing close to the end of this last stage, since it seems that the possibilities have been exhausted

Nº	PARAMETER	UNIT	SOURCE (FORMULA)	WITHOUT WATER BALLAST: CHORD VARIATION GLIDE -9-	CHORD VARIATION CLIMB -10-	SPAN VARIATION GLIDE -11-	SPAN VARIATION CLIMB -12-	WITH WATER BALLAST (187.5 Kg): CHORD VARIATION GLIDE -13-	CHORD VARIATION CLIMB -14-	SPAN VARIATION GLIDE -15-	SPAN VARIATION CLIMB -16-
1	SPAN (b)	m	DESIGN;	15.00	15.00	10.00	15.00	15.00	15.00	10.00	15.00
2	WING AREA (S)	m^2	DESIGN;	7.50	11.25	7.50	11.25	7.50	11.25	7.50	11.25
3	ASPECT RATIO (AR)	—	b^2/S; ①²/②;	30.00	20.00	13.33	20.00	30.00	20.00	13.33	20.00
4	WEIGHT (W_T)	Kgf	DESIGN;	375.0	375.0	375.0	375.0	562.5	562.5	562.5	562.5
5	WING LOADING (W_T/S)	Kg/m²	W_T/S; ④/②;	50.00	33.33	50.00	33.33	75.00	50.00	75.00	50.00
6	WING DRAG COEF. (C_{D0W})	—	DESIGN ESTIMATE	0.0050	0.0082	0.0062	0:0065	As per column 9	As per column 10	As per column 11	As per column 12
7	PARASITE DRAG COEF. (C_{Dp})	—	ESTIMATED; $\Sigma sC_{Dp}/S$;	0.0062	0.0042	0.0062	0.0042				
8	ZERO LIFT DRAG COEF. (C_{D0})	—	$C_{D0W} + C_{Dp}$; ⑥+⑦;	0.0112	0.0124	0.0124	0.0107				
9	WING EFFICIENCY (e)	—	-0,9615-0,00325AR;	0.8640	0.8965	0.9182	0.8965				
10	MAX. GLIDE LIFT COEF. (C_{Lg})	—	$(C_{D0} \times \pi \times AR \times e)^{0,5}$;	0.9550	0.8357	0.6906	0.7763				
11	MAX. GLIDE DRAG COEF. (C_{Dg})	—	$\sim 2 \times C_{D0}$; 2 × ⑧;	0.0224	0.0248	0.0248	0.0214				
12	MIN. SINKING LIFT COEF. (C_{Ls})	—	$(C_{D0} \times \pi \times AR \times e \times 3)^{0,5}$;	*1.20	1.4476	1.1961	1.3447				
13	MIN. SINKING DRAG COEF. (C_{Ds})	—	$\sim 4 \times C_{D0}$; 4 × ⑧;	*0.0289	0.0496	0.0496	0.0428				
14	SINKING RATIO $(C_L^3/C_D^2)_{max}$	—	⑫³/⑬²;	2,071.25	1,232.95	695.65	1,327.29				
15	MAX. LIFT COEFFICIENT (C_{Lmax})	—	DESIGN ESTIMATE	1.25	2.70	1.30	1.38				
16	MAXIMUM GLIDE $(L/D)_{max}$	—	C_{Lg}/C_{Dg}; ⑩/⑪;	42.63	33.70	27.85	36.28	42.63	33.70	27.85	36.28
17	MAX. GLIDE SPEED $(V_g)_0$	Km/h	$14,4(W_T/S \; 1/C_{Lg})^{0,5}$;	104.19	90.94	122.53	94.36	127.61	111.38	150.07	115.57
18	MIN. SINKING SPEED $(V_s)_0$	Km/h	$14,4(W_T/S \; 1/C_{Ls})^{0,5}$;	92.95	69.10	93.10	71.70	113.84	84.63	114.03	87.81
19	STALL SPEED $(V_s)_0$	Km/h	$14,4(W_T/S \; 1/C_{Lmax})^{0,5}$;	91.07	50.60	89.31	70.77	111.54	61.97	109.38	86.68
20	MIN. SINKING RATE (s min)	m/s	$4(W_T/S \; 1/(C_L^3/C_D^2)_{max})^{0,5}$;	0.621	0.658	1.072	0.634	0.761	0.806	1.313	0.776
21	MAX. GLIDE SINKING RATE (s_g)	m/s	V_g (m/s)/(L/D)max; ⑰/⑯;	0.679	0.750	1.222	0.723	0.831	0.918	1.497*	0.885
22	SINKING RATE AT 100 Km/h	m/sec	$\frac{V_g(m/s)}{2(L/D)}\left[1/V/V_g + (V/V_g)^3\right]$,	0.721	0.973	1.123	0.882	——	0.907	——	0.846
23	SINKING RATE AT 110 Km/h			0.813	1.145	1.198	1.027	0.788	1.000	1.319	0.921
24	SINKING RATE AT 120 Km/h			0.931	1.357	1.306	1.207	0.848	1.123	1.351	1.023
25	SINKING RATE AT 130 Km/h			1.076	1.611	1.446	1.423	0.928	1.277	1.410	1.152
26	SINKING RATE AT 140 Km/h			1.450	2.254	1.829	1.974	1.151	1.680	1.609	1.494
27	SINKING RATE AT 160 Km/h			1.947	3.096	2.353	2.697	1.461	2.222	1.916	1.956
28	SINKING RATE AT 180 Km/h			2.578	4.157	3.032	3.610	1.866	2.914	2.333	2.549
29	SINKING RATE AT 200 Km/h			3.356	5.462	3.878	4.734	2.371	3.770	2.869	3.265

Table 2

*VALUE LIMITED BY C_L max.

and the superiority of a new conception is exclusively assignable to the gradually increasing wing loading, with detrimental effects upon thermal climb qualities and off-field landing performance.

Held as an extension of the evolutionary trend, the thought of laminarizing the flow all over the sailplane surface is emerging now, aimed at practically doubling the glide performance, which seems feasible – even theoretically – by power-aspirating the boundary layer or power-controlling the circulation, which would be unacceptable in soaring practices.

In the thirties, possibly no sailplane attained a wing loading above about 20 kg/m². The highest values were those of the "Condor II" (19.75 kg/m²) and the "Fafnir II" (19.7 kg/m²). Today it is not uncommon to have sailplanes flying in competitions with 45 kg/m² wing loading (with water ballast), whereby landing on rough land is rendered problematical, requiring ever increasing piloting techniques, notwithstanding the fact that these sailplanes, for having a glide ratio of 1:50, offer larger mobility and improved chances of finding the "rescuing thermal" or a better landing ground. Within this evolutionary trend, it turns out that it is not so daring to imagine that in the not too distant future the wing loading will grow to the region of 75 kg/m² as a routine, but the configuration and general conception of sailplanes will no longer be the same.

It is a known fact that the use of droppable ballast (water) in sailplanes, displaces the velocity polar in the direction of the maximum glide tangent, improving performance at high speeds. This could be called a "patch solution", but is easily the possible solution – with the sailplane kept within the same external geometry, therefore maintaining the same drag level. Ideally, the wing loading should be increased through a wing surface reduction, causing the velocity polar to be displaced approximately parallel to the abscissa, since this could be done in flight as many times as required, in addition to affording a greater advantage in performance.

The folklore era of soaring is now past, and these days a wide ranging design compromise has to be met, penalizing the sailplane qualities in all flight conditions. To lessen the impairing effect of this compromise, a wide range of special sailplanes, fit for special weather conditions would have to be developed, which would turn out to be

Nº	PARAMETER	UNIT	SOURCE (FORMULA)	WITHOUT WATER BALLAST				WITH WATER BALLAST (250 Kg)			
				CHORD VARIATION		SPAN VARIATION		CHORD VARIATION		SPAN VARIATION	
				GLIDE -17-	CLIMB -18-	GLIDE -19-	CLIMB -20-	GLIDE -21-	CLIMB -22-	GLIDE -23-	CLIMB -24-
1	SPAN (b)	m	DESIGN;	18.00	18.00	12.00	18.00	18.00	18.00	12.00	18.00
2	WING AREA (S)	m²	DESIGN;	10.00	15.00	10.00	15.00	10.00	15.00	10.00	15.00
3	ASPECT RATIO (AR)	—	b^2/S; ① ² / ② ;	32.40	21.60	14.40	21.60	32.40	21.60	14.40	21.60
4	WEIGHT (W_T)	Kgf	DESIGN;	500	500	500	500	750	750	750	750
5	WING LOADING (W_T/S)	Kg/m²	W_T/S; ④ / ② ;	50.00	33.33	50.00	33.33	75.00	50.00	75.00	50.00
6	WING DRAG COEF. (C_{D0W})	—	DESIGN ESTIMATE	0.0050	0.0082	0.0062	0.0065	As per column 17	As per column 18	As per column 19	As per column 20
7	PARASITE DRAG COEF. (C_{Dp})	—	ESTIMATED; $\Sigma s C_{Dp}/S$;	0.0047	0.0032	0.0047	0.0032				
8	ZERO LIFT DRAG COEF. (C_{D0})	—	$C_{D0W} + C_{Dp}$; ⑥ + ⑦ ;	0.0097	0.0114	0.0109	0.0097				
9	WING EFFICIENCY (e)	—	-0,9615-0,00325AR;	0.8562	0.8913	0.9147	0.8913				
10	MAX. GLIDE LIFT COEF. (C_{Lg})	—	$(C_{D0} \times \pi \times AR \times e)^{0,5}$;	0.9194	0.8304	0.6720	0.7660				
11	MAX. GLIDE DRAG COEF. (C_{Dg})	—	~2 × C_{D0} ; 2 × ⑧ ;	0.0191	0.0228	0.0218	0.0194				
12	MIN. SINKING LIFT COEF. (C_{Ls})	—	$(C_{D0} \times \pi \times AR \times e \times 3)^{0,5}$;	*1.20	1.4382	1.1632	1.3267				
13	MIN. SINKING DRAG COEF. (C_{Ds})	—	~4 × C_{D0} ; 4 × ⑧ ;	*0.0262	0.0456	0.0436	0.0388				
14	SINKING RATIO (C_L^3/C_D^2)max	—	⑫ ³ / ⑬ ² ;	2,512.89	1,430.71	828.01	1,551.02				
15	MAX. LIFT COEFFICIENT (C_{Lmax})	—	DESIGN ESTIMATE	1.25	2.70	1.30	1.38				
16	MAXIMUM GLIDE (L/D)max	—	C_{Lg}/C_{Dg}; ⑩ / ⑪ ;	47.39	36.42	30.81	39.48	47.39	36.42	30.81	39.48
17	MAX. GLIDE SPEED (V_g)$_0$	Km/h	$14,4(W_T/S \; 1/C_{Lg})^{0,5}$;	106.19	91.23	124.21	94.99	130.06	111.74	152.13	116.34
18	MIN. SINKING SPEED (V_s)$_0$	Km/h	$14,4(W_T/S \; 1/C_{Ls})^{0,5}$;	92.95	69.33	94.41	72.18	113.84	84.91	115.63	88.40
19	STALL SPEED (V_s)$_0$	Km/h	$14,4(W_T/S \; 1/C_{Lmax})^{0,5}$	91.07	50.60	89.31	70.77	111.54	61.97	109.38	86.68
20	MIN. SINKING RATE (s min)	m/s	$4(W_T/S \; 1/(C_L^3/C_D^2)_{max})^{0,5}$;	0.564	0.611	0.983	0.586	0.691	0.748	1.204	0.718
21	MAX. GLIDE SINKING RATE (s_g)	m/s	V_g (m/s) / (L/D)max; ⑰ / ⑯ ;	0.622	0.696	1.120	0.668	0.762	0.852	1.372	0.819
22	SINKING RATE AT 100 Km/h	m/sec	$\frac{V_g (m/s)}{2(L/D)} \left[1/V/V_g + (V/V_g)^3\right]$;	0.646	0.898	1.021	0.807	—	0.839	1.208	0.779
23	SINKING RATE AT 110 Km/h			0.724	1.056	1.085	0.938	0.712	0.925	1.206	0.846
24	SINKING RATE AT 120 Km/h			0.825	1.251	1.177	1.101	0.762	1.037	1.231	0.937
25	SINKING RATE AT 130 Km/h			0.949	1.484	1.299	1.297	0.829	1.178	1.280	1.053
26	SINKING RATE AT 140 Km/h			1.271	2.075	1.632	1.795	1.019	1.549	1.450	1.362
27	SINKING RATE AT 160 Km/h			1.699	2.849	2.091	2.450	1.286	2.046	1.716	1.780
28	SINKING RATE AT 180 Km/h			2.244	3.824	2.686	3.278	1.634	2.682	2.080	2.317
29	SINKING RATE AT 200 Km/h			2.917	5.023	3.428	4.296	2.070	3.469	2.548	2.984

Table 3

*VALUE LIMITED BY C_L max

COMPARATIVE TABLE

Climb in (m/s)
Average speed in (Km/h)

SAILPLANE CONFIGURATION			ITEM	THERMAL STRONG	THERMAL BROAD	THERMAL WEAK	PERCENTAGE CORRESPONDING TO: PIK-20 THERMAL Str.	PIK-20 Brd	PIK-20 Wk.	NIMBUS II THERMAL Str.	NIMBUS II Brd.	NIMBUS II Wk.	VAR. SPAN THERMAL Str.	VAR. SPAN Brd	VAR. SPAN Wk.	REMARKS
① PIK-20 (326 Kgf)			CLIMB	2.74	2.92	0.68	×	×	×	-0	0	+1	+12	+5	+39	values in the variable span column cover the unballasted 15m class only; ⑩ - ⑫
			AVERAGE SPEED	94	96	49	×	×	×	-7	-8	-11	+1	-2	+27	
NIMBUS II (~430 Kgf)			CLIMB	2.73	2.92	0.67	-0	-0	-1	×	×	×	+12	+5	+37	
			AVERAGE SPEED	101	104	55	+7	+8	+12	×	×	×	+9	+6	+43	
OLYMPIA M. (~280 Kgf)			CLIMB	3.68	3.07	1.10	+34	+5	+62	+35	+5	+64	+51	+10	+124	
			AVERAGE SPEED	67	63	42	+29	-35	-15	-34	-40	-24	-28	-36	+9	
15 m CLASS	WITHOUT BALLAST	VARIABLE CHORD ⑨ - ⑩	CLIMB	4.00	3.25	1.36	+46	+11	+100	+47	+11	+103	+64	+17	+178	
			AVERAGE SPEED	123	113	78	+31	+18	+59	+22	+9	+42	+33	+16	+103	
		VARIABLE SPAN ⑪ - ⑫	CLIMB	2.44	2.78	0.49*	-11	-5	-28	-11	-5	-27	×	×	×	min. lift 1.46 m/s for ⑪; lower for ⑫
			AVERAGE SPEED	93	98	39	-1	+2	-21	-8	-6	-30	×	×	×	
	WITH BALLAST	VARIABLE CHORD ⑬ - ⑭	CLIMB	2.87	2.73	0.58	+5	-7	-15	+5	-7	-13	+2108	+44	+ —	
			AVERAGE SPEED	121	119	54	+29	+24	+11	+20	+14	-1	+766	+32	+ —	
		VARIABLE SPAN ⑮ - ⑯	CLIMB	0.13*	1.90	minus	-95	-35	–	-95	-35	–	×	×	×	min. lift 1.72 m/s for ⑮; lower for ⑯
			AVERAGE SPEED	14	90	~	-85	-6	–	-86	-13	–	×	×	×	
18 m CLASS	WITHOUT BALLAST	VARIABLE CHORD ⑰ - ⑱	CLIMB	4.07	3.32	1.42	+49	+14	+109	+49	+14	+112	+57	+16	+145	
			AVERAGE SPEED	130	120	85	+38	+25	+73	+29	+15	+54	+30	+15	+84	
		VARIABLE SPAN ⑲ - ⑳	CLIMB	2.59	2.86	0.58*	-5	-2	-15	-5	-2	-13	×	×	×	min. lift 1.17 m/s for ⑲; lower for ⑳
			AVERAGE SPEED	100	104	46	+6	+9	-6	-1	-0	-16	×	×	×	
	WITH BALLAST	VARIABLE CHORD ㉑ - ㉒	CLIMB	3.00	2.82	0.70	-9	-3	+3	+10	-3	+4	+782	+38	+ —	
			AVERAGE SPEED	131	128	66	+39	+33	+35	+30	+23	+20	+274	+29	+ —	
		VARIABLE SPAN ㉓ - ㉔	CLIMB	0.34*	2.04	minus	-88	-30	–	-88	-3	–	×	×	×	min. lift 1.42 m/s for ㉓; lower for ㉔
			AVERAGE SPEED	35	90	~	-63	+3	–	-65	-5	+ —	×	×	×	

REMARK: At values below the minimum rate of climb indicated in the Remarks column, the variable span sailplane versions should be flown with extended wings between thermals.

Table 4

excessively expensive for such an activity as soaring.

Apart from that compromise, what resources would be available to improve performance of a sailplane with no energy source?

(a) The most reasonable possible conception (design quality) and extensive "debugging", as already mastered by experienced and well-inspired designers,
(b) the smoothest possible surface (even accounting for inflight deformations), which by now is nearly reaching absolute perfection, through the use of plastics-reinforced and composite structures,
c) surface in-flight variable geometry, allowing the design to be optimized for various conditions (with no detrimental effect of one upon the other) simultaneously.

This last item (added to the others that have previously been achieved) seems to me to be the most promising path and will probably lay the milestone for a new evolutionary era.

As a matter of fact, variable surfaces are not a novelty. Relatively fruitless attempts to use them have been made in the four corners of the world since the thirties. Recent attempts directed to the glider area seem not to have been too lucky.

The history of wings of variable geometry, either in the form of variable sweepback or spanwise telescoping, goes back as far as 1931, and a patent application on it was even granted in 1916; however, their application to sailplanes (in this case dealing much more with wing surface variation) gains a very peculiar meaning.

Nature teaches us a lot when it comes to matters related to slow flying. Dozens of years ago, exhaustive performance tests using sailplanes were conducted with certain soaring birds by A. Raspet and others, the results of which included two significant truths: that the performance of these birds is extremely high as compared to the geometric parameters (optimum configuration, boundary layer aspiration by capilarity, etc.) and that the performance is fully variable and absolutely adapted to each flight condition (moreover, allowing almost vertical landing and take-off at moderate power), since the geometry in these birds is globally variable and almost limitless.

Nature cannot be copied to that extent, but two basic types of wing surface variation can be outlined as feasible, within the resources we have available namely varying the wing span and varying the wing chord. The technical means available do not enable the simultaneous application of both forms. On aircraft having lower aspect ratio (aeroplanes), a third form arises by doubling the lifting surface in flight – which in a way, can be classed as chord variation.

The span variation provides an increase of the lifting surface only, while the chord variation affords the chance of largely increasing the wing lift coefficient by varying an aerofoil, which proves to be the prevailing factor.

In the belief that the variable surface in flight will mark the forthcoming stage of the evolutionary path of high-performance sailplanes, the features involved therein should be studied. The present study attempts to be as representative as possible, to give it a more pragmatic character; this is in addition to the validity of the comparison between the two methods. (A comparative study was made several years ago, essentially aimed at determining the fitness of the form of wing surface variation, without giving special heed to the absolute accuracy of the performance values).

The study embraces 24 configurations (feasible or imaginary as one may think) which are defined in Tables 1 to 3 and comprise the following:

1. "Standard" PIK-20 sailplane as is, without ballast, considered as a configuration for climb.
2. PIK-20 sailplane with wing loading increased by 50% through reduction of the chord (increased aspect ratio), as the configuration for soaring.
3. PIK-20 sailplane with wing loading increased by 50% through reduction of the wing span (decreased aspect ratio), for soaring configuration.
4. PIK-20 sailplane with wing loading increased by 50% through proportional variation (imaginary) of the

surface (unchanged aspect ratio), for soaring configuration.

5. PIK-20 sailplane as is, with 164 kg water ballast (increasing wing loading by 50% as compared to item 1), for climb configuration.
6. Ballasted PIK-20 sailplane, with wing loading increased by 50% through chord variation (increased aspect ratio), for soaring configuration.
7. Ballasted PIK-20, with wing loading increased by 50% through wing span variation (decreased aspect ratio), for soaring configuration.
8. Ballasted PIK-20, with wing loading increased by 50% through proportional surface variation (imaginary) (unchanged aspect ratio), for soaring configuration.
9. Fictitious sailplane (basic wing span of 15 m), in configuration fit for soaring ("compacted" wing), with high wing loading.
10. Ditto, with wing loading reduced to ⅔ (~67%) through chord variation (cambered wing, decreased aspect ratio), for climb configuration.
11. Another fictitious sailplane (telescopic) in soaring configuration (retracted telescoping wing), high wing loading.
12. Ditto, with wing loading reduced to ⅔ (~67%) through wing variation (extended telescoping wing, increased aspect ratio), for climb configuration through chord variation (cambered wing, decreased aspect ratio), for climb configuration.
15. Another fictitious sailplane (item 11) with 187.5 kg water ballast (increasing wing loading by 50% as compared to item 11), for soaring configuration (retracted telescoping wing, decreased aspect ratio, high wing loading).
16. Ditto, with wing loading decreased to ⅔ (~67%) through wing span variation (extended telescoping wing, increased aspect ratio), for climb configuration.

    The configurations numbered from 17 to 24 correspond to configurations 9 to 16, with fictitious sailplanes having a basic wing span of 18 m (free class) of the same shape, at wing loadings varying from 33.3 to 75 kg/m², in +50% steps, either by surface variation or by adding droppable water ballast.

The detailed methods normally used in the design of a specific sailplane, if applied to the comparative analysis of the 24 configurations, would require a disproportionate amount of work having regard to the purposes of this study. Simplified methods (but uniform for all configurations) have therefore been applied, however, with a permanent watch upon the consistency of the results. For instance, the estimate of drag coefficients (a most critical job in sailplane design) has been based on values recalculated from the actual performance of a number of sailplanes of worldwide success, such as the "PIK-20" and the "Standard Cirrus" (for the 15 m class), "Nimbus II" and "ASN-17" (for the free class) and subsequently adapted to our specific case. The performance data of all these sailplanes have been taken from Richard Johnson's extensive testing results published by "Soaring" in a series of articles, and may be considered to be reliable (the use of data published by sailplane manufacturing companies was avoided, as they normally are biased).

Span efficiency "e" – the determination of which normally involves greater complexity and requires more actual data on the wing – was determined by an empirical formula, applicable to high-performance sailplanes having good configuration.

Wing section maximum lift coefficient was estimated in comparative terms and then related for the complete wing. As for all other coefficients, it is referred to the wing surface corresponding to the relevant configuration.

The drag polar was determined from these coefficients and from estimated factors, by use of the Prof. Klemperer's widely known and old (1922) method to determine the value of (C_L^3/C_D^2) maximum. To plot the approximate polar we will have four points and four tangents corresponding, respectively, to C_{D0}, (L/D)max., (C_L^3/C_D^2) max. and C_L max. Consider these in turn:

(1) The estimated C_{D0} value. The minimum value corresponds to $C_L \cong 0$ (in practice slightly above zero). The tangent to this point is parallel to the ordinate.
(2) The L/D max value. This normally occurs with a C_D which is twice the value of total C_{D0}. The tangent to the polar curve at this point intersects the origin of the axis system.
(3) The (C_L^3/C_D^2) max value. This corresponds to minimum sinking rate and normally occurs with a C_D which is four times the total C_{D0}. The tangent of the polar curve at this point is the straight line that intersects the ordinate at ⅓ of the corresponding C_L and the abscissa at the negative value of C_D, which is twice the total C_{D0}.

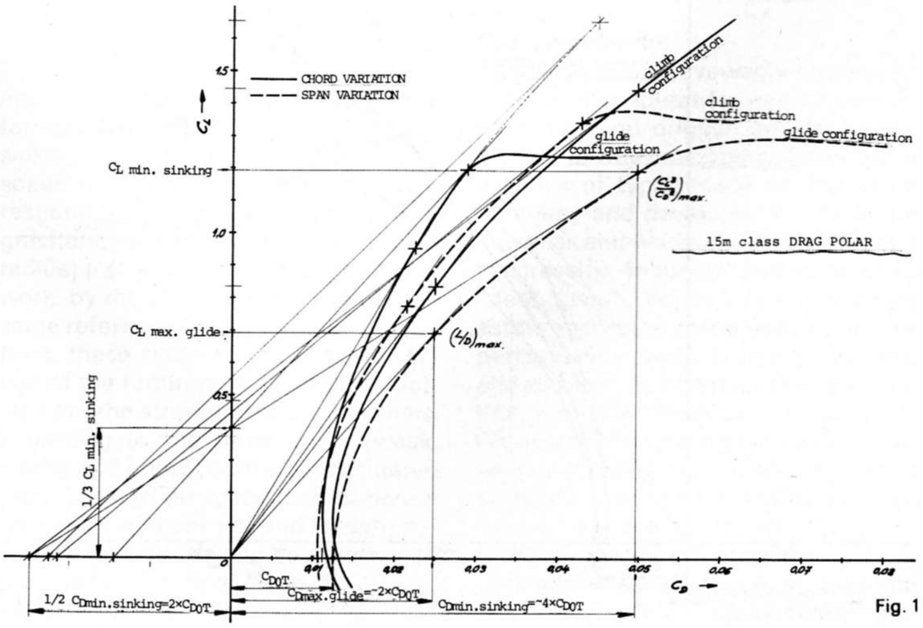

Fig. 1

(4) The already estimated C_L max. value. The C_L values corresponding to (2) and (3) are obtained from the simple induced drag formula; $C_{Di}=C_L^2/\pi.AR.e$, according to the enclosed tables, assuming that the total C_{D0} value remains constant up to a high C_L value. The C_D value corresponding to (4) can be only roughly determined by the same formula because the efficiency "e" value differs considerably in the vicinity of stall. The tangent at that point is parallel to the abscissa.

The drag polars for each configuration are plotted in fig. 1 and 2 for the 15m and 18m span versions respectively. Together with the four points discussed above and their tangents they offer acceptable reliability, even if profiles are extensively laminar, as is the case with these sailplanes.

The "universal velocity polars" (ref. 2) can be determined from the estimated drag polar, for each configuration, and are shown in fig. 5 to 7.

Parameters, coefficients, polar data, as well as the manner of determining them are found from tables 1 to 3.

Fig. 3 and 4 show an attempt to suggest the way of varying the chord, by increasing the wing surface and the wing C_L max. (which would have to be wind tunnel tested in the event of an actual design). The method involves sliding the upper wing "slice" (eventually tilting at the end of the travel) and trailing edge flap extension, normally built-in on an elastic hull. A deeper analysis would probably indicate a thicker and longer "slice" on the upper surface. By simultaneously extending both high-lift devices (leading and trailing edge) the curvature and surface area are increased, keeping the centre of pressure nearly unaltered along full span.

The last word in the most successful modern sailplanes is the combination of the FX67-K-170/150 profiles. However, for the variable surface design the use of the root-tip FX67-VC-194/170 combination would probably be better, having smaller curvature, higher relative thickness, and lower C_L value corresponding to $(L/_D)$ max., as we have no longer to meet the compromise of various flight conditions and the selected profile fully favours the high-speed condition (above that of max. glide). On the other hand, profiles do not change in the telescoping wing method.

The velocity polar curves for the various configurations originated from the PIK-20 (fig. 5, configurations 1 to 8) have been plotted as thick paired lines for the upper envelope (with and without ballast) in the three forms of wing loading variation. From this figure, it can be noted that, in principle, it is more advantageous to vary (reduce) the surface than to add ballast. The ideal would be to use both.

The velocity polars for the various 15m and 18m basic span configurations (fig. 6 and 7) have been plotted as thick tri-set lines for the upper envelope (cambered or extended wing, compacted or retracted wing without ballast, and compacted or retracted wing with ballast) for the two forms of surface variation. The measured velocity polars of the "Cirrus-Standard", "PIK-20" and "Olympia" (for 15m), "Nimbus II" and "SW-17" (for 18m) and again "Olympia" have been included for comparison purposes.

The three tangents plotted to each curve correspond to the relevant rate of climb in each kind of thermal considered (weak, strong and broad) and serve the purpose of determining the indicated speed between thermals and average speeds in cross-country flights in the three weather conditions.

The absolute superiority of the chord variation method over the telescoping wing method can be noted only by comparing the velocity polar curves. Even the slight superiority of the latter in a small region of the envelope curve, will vanish when the turning performance is analyzed, showing that as the lower speed of the variable chord prevails, an improved average speed is afforded, even with weak thermals.

It can be further noticed that with the telescoping method, in certain weather conditions – from the standpoint of average speed – the wing retraction would have negative effects between thermals. In other words, the telescoping mode is not justifiable against an

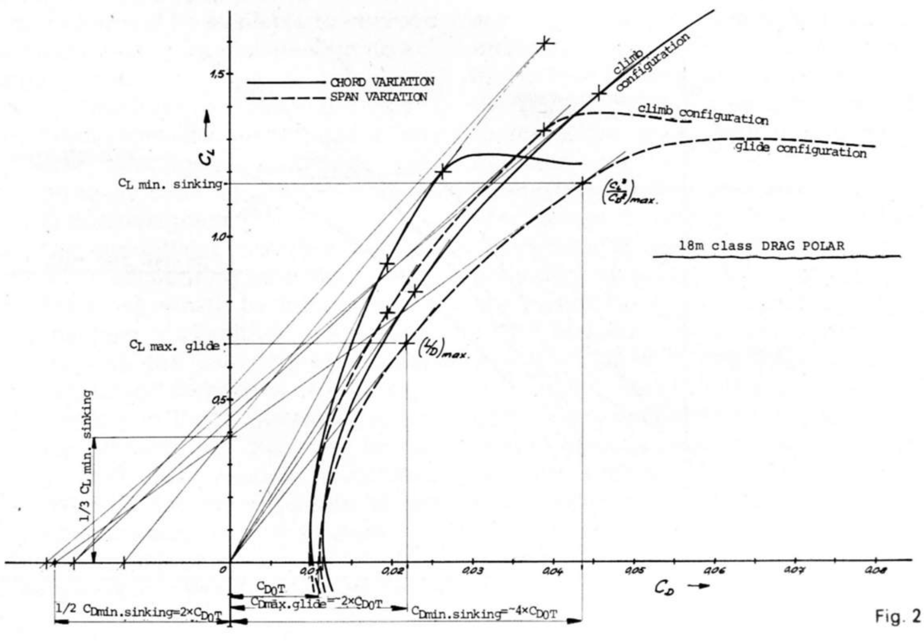

Fig. 2

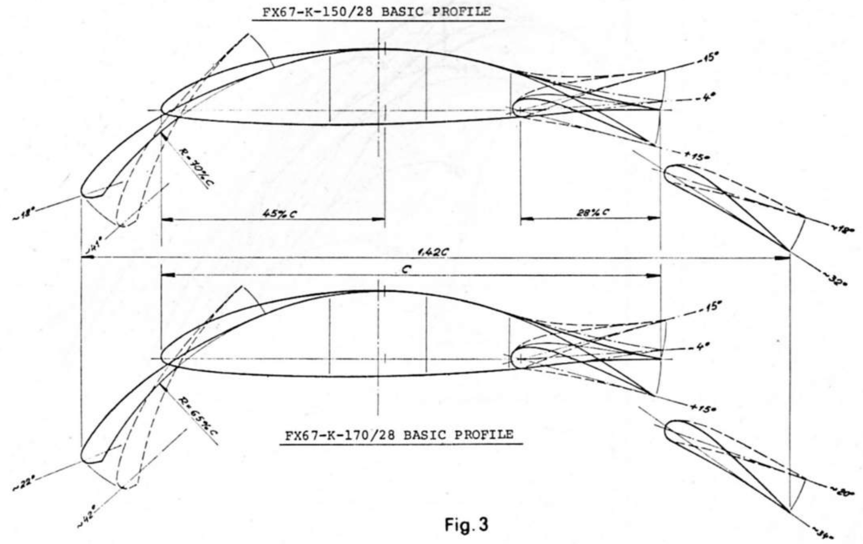

Fig. 3

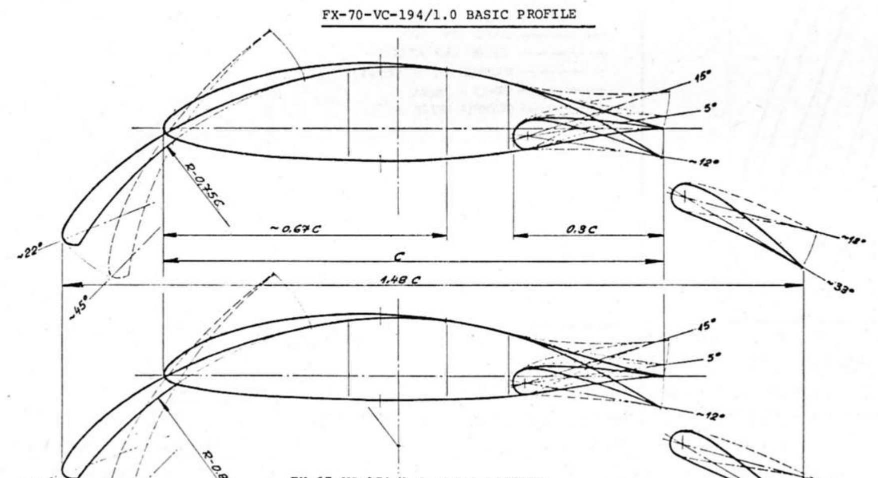

Fig. 4

equally sized conventional sailplane of the extended form (telescoping) with water ballast, which would ensure the same variation of wing loading.

For the sake of illustration a comparison has been made between the 15m class chord variation and the 18m class telescoping wing (fig. 8) and the results are obvious.

Turning performance was analysed by the method of Olenski (ref. 3) and is "shown in fig. 9 and 10, as minimum sinking rate as a function of the turning radius, for" minimum sinking rate as a function of the turning radius, for each climb configuration with 15m and 18m wing span, and for the "PIK-20", "Olympia" and "Nimbus II".

The sinking speeds could be determined for each turning radius by the formula $S_T = S_s/(1-V^4\ g.R^2)\ ^3\!/\!_4$; ($S_T$ = sinking speed in turns, S_s = sinking speed in straight line flight, V = corresponding indicated airspeed, g = gravitational acceleration, R = turning radius) (ref. 4) or, to reduce the bulk of work, by the simpler nomogram of the same reference (Hakkinen method).

Next, these sinking speeds as a function of the turning radius were deducted from the strengths of the thermals, according to the three types (weak, strong and broad) normally considered (ref. 4), based on speed distribution of free and turbulent jet, and to date accepted as valid. Having so determined the maximum rate of climb (fig. 11 and 12) as a function of the turning radius for each climb configuration corresponding to the 15m and 18m wing span classes, we can determine the respective optimum indicated airspeeds between thermals and the average speeds with each type of thermal, thus obtaining the most significant performance items. These values are obtained by plotting the maximum rates of climb into the velocity polar ordinate and from this point plotting the tangents to the curves, as seen in fig. 6 and 7. It is clearly noted that low speed in thermals (allowing small radii) prevails, even if minimum sinking speed in straight flight is higher.

The variable chord configuration is favoured by the changed profile when cambered, which besides the high C_L, produces characteristics inherent to slow and ancient sailplanes, that is, providing a large margin between the speed corresponding to the minimum sinking and stall speed – a very valuable region in narrow thermals – in addition to ensuring ease of piloting. Configurations 10 and 18 show better characteristics than those of the "Olympia" (optimistic possibly) with identical stall speed (50 km/h) and at the opposite end (compacted and ballasted wing) with 2m sinking rate between thermals, developing an airspeed of 206 and 217 km/h (15 and 18m wing span).

Table 4 provides a panoramic view on the performance of each configuration and the percentage differences. The advent of a sailplane that would land and climb in thermals like the "Olympia" and penetrate between thermals like the "SB-10", would mean that the dreams of the father of soaring meteorology – the late Prof. Georgii – were drawing close to coming true.

Closing remarks

The existing and avowedly successful sailplanes in operation, even if considered new and original developments, are in one way or another offsprings of a series of types made by the same company and developed by the same designer and his team, as a result of a progressive evolution and exhaustive "debugging". When not so, a larger safety margin is to be considered for performance, weight, flying qualities, and so forth, as a compensation for the lack of specific tradition.

I realize that in dealing with a non-conventional development as this paper suggests, the most painstaking heed cannot be overemphasized.

I also realize that the problem in optimizing the performance of first-line sailplanes, grows exponentially with

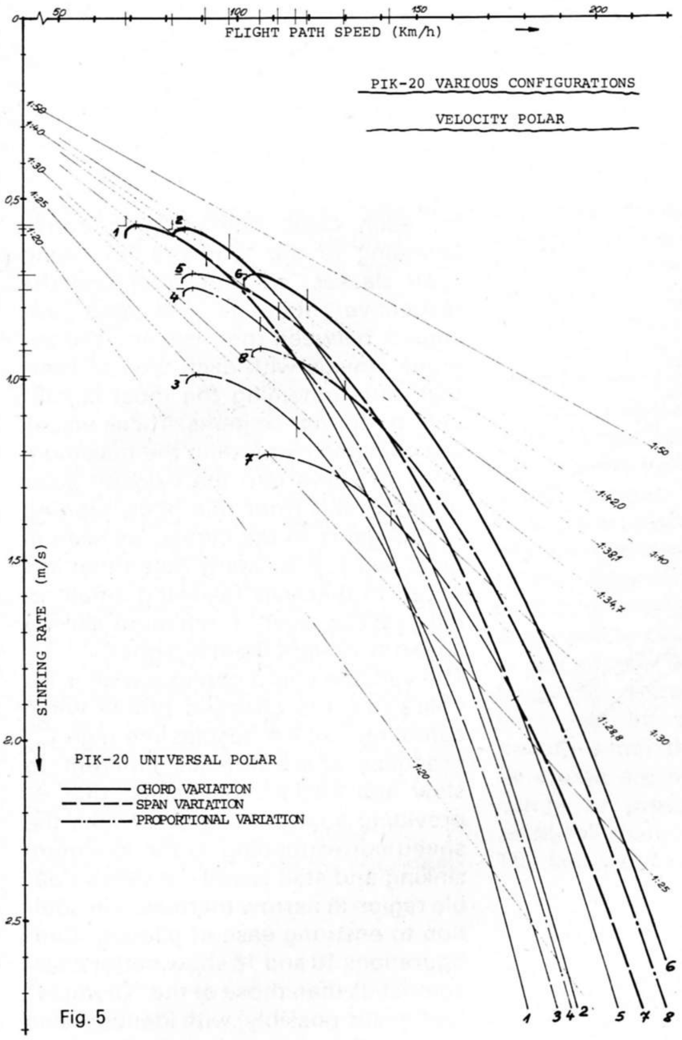

Fig. 5

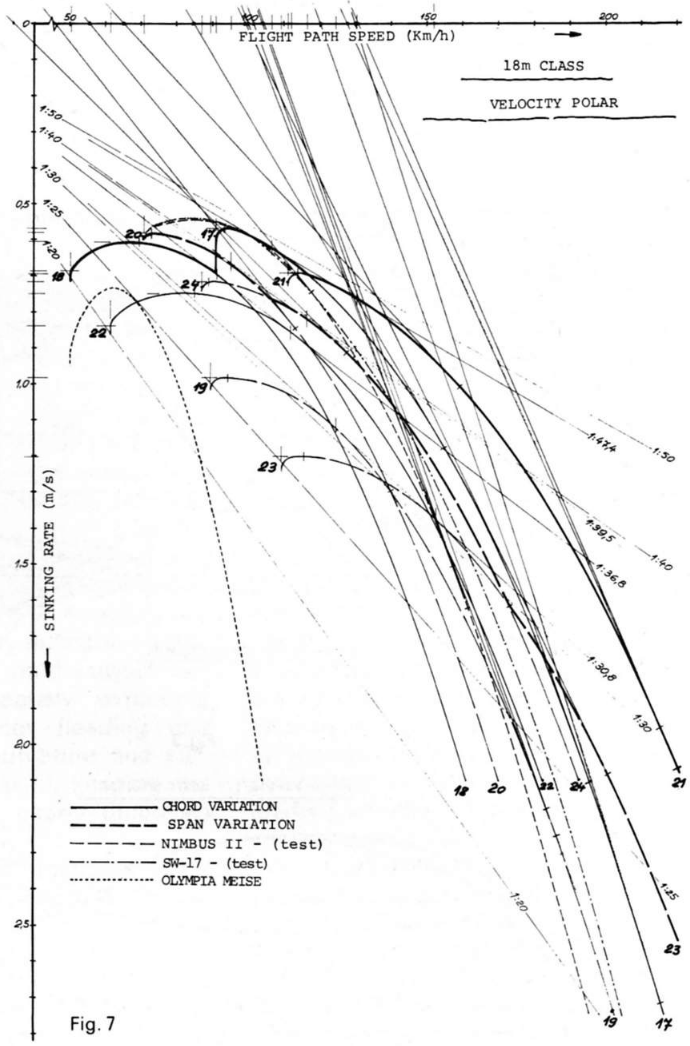

Fig. 7

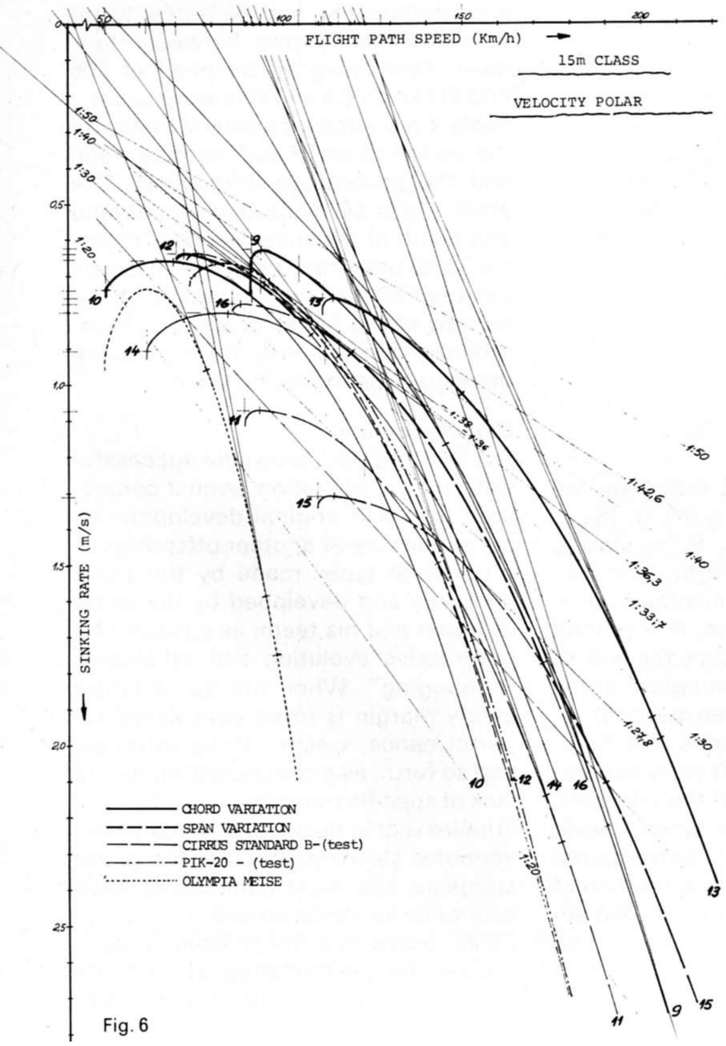

Fig. 6

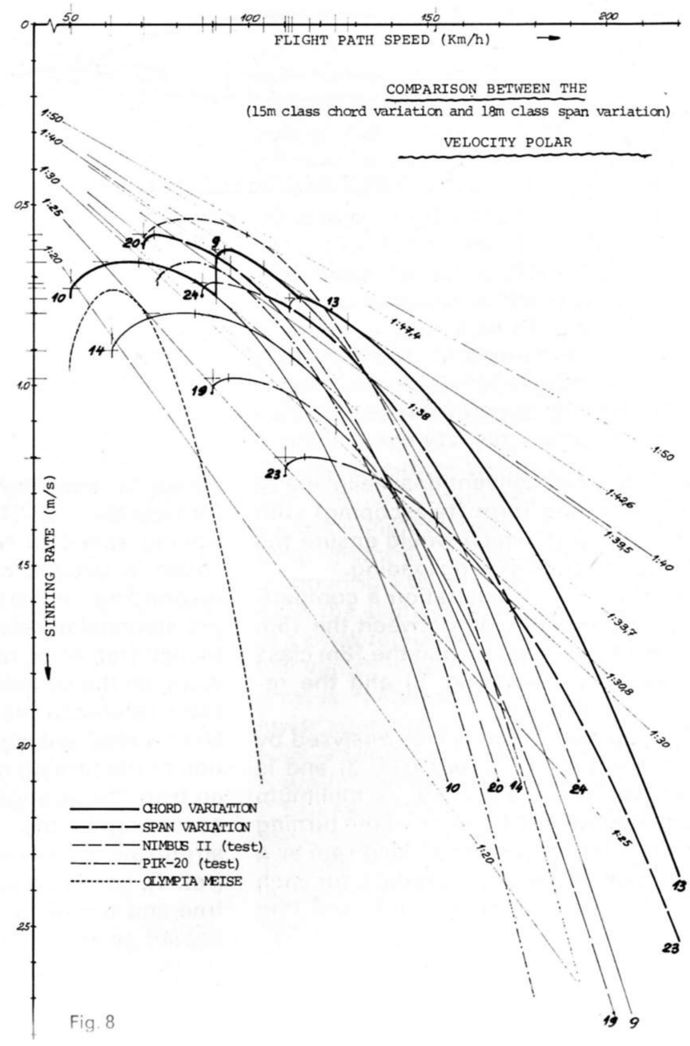

Fig. 8

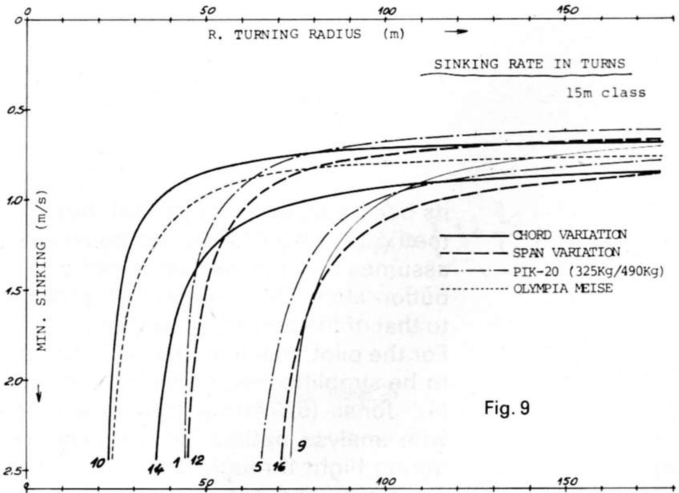

Fig. 9

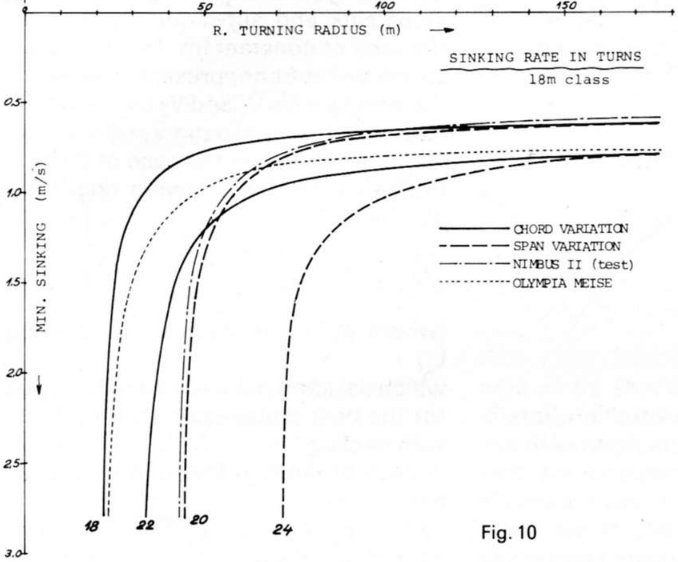

Fig. 10

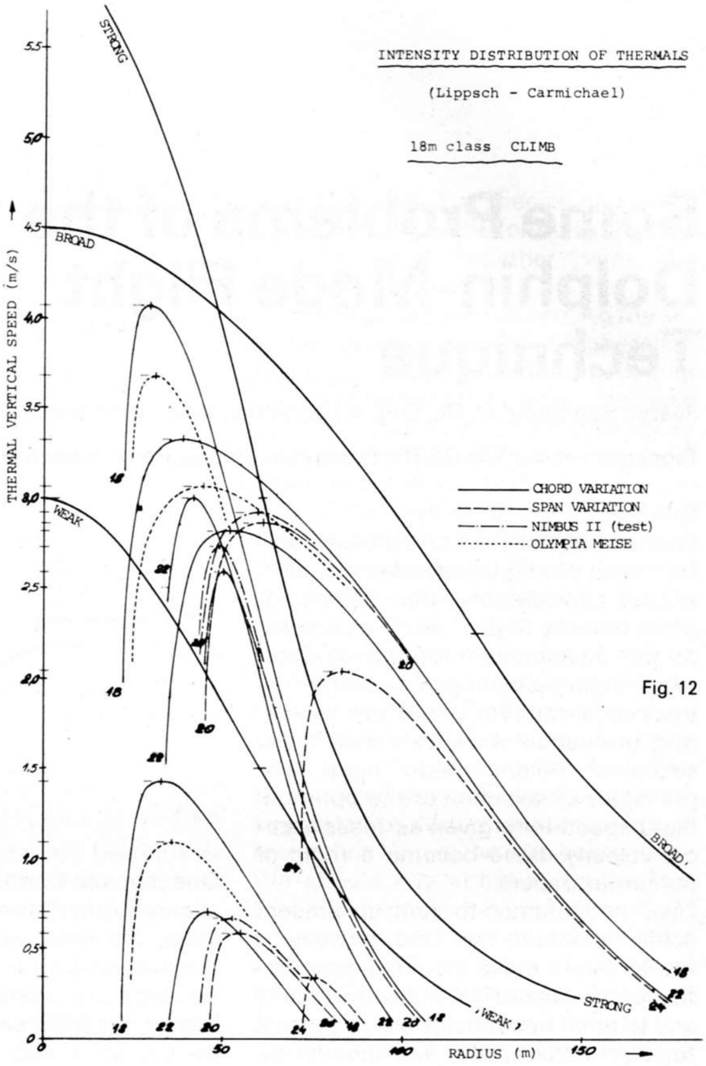

Fig. 12

the efficiency expressed by glide ratio, which reacts sensitively to any roughness or shape inadequacy of the external surface. These design problems are manifold and will be a challenge for the designer.

Therefore, the success of a development of this nature – besides requiring a considerable volume of tests, research work, and funding – will largely depend on the ingenuity of the mechanical solutions adopted for wing cambering to achieve a flawless external surface in addition to perfect operability in all flight conditions.

Consideration of problems related to structures, general conception, stability and control, systems or aero-elasticity would be premature at this point – however much this might be frustrating to the reader. These are matters to be dealt with in a subsequent stage; equally premature is a three-view arrangement, but even so, a preliminary three-view sketch (fig. 13) is included for illustrative purposes.

Should this unpretentious work arouse interest among those devoted to soaring pursuits and somehow contribute towards finding ever improved solutions in sailplane design, as well as adding support to the initiatives that have been unleashed in the field, then its goal will have been achieved.

References

1. R. Jaeschke: "Flugzeugberechnung" (Chapter 2, Section 1, page 91).
2. F. L. Galvão: Polar Universal. Boletim A.B.V.V.
3. J. Kovács: "Nomograma de Desempenho em Curvas para Planadores". ITA Engenharia – Set/Out 1958.
4. B. H. Carmichael: "What price performance?" Soaring – May/June 1954.

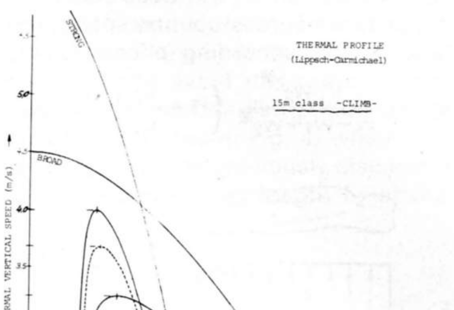

Fig. 11

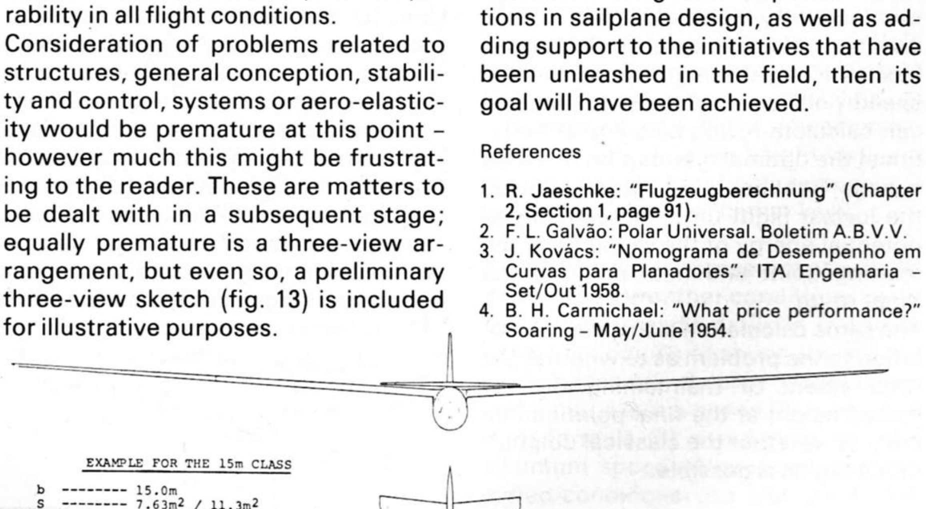

Fig. 13