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Glider Tow-Planes

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The launching of a glider has been achieved in four basic different ways: by elastic cords, auto-towing, winch and aero-towing.

• Launching by elastic cords ("bungey"-launching): It was historically the first to appear. This rudimentary catapult was operated by the man-force provided by two separate crews pulling the ends of two elastic cords diverging with an angle of 30° to 60° in a forward direction. The method was appropriate for launching from the summit of a hill, owing to the limited altitude attainable.

It is not known to the author whether this launching method is still used somewhere. In the near future, however, it could receive a revival of interest for launching self-sustaining (not self-launching) sailplanes from a flat ground. In this case a simple mechanical catapult could be devised in which elastic cords could still be used for the storage of energy. It is not known to the author whether such a catapult has ever been used.

• Auto-towing: 1981 The glider is pulled by a motor car up to the release altitude, has never been widely adopted, but is probably still in use in some place where suitable conditions exist (close proximity of a ridge or sufficient space to accommodate the cable length and the car run).

• Winch-launching: Widely used in some countries and completely ignored in others. Equipment and operation cost less than for aero-tow. However, ground handling is more demanding and the possibilities of starting a soaring flight are more limited.

• Aero-tow: The most widely used launching method nowadays although very expensive in both equipment and operation. Moreover, pollution from fuel and noise are already or tend to become critical problems in several cases.

As it is well known to everybody, the cost of gliding is steadily rising. Some of the factors affecting this tendency are of a general nature and are, therefore, out of control. Some other factors, being inherent to the technology of the air and ground equipment employed, are liable to be modified.

In the author's opinion, the launching method is one of the factors of considerable influence on costs: efforts aiming at reducing the cost of launching a glider may be well worthwhile. Although it is possible that economic reasons will determine a revival of launching methods of the past, such as the catapult or the auto-tow, it is unlikely that the aero-tow will be abandoned. In fact, it offers some unique advantages, like the freedom to choose where, and to a certain extent when to release, and the possibility to transport quickly a glider from place to place (see Table I).

The rest of this paper is confined to the consideration of the tow-plane, as any improvement of the aero-tow is mainly and closely related to improvements of its basic tool: the towing aeroplane. The actual situation in a few countries, for which some data are available, is examined first. Then some considerations are presented aiming at the definition of an aeroplane specifically designed for towing gliders.

The Actual Situation

Any aeroplane having a sufficiently low minimum speed in steady flight and adequate power can be used for towing gliders. The choice in each particular country depends on what is available in the market. Sometimes surplus aircraft are available from military aviation. Therefore, aeroplanes used for towing gliders are not specifically designed for this task. They are designed for other purposes and are suitable or acceptable for aero-towing too. However, their performance is usually poor, if related to the engine power available. Furthermore, they are usually unsatisfactory from other points of view. It is likely that an aeroplane specifically designed for towing gliders would cut down operating costs to a considerable extent, and offer a number of desirable characteristics which are never found all together on the tow-planes presently used.

On the basis of these considerations, an inquiry was started by CIVV. A short paper asking for data and opinions, was circulated among delegates at the CIVV meeting of March 1984. Some information, opinions and suggestions were received from the following countries: Denmark, Finland, Sweden, Japan, Switzerland, USA, Germany, and South Africa. They are briefly reviewed here.

• Denmark: The prototype of a tow-plane designed specifically for towing gliders—the POLYT 5—was built in this country in the late 60s by the "Polyteknisk Flyvegruppe». According to Mr. P. Weishaupt, although its performance was satisfactory and its operational superiority over other aircraft currently used as tugs (KZ-VII, MFI-9B, Piper Cherokee 180, Piper Pawnee) was clearly demonstrated, this remarkable aeroplane never went into production.

• Finland: According to information received from Prof. U. Mai, Helsinki University of Technology, the PIK-23 "Towmaster", a development of the PIK-19, was built in recent years as a two-seat glider towing aircraft and trainer. The PIK-23 first prototype was first flown in March 1982, the second prototype in March 1983. Although their performance was satisfactory, they have not yet raised sufficient interst to encourage series production.

• Sweden: The Royal Swedish Aero-Club, through Mr. J.E. Olsson, reported that they think to have found a satisfactory solution by reducing the noise (through the adoption of a special propeller) of the 260-hp Piper "Pawnee" PA-25 agricultural aircraft, which was available as a used aircraft at low price in the Swedish market.

• Japan: Prof. A. Azuma on behalf of the Technical Committee, The Japan Soaring Association, expressed interest on a tow-plane adequately improved with respect to the ones actually employed as far as

Table I Characteristics of Launching Methods

	Cost of Installation and/or Equipment	Cost of Operation	Labour req'd	Freedom of Searching for lift	Period of Launching Cycle	Pollution Fuel	Pollution Noise	Transfer of Glider from site to site	space needed
Catapult	Low	Low	2	None	2' to 5'	None	Low	No	Little
Auto-Tow	Low	Low	2	Limited	5' to 8'	Little	Low	No	Large
Winch	Medium	Low	3	Limited	3' to 5'	Little	Medium	No	Large
Aero-Tow	High	High	2	Unlimited	5' to 10'	High	High	Yes	Large

rate-of-climb, maintenance costs, noise level and visibility from cockpit are concerned.

● Switzerland: Mr. E. Lobsiger, a member of the Swiss Aero-Club Gliding Committee and a professional physicist of the Institute of Applied Physics in the University of Berne, reported that low noise and Short Take-Off and Landing characteristics are strongly demanded for in his country. He writes: "Actually to our knowledge no aircraft has yet been specially designed and built to tow gliders. This is a rather astonishing fact if we have in mind the tremendous efforts that are undertaken to improve not only sailplane performance but to find better solutions in a lot of soaring related fields".
Mr. Lobsiger states that "as people are getting increasingly sensitive to all sorts of environmental problems, the noise of the glider tow has become the problem number one of soaring flight in Switzerland today. Many clubs suffer severe operating restrictions... According to the new Swiss law on environmental protection, noise immissions are evaluated and judged on an energy equivalent sound level (L_{eq}) basis:

$$L_{eq} = 10 \log_{10} \frac{1}{T_o} \int_o^{T_o} 10^{0.1 L_A(t)} \, dt$$

where: t is the time, L_A is the A-weighted sound level and T_o is the averaging time interval. Problem number two arising now is the fact that the number of glider pilots keeps growing, but no new airfields have been built for more than a decade... The chance of opening new glider sites in Switzerland could be better by an order of magnitude if we could tow from short strips. Therefore, the length of a glider site should not be given by the take-off of the tow, but by the landing requirements of the gliders Runways of 300-400 m would be easier to find and finance".
Upon these considerations, the study of a specific glider towing plane (the "Starter") was carried out, leading to the conclusion that the most efficient tow-plane should be an overpowered motorglider for which the following characteristics are attainable:

- take-off within 300 m towing two-seater gliders;
- rate-of-climb up to 7 m/s with 180 hp engine, towing single-seat gliders;
- fast descent using airbrakes;
- thew tow rope can be retracted in flight after release.

The "Starter" project is presently in a feasibility study status. Mr. Lobsiger also informs that "in 1978, on a private basis, four engineers at the Pilatus factory in Stans began to work on their "optimized tow-plane". To start with, they put a number of specific questions about tow-planes to all Swiss glider clubs. "We mention but one result here: already at that time, 80% of the answering groups reported restrictions in operating hours due to noise problems. The final design of the Pilatus engineers was a lightweight single-seater 160 hp aircraft. The plane had a steel tube fuselage and a 8.5 m wing using an especially simple aluminium construction. Design goals were 65 dB(A) certification noise level (305 m, MRP - according to ICAO Annex 16), 5 m/s climb rate when towing a Ka-6. This private project was finally abandoned due to lack of funding".
Mr. Lobsiger stresses the point that, if the overpowered motorglider could comply with the OSTIV/JAR definition, certification under JAR-22 would be much easier than under FAR-23. In addition, motor gliders can be flown with a licence much easier to obtain than the normal motor pilots' licence. Moreover, Mr. Lobsiger remarks: "Meanwhile everybody speaks about the 'Primary Aircraft' (USA) or the "Basic Airplane" (Europe). Maybe that, therefore, a certification could also take place within such basic airworthiness requirements yet to be agreed upon", and suggests: "CIVV and OSTIV should invite entries for an international competition to build an optimized tow-plane (the Robin ATL is one of the results of a similar procedure in France looking for a cheaper school trainer)".

● U.S.A.: Captain Robert N. Buck provided the following comments as "the result of inputs from tow-plane pilots, glider pilots and a tow-plane operation that does in excess of 3000 tows per year".
"The Cessna L-19 is probably the best tow-plane available in the USA, however, it is not being manufactured and the supply is almost exhausted. The L-19 offers excellent visibility allowing a 360° range as well as vertical through sky-light windows. These have been found especially valuable during landing approach; a procedure has been established wherein, on base leg, the tow pilot does a quick roll to the right—on a left hand base—to look through the sky-light windows for any possible traffic on a long final approach he might be in conflict with—then roll back to the left and complete base leg and landing. On an airport with mixed glider and power aircraft traffic, especially itinerant power aircraft, this has proved to be a large safety factor. The most negative comment on this airplane is that it makes considerable noise for those on the ground. Mufflers have been fitted to cut engine noise, but the high propeller speeds alone make objectionable noise. At this operation 'Q' tip props are being tried to help reduce noise as it's been found they help on a Beech Bonanza—though very little".
According to Buck's report a specific glider tow-plane should include the following characteristics:

- Be as quiet as possible. This is considered a major requirement. In the New England area of the USA three glider operations have been closed due to noise complaint and community action. Two other operations are restricted as to hours of operation, i.e., no Sunday morning operation in one case; operation only between the hours of 9 AM and 5 PM in another with restricted flight paths to keep the tow away from noise sensitive areas (people who complain most!).
- Good visibility with a 360° capability as well as vertical.
- Easy to fly and land with close turning maneuverability on the ground. Tricycle landing gear preferred for ground handling ease and convenience of rope hook up by ground personnel.
- Airbrakes that enable fast descent and create enough drag so sufficient engine power can be applied during descent to prevent too rapid engine cooling and subsequent damage to the engine, or wear that decreases time between overhaul.
- Quick initial acceleration is important to get the glider up to control speed in a short distance to prevent large glider "wandering" during take-off run.
- A low enough power loading so tows to release altitude will be fast allowing quick tows and fast turn arounds. Glider operation economics, with tow-planes, is directly related to performing the maximum number of tows per hour; quick tow to altitude—release—and quick descent and landing. High power loading of aircraft, such as a motor glider for towing might have, would not allow this. This factor is very important to make tow-plane operation financially possible. Without it less persons will operate tow-planes and this will restrict glider flying—at least that is the way it is in the USA where most towing is dependent on financial success.
- Ease of maintenance; cowlings easy to remove, spark plugs simple to get at and change, strong landing gear, easy access to brakes for maintenance, refuelling that is simple and does not require ladders or akward climbing about the aircraft.
- Simple fuel system that minimizes the chance for pilot error—minimum of tank selection changes during flight. An accurate fuel level indication so pilots can operate to minimum fuel without danger of running out.
- Easy, quick rudder trim to relieve the high rudder forces and consequent tiring of pilot's leg when he counters the torque

Table II Existing Tow-Planes

AIRCRAFT	No. seats	ENGINE hp	ENGINE rpm	ENGINE type	PROPELLER type	PROPELLER diam. (m)	PROPELLER No. bl.	PROPELLER pitch F = fix. V = var.	b (m)	S (m²)	AR	We (kg)	Wmax (kg)	Wmax/S (kg/m²)	We+200/S (kg/m²)	source of data
1 L-19 Mountaineer Ector (USA)	2T	213	2400	Cont. 0-470-11 6 cyl. - flat			2	F V	10.97	16.4	7.35	658	1043	63.7	52.3	Jane's 1982/83
2 L-19 L = Cessna 182 G Cessna (USA)	4S	230	2600	Cont. 0-470-R 6 cyl. - flat		2.08		V	11.02	16.16	7.51	703	1270	78.6	55.9	Jane's 1964/65
3 Pawnee D - PA 25-235 Piper (USA)	1	235	2575	Lyc. 0-540 6 cyl. - flat	McCauley 2A36/90M-B		2	F	11.02	17	7.15	725	1315	77.1	54.4	Jane's 1981/82
4 Super Cub - PA 18 Piper (USA)	2T	150	2700	Lyc. 0-320 4 cyl. - flat	Sensenich metal		2	F	10.73	16.58	7	429	794	47.9	37.9	Jane's 1978/79
5 Super Cub - PA 18-180 Piper Transair (USA-CH)	2T	180	2700	Lyc. 0-360 A2A 4 cyl. - flat	metal		2	F	10.73	16.58	7	440	794	47.9	38.6	Jane's 1969/70
6 MS 893 Rallye Commodore 180 Socata (F)	4S	180	2700	Lyc. 0-360 A2A 4 cyl. - flat			2	F V	9.61	12.30	7.57	550	1050	85.4	61	Jane's 1972/73
7 Rallye 180T - Galerien Socata (F)	4S	180	2700	Lyc. 0-360 A3A 4 cyl. - flat			2	F	9.74	12.66	7.57	545	770	60.0	58.8	Jane's 1983/84
8 Robin DR-400/ 180R (F)	4S	180	2700	Lyc. 0-360 a 4 cyl. - flat			2		8.72	13.6	5.6	560	1000	73.5	55.9	Jane's 1983/84
9 Cherokee 180 - PA 28-180 Piper (USA)	4S	180	2700	Lyc. 0-360 A3A 4 cyl. - flat	Sensenich		2	F V	9.14	14.86	5.63	607	1089	73.2	54.3	Jane's 1972/73
10 PZL-104 Wilga 32A PZL (PL)	4S	230	2600	Cont. 0-470 L or R, 4 cyl - flat	McCauley 2A346-050- 90A, metal		2	V	11.14	15.5	8	737	1250	79.4	60.5	Jane's 1973/74
11 PZL-104 Wilga 35A PZL (PL)	4S	260	2350 (.787)	Ivchenko AI-14R 9 cyl., radial	PZL US-122000 wood		2		11.14	15.5	8	850	1250	79.4	67.7	Jane's 1973/74
12 MFI-9B (S)	2S	100	2750	RR/Cont. 0-200-A 4 cyl. - flat	McCauley MCM 6758, metal		2	F	7.43	8.7	6.3	340	575	66.1	62.1	Jane's 1969/70
13 PIK-15 Hinu (SF)	2S	150	2700	Lyc. 0-320 A2B 4 cyl. - flat	McCauley 1A175 /GM-82-43 mod.		2	F	10	14	7.15	502	764	54.6	50.1	Jane's 1972/73
14 PIK-19 Muhinu (SF)	2S	160	2700	Lyc. 0-320-B2B 4 cyl. - flat	McCauley 1A175 /GM-82-41 metal		2	F	10	14	7.14	560	840	60	54.3	Jane's 1975/76
15 L-5 Stinson (USA)	2T	190	2550	Lyc. 0-435-1 - flat		2.14	2	F	10.35	14.4	7.44	688	1025	71.2	61.7	Registro Aeron. Italiano
16 L-5 SSW-235 Stinson - SSW (USA-I)	2T	235	2575	Lyc. 0-540-B1A5 6 cyl. - flat	Hoffman HO-27BHM 220B116 or B105	2.20	2	F	10.35	14.4	7.44	743	1021	70.9	65.5	Registro Aeron. Italiano
17 ZLIN 226 M (CS)		180	2750	Avia M-137A 6 cyl. - linear	Z 42.6411	2.05			10.28	15.45	6.66	600	770	49.8	(49.8)	CSSR - CAA
18 Aero L-60 S Brigadyr (CS)		260	2350 (?)	Ivchenko AI-14RA 9 cyl., radial	US-122-00 or W530- D11/N	2.75			13.96	24.3	8.02	1030	1560	64.2	50.6	CSSR - CAA
19 ZLIN 42 M (CS)	2S	180	2750	Avia M-137AZ 6 cyl., linear	V 503 A	2.00			9.11	13.15	6.24	645	970	73.8	64.3	Jane's 1979/80 CSSR - CAA
20 ZLIN 142 (CS)	2S	210	2750	Avia M-337 AK 6 cyl. lin. s/ch.	V 500 A	2.00			9.16	13.15	6.28	730	1090	82.9	70.7	Jane's 1983/84 CSSR - CAA
21 Aero Boero 180 RVR (RA)	3	180	2700	Lyc. 0-360-A1A 4 cyl. - flat	Sensenich 76-EM8 Hartzell HC922K8D			F V	10.9	17.55	6.77	550	844	48.1	42.7	Jane's 1983/84
22 Tomahawk II PA 38-112 Piper (USA)	2S	112	2700	Lyc. 0-235-L2C 4 cyl. - flat	Sensenich metal	2.07	2	F	10.36	11.59	9.27	512	757	65.4	61.4	Jane's 1981/82
23 Polyt-5 (DK)	1	200	2700	Lyc. IO-360-A2B 4 cyl. - flat		1.96	2	F	9.6	14.4	6.4	615	760	52.8	(52.8)	Flyv 1972 Jane's 1972/73
24 ESS-641 Fluwag Bremen (D)	1	180	2700	Lyc. 0-360-A3A 4 cyl. - flat	Hoffman HO-27- 198/115 wood		2	F	10.5	16.5	6.7	554	700	42.5	(42.5)	Jane's 1973/74
25 PIK 23 Towmaster (SF)	2S	180	2700	Lyc. 0-360-A4M 4 cyl. - flat		2.00	2	F	10	14	7.14	590	870	62.1	56.4	VALMET OY Jane's 1983/84
26 EMB-201 R Ipanema Embraer (BR)	1	300	2700	Lyc. IO-540 K1J5D 6 cyl. - flat	Hartzell	2.13	2	V	11.20	18	7	720	1250	69.4	51.1	Jane's 1977/78
27 Nash Petrel Nash (GB)	2S	180	2700	Lyc. 0-360-A3A	Sensenich		2	F	9.04	13	6.3	544	794	61.1	57.2	Jane's 1984/85
28 NAC 1 Freelance NDN (GB)	4S	180	2700	Lyc. 0-360-A 4 cyl. - flat	Sensenich	1.93	2	F V	11.99	15.7	9.15	635	1111	70.7	53.2	Jane's 1984/85
29 MD-3-160 Datwyler (CH)	2S	160	2700	Lyc. 0-320-D2A 4 cyl. - flat	Hoffmann	1.82	2	F	10	15	6.67	570	900	60	51.3	Jane's 1984/85
30 UTVA-66 UTVA (YU)	4S	270	3000	Lyc. GSO-480- B1J6 6 cyl. - flat	Hartzell HC-83220- 1/10151C5		2	V	11.4	18.08	7.19	1250	1814	100.5	80.2	Jane's 1984/85
31 UTVA-75 UTVA (YU)	2S	180	2700	Lyc. IO-360-B1F 4 cyl. - flat	Hartzell HC-C2YK- 18F/F7666A	1.93	2	V	9.73	14.63	6.47	685	960	65.6	60.5	Jane's 1984/85
32 P-66 B Oscar-150 Partenavia (I)	2S +1	150	2700	Lyc. 0-320-E2A 4 cyl. - flat	Sensenich 74D- DM6S5-2-60	1.83	2	F	9.99	13.4	7.45	610	930	69.4	60.4	Jane's 1973/74
33 S.208 M Siai Marchetti (I)	4S	260	2700	Lyc. 0-540-E4A5 6 cyl. - flat	Hartzell	1.88	2	V	10.86	16.04	7.35	820	1500	93.5	63.6	Jane's 1975/76

effect during slow climb. This can be a very fatiguing factor during a day of many tows.

● Germany: Mr. Manfred Schliewa, a professional designer for Rheinflugzeugbau, expressed the opinion that a specific glider towing aircraft would be highly desirable but, as an alternative, a satisfactory solution could be obtained by modification of an existing aircraft. Suitable examples, in his opinion, are the 180 hp Piper Super Cub, the Piper PA-38 "Tomahawk", a motorglider.

He would be interested on co-operating in the design and realization of such an aircraft, provided that sufficient interest is shown.

● South Africa: Mr. Stephen R. Murray stated that present tow-planes in his country are mostly Piper Super Cubs (150 or 180 hp). Cessna 182 and 206, or converted Cessna 150 with 150 hp are also employed. "They all do a good job" he says "but are not ideal".

Areas which could be improved are:

"Super Cubs: Maintenance costs, i.e. expensive to re-cover. High rate of engine wear due to dust. Rate-of-climb at our high altitudes. Comfort, i.e. noise and seating. Rate-of-descent with power on to keep engine warm. Rearward visibility.

Cessnas: Maintenance of nose oleo due to rough strips. Cost of extra two cylinders at top-overhaul and complete-overhaul time. Cost of overhaul of V/P propellers and their maintenance on gravel strips. High fuel consumption. Tow speeds too high for lighter club gliders. Rate-of-descent as per Pipers."

Mr. Murray is doubtful whether any club in his country could afford a brand new purpose-built tow-plane.

He then lists some characteristics they would like to see in an "ideal" tow-plane:

- Good power to weight ratio.
- Simple rugged nose gear (not air/oil or pneumatic) for ease of ground handling.
- Four cylinder carburettor engine for low overhaul and maintenance costs. Must have a very good air filter system and be tightly cowled and baffled for even cooling at all power settings. Preferably no cowl flaps, as pilots tend to "forget" the use or correct use of cowl flaps. It is recommended that exhaust-augmented cooling (preferably activated automatically) be incorporated.
- Fixed pitch propeller with ample tip clearance. Prop diameter must be quite large for max. efficiency, which clashes with nose wheel and tip clearance reqs. (back to tail wheel).
- Metal or composite construction (no fabric).
- All round view. If high wing type, it must have a clear vision panel in centre section.

- Drag devices for fast descent with enough power on to keep engine warm, i.e. dive brakes or flaps with high operating and limit speeds.
- Two seats.
- Simple shock-mounted instrument panel.
- Easily accessible tow release.
- High aspect ratio wing for good climb characteristics.

Existing Tow-Planes

Most presently used tow-planes are listed in Table II.

Although it is not known to the author whether it is actually used as a glider tow-plane somewhere, the Piper PA-38 "Tomahawk" is included in consideration of its suitability to become a rather efficient tow-plane. The POLYT-5, ESS-641 and PIK-23 "Towmaster" were specifically designed as glider tow-planes.

It can be noted that the engine power ranges from 150 to 235 hp, the empty weight from 429 to 725 kg. The significant wing loading, in the author's opinion, is the one corresponding to the average weight at which a tow-plane operates, roughly the empty weight, W_e, plus 200 kg. On this respect, W/S ranges practically from 50 to 65 kg/m², with the exception of the Piper Super Cubs and the Aero Boero.

The POLYT-5, ESS-641 and PIK-23 deserve some additional description and remarks. Performance data for these are given in Table III.

● POLYT-5: Designed and built by a group of graduates and students of the Danish Technical University in Copenhagen, this prototype (Fig. 1) was first flown on 12 April 1970 [1].

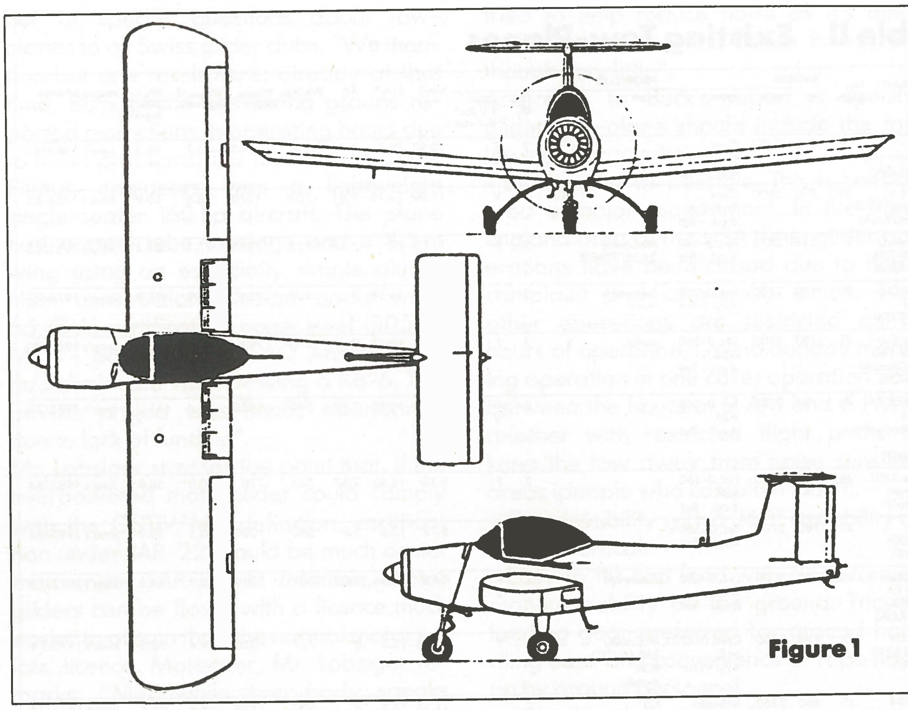


Figure 1

Construction is of wood and GRP.

Single-seat. Wide-span ailerons, each having a centrally-located trim tab. Inboard of each aileron is an air-brake/spoiler which can be deflected to nearly 90°. All-flying horizontal tail, with full-span anti-balance tab. Trim tab in rudder. Two-blade propeller, diam. 2.06 m. For cooling the 200 hp Lycoming IO-360-A2B engine during low-speed flight, a fan with 16 plastic blades is mounted in the circular air intake behind the propeller and is capable of blowing 99 m³ of air per minute, about four times the normal cooling flow. To prevent excessive cooling (i.e., during diving), the cooling grilles can be closed, and the under-nose cooling flap aft of the cowling closes automatically during a dive.

Operational equipment includes an electrical winch in the rear fuselage, which can reel in 40 m of nylon tow line in 40 sec after sailplane is released.

Performance data are:

● ESS-641: Designed by FLUWAG BREMEN, it was flown for the first time in September 1971 [2].

Single-seat low-wing monoplane. Tail-wheel type landing gear.

Plain flaps.

Construction of wood, fabric and GRP.

Steel tube fuselage.

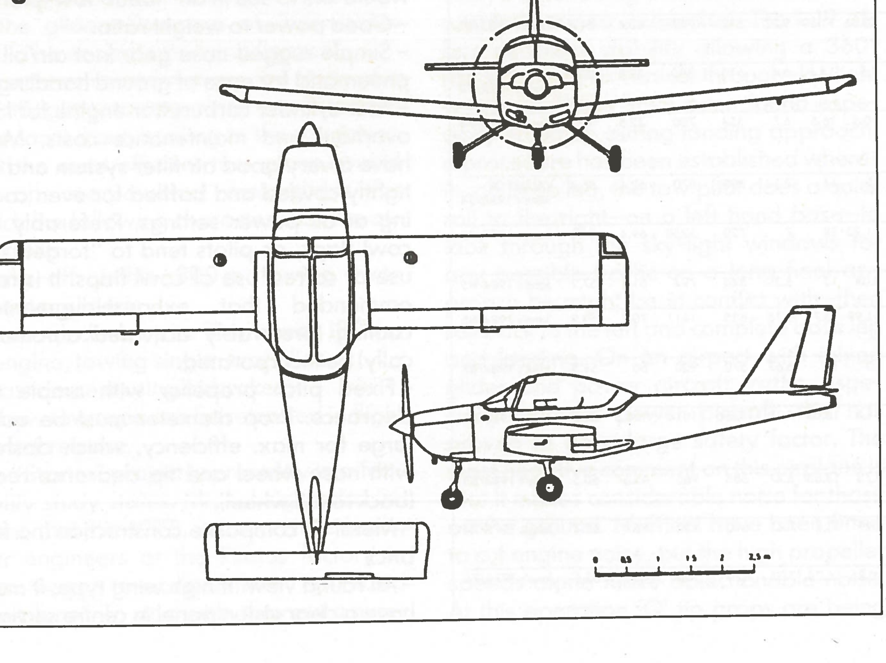
180 hp Lycoming engine. 2-blade fixed pitch wooden propeller.

● PIK-23 "Towmaster": A co-operation project between the Helsinki University of Technology and VALMET OY, the PIK-23 (Fig. 2) is a development of PIK-19 (flying since 1972) [3] [4]. The PIK-23 first prototype was flown in 1982; the second prototype in 1983. The first prototype was displayed at Le Bourget 1981 and Farnborough 1982.

Construction is of composite materials. A two-seat aircraft, powered by a 180 hp Lycoming 0-360-A4M.

After release of glider cowl flaps are closed and flaps lowered. High flap speed (200 km/h) for rapid descent. Rate-of-descent up to 15÷20 m/s.

Figure 2



The theoretical design approach for climb performance

One of the basic requirements for a tow-plane is the highest possible rate of climb when towing a glider.

Neglecting the weight and aerodynamic drag of the tow-line and its influence on the balance of forces acting on both aircraft, the rate of climb, w, can be expressed as

$$(1) \quad \omega = \frac{1}{W_t + W_g} (\eta P - D_t V - D_g V)$$

where:
W_t = tow-plane weight,
W_g = glider weight,
η = propeller efficiency,
P = engine shaft horsepower,
D_t = tow-plane drag,
D_g = glider drag,
V = airspeed.

At constant airspeed, V, and altitude, it is therefore:

$$\omega = \omega\,(\eta, P, W_t, D_t, W_g, D_g).$$

If we refer to a given tow-plane and a given glider, we can assume that the increment of the rate of climb is a function of the above variables' increments:

$$\Delta\omega = \Delta\omega\,(\Delta\eta, \Delta P, \Delta W_t, \Delta D_t, \Delta W_g, \Delta D_g).$$

The variables, however, are partly interdependent:

$\Delta\eta$ affects W_t (weight increment of propeller and/or due to reduction gear);
$\Delta\eta$ affects D_t (drag increment due to modifications required by propeller installation or reduction gear);
ΔP affects W_t (weight increment of engine, accessories and airframe);
ΔP affects D_t (drag increment due to the installation of more powerful engine);
ΔW_t affects D_t (induced drag increment of the tow-plane);
ΔW_g affects D_g (induced drag increment of the glider).

Among the various parameters affecting the climb performance, the tow-plane wing aspect ratio, A_t, is of particular importance.

A_t, however, interacts with D_t and W_t:
A_t affects D_t (through the tow-plane induced drag);
A_t affects W_t (through the tow-plane wing weight).

Taking into account the above listed interdependences and assuming relatively small increments of the variables, the function $\Delta\omega$ can be expressed as follows:

$$(2) \quad \Delta\omega = \frac{\partial\omega}{\partial\eta}\Delta\eta + \frac{\partial\omega}{\partial P}\Delta P + \frac{\partial\omega}{\partial W_t}\left(\Delta W_{to} + \frac{\partial W_t}{\partial P}\Delta P + \frac{\partial W_t}{\partial\eta}\Delta\eta + \frac{\partial W_t}{\partial A_t}\Delta A_t\right) +$$

$$+ \frac{\partial\omega}{\partial D_t}\left(\Delta D_{to} + \frac{\partial D_t}{\partial P}\Delta P + \frac{\partial D_t}{\partial\eta}\Delta\eta + \frac{\partial D_t}{\partial W_t}\Delta W_t + \frac{\partial D_t}{\partial A_t}\Delta A_t\right) +$$

$$+ \frac{\partial\omega}{\partial W_g}\Delta W_g + \frac{\partial\omega}{\partial D_g}\left(\Delta D_{go} + \frac{\partial D_g}{\partial W_g}\Delta W_g\right)$$

where: ΔW_{to} = the tow-plane weight increment due to any other cause than $\Delta P, \Delta\eta, \Delta A_t$;
ΔD_{to} = the tow-plane drag increment due to any other cause than $\Delta P, \Delta\eta, \Delta W_t, \Delta A_t$;
ΔD_{go} = the glider drag increment due to any other cause than ΔW_g

The partial derivatives must be evaluated. An approximate evaluation is not too difficult, although care should be given to possible singularities.

For instance, when evaluating $\partial W_t/\partial P$ one should consider whether, in the particular case being studied, the engine power increment can be obtained simply by increasing the compression ratio or the r.p.m. (which would give a very low value of the derivative $\partial W_t/\partial P$) or more cylinders should be added, the engine weight being thus considerably increased.

An example will better clarify.

Example: Let us take the Robin DR-400/180R as the reference tow-plane, and a single-seater as the towed glider. The following data are assumed:

$\eta = 0.65$, $P = 75 \times 180$ kgm/s,
$W_t = 760$ kg, $A_t = 5.6$, $S_t = 13.6$ m²
$C_{Dot} = 0.040$, $e_T = 0.85$
$W_g = 450$ kg, $A_g = 20$, $C_{Dog} = 0.008$,
$e_g = 0.9$, $S_g = 10$ m².

The airspeed is assumed to be:
$V = 33$ m/s $= 118.8$ km/h.

The reference altitude is sea level.
It results:

$$C_{Lt} = 16\,\frac{W_t}{S_t V^2} = 16\,\frac{760}{13.6 \cdot 33^2} = 0.82$$

$$C_{Dt} = C_{Dot} + C_{Dit} = C_{Dot} + \frac{C_{Lt}^2}{\tau e_t A_t} = 0.085$$

$$D_t = C_{Dt} S_t V^2/16 = 78.6 \text{ kg}$$

$$C_{Lg} = 16 \cdot W_g/S_g V^2 = 0.66$$

$$C_{Dg} = C_{Dog} + C_{Dig} = C_{Dog} + \frac{C_{Lg}^2}{\tau e g A g} = 0.0157$$

$$D_g = C_{Dg} S_g V^2/16 = 10.7 \text{ kg}$$

$$\omega = (\eta P - D_t V - D_g V)/(W_t + W_g) = 4.82 \text{ m/s}.$$

Whether this rate of climb is overestimated or not, it is not known for certain by the author. Considering the assumption of full power, reduced W_t (=W_e+200 kg) and a mid-weight glider, it should not be too unlikely. The considerations which follow, however, are not affected by the accuracy of this estimation.

Evaluation of the derivatives:

$$\frac{\partial\omega}{\partial\eta} = \frac{P}{W_t + W_g} = 11.16 \text{ m/s}$$

$$\frac{\partial\omega}{\partial P} = \frac{\eta}{W_t + W_g} = 0.000537$$

m/s/kgm/s = 0.040 m/s/hp

$$\frac{\partial\omega}{\partial W_t} = [-\eta P + (W_t + W_g)V]/$$

$(W_t + W_g)^2 = -0.0041$ m/kgs

$$\frac{\partial W_t}{\partial P} = \begin{Bmatrix} 0.4 \text{ kg/hp} \\ 1 \text{ kg/hp} \end{Bmatrix}$$

depending on whether the same engine can be overpowered or not (rough assumptions)

$$\frac{\partial W_t}{\partial\eta} = 100 \text{ kg} \quad \text{(rough assumption)}$$

$$\frac{\partial W_t}{\partial A_t} = 6 \text{ kg} \quad \text{(rough assumption)}$$

$$\frac{\partial\omega}{\partial D_t} = \frac{V}{W_t + W_g} = -0.027 \text{ m/kgs}$$

$$\frac{\partial D_t}{\partial P} \cong 0$$

$$\frac{\partial D_t}{\partial\eta} \cong 0$$

$$\frac{\partial D_t}{\partial W_t} = \frac{32\,W_t}{\tau A_t e_t S_t V^2} = 0.11$$

$$\frac{\partial D_t}{\partial A_t} = -\frac{16\,W_t^2}{\tau e_t S_t V^2 A_t^2} = -7.45 \text{ kg}$$

$$\frac{\partial\omega}{\partial W_g} = \frac{\partial\omega}{\partial W_t} = -0.0041 \text{ m/kgs}$$

$$\frac{\partial \omega}{\partial D_g} = \frac{\partial \omega}{\partial D_t} = -0.027 \text{ m/kgs}$$

$$\frac{\partial D_g}{\partial W_g} = \frac{32 W_g}{\tau A_g e_g S_g V^2} = 0.023$$

Let us evaluate the gain in rate of climb that would be obtained by increasing A_t from 5.6 to 10 ($\Delta A_t = 4.4$), all the rest remaining unchanged except W_t which is affected by ΔA_t:

$$\Delta\omega = \left(\frac{\partial \omega}{\partial W_t}\frac{\partial W_t}{\partial A_t} + \frac{\partial \omega}{\partial D_t}\frac{\partial D_t}{\partial A_t}\right)$$
$$\Delta A_t = 0.78 \text{ m/s}$$

Therefore, the rate of climb would be increased from 4.82 m/s to 4.82 + 0.78 = 5.6 m/s.

Should the same increment, $\Delta\omega$ = 0.78 m/s, be obtained by decreasing the tow-plane weight, W_t, the decrement should be:

$$\Delta\omega = \frac{\partial \omega}{\partial W_t}\Delta W_t = 0.78 \text{ m/s}$$

$$\Delta W_t = \Delta\omega \frac{\partial W_t}{\partial \omega} = 0.78/-0.0041 = -190 \text{ kg!}$$

Should the same increment $\Delta\omega$ be obtained by improving the propeller efficiency, the increment $\Delta\eta$ should be:

$$\Delta\omega = \frac{\partial \omega}{\partial \eta}\Delta\eta = 0.78 \text{ m/s}$$

$$\Delta\eta = \Delta\omega \frac{\partial \eta}{\partial \omega} = 0.78/11.16 \simeq 0.07$$

i.e. η should be increased from 0.65 to 0.72!

If we assume that we can achieve simultaneously:

$\Delta\eta = +0.05$, i.e.: η increased from 0.65 to 0.70,

$\Delta P = +30$ hp, i.e.: p increased from 180 to 210 hp,

$\Delta W_t = -100$ kg, i.e.: W_t decreased from 760 to 660 kg (W_e = 460 kg),

$\Delta A_t = +6.4$, i.e.: A_t increased from 5.6 to 12,

and assume that the following quantities can be neglected:

$$\frac{\partial W_t}{\partial P}, \frac{\partial W_t}{\partial \eta}, \Delta D_{to}, \frac{\partial D_t}{\partial P}, \frac{\partial D_t}{\partial \eta},$$

for the same towed glider ($\Delta W_g = 0$, $\Delta D_g = 0$) at the same airspeed and altitude, we obtain:

$$\Delta\omega = \frac{\partial \omega}{\partial \eta}\Delta\eta + \frac{\partial \omega}{\partial P}\Delta P + \frac{\partial \omega}{\partial W_t}\Delta W_t + $$
$$+ \frac{\partial \omega}{\partial D_t}\frac{\partial D_t}{\partial A_t}\Delta A_t + \frac{\partial \omega}{\partial D_t}\frac{\partial D_t}{\partial W_t}\Delta W_t +$$
$$\frac{\partial \omega}{\partial W_g}\Delta W_g + \frac{\partial \omega}{\partial D_g}\Delta D_g =$$
$$= 0.56 + 1.2 + 0.41 + 1.29 + 0.30 = + 3.76 \text{ m/s}$$

which gives:
$w = w_{Robin} + 3.76 = 4.82 + 3.76 = 8.58$ m/s!

It can be seen that 34% of the $\Delta\omega$ increment is obtained by increasing the wing aspect ratio and 32% by increasing the engine power.

Although several simplifications and approximations are made in this calculation, it seems clear that the ideal tow-plane, as far as the climb performance is concerned, resembles an *overpowered motorglider.*

Design Considerations

Apart from the preceding remarks on the climb performance, several other considerations have to be made.

● Wing Loading: The C_L for minimum power required in level flight (with the cubic polar approximation [5]) can be estimated as:

(3) $C_{LPmin} = \sqrt[3]{\tau A C'_{Do}} = 1.462\sqrt{A C'_{Do}}$
$(C'_{Do} = C_{Do} + 0.046/A)$

For optimum climb performance, this C_L should be achieved simultaneously by both the glider and the tow-plane.

As a matter of fact, C_{LPmin} changes very little for a traditional tow-plane or a motorglider or a glider, because it occurs normally that a higher wing aspect ratio is accompanied by a lower minimum drag coefficient. Examples:

tow-plane Robin: $A.C^*_{Do} = 5.6 \cdot 0.048 = 0.27$

motorglider: $A.C^*_{Do} = 12 \cdot 0.022 = 0.26$

single-seat glider: $A.C^*_{Do} = 22.5 \cdot 0.01 = 0.22$

two-seat glider (~ ASK-21): $A.C^*_{Do} = 16.1 \cdot 0.014 = 0.23$.

Therefore, if both tow-plane and glider have the same wing loading, the optimum condition is approximately achieved.

Although the actual trend shows an increase of the glider wing loading, leading to extreme cases—in competitions—in which the glider wing loading exceeds that of the tow-plane, the normal situation (in club activity, for instance) is that the glider wing loading is around 30, whereas the tow-plane wing loading can rarely be less than 50 kg/m².

The design requirement for a tow-plane, therefore, should be for a wing loading approaching that of the average glider. A low wing loading, moreover, is highly beneficial to the reduction of the "power required for steady level flight", P_r.

A highly desirable characteristic would be that the P_r vs. airspeed curve is as flat as possible. This would allow towing at different airspeeds with a reduced loss of climb performance. As shown clearly in Fig. 3, the "overpowered motorglider" offers a remarkable advantage under this respect if compared with a traditional tow-plane.

● Propeller: Due to the low advance ratio (V/nD = 0.32 to 0.35), being 60 n in the range 2400/2750 rpm, D around 2 m and V around 30 m/s (see Table II), the propeller efficiency cannot possibly exceed a maximum value of approximately 0.65. This means that more than ⅓ of the engine power is lost in air vortices.

The direct way to improve the propeller efficiency would be to reduce its rotational speed. The propeller noise would thus be reduced at the same time. A gear ratio of 2:1 would raise the propeller efficiency from 0.65 to 0.75. However a reduction gear increases costs and weight. The larger propeller diameter would also bring direct and indirect weight increases.

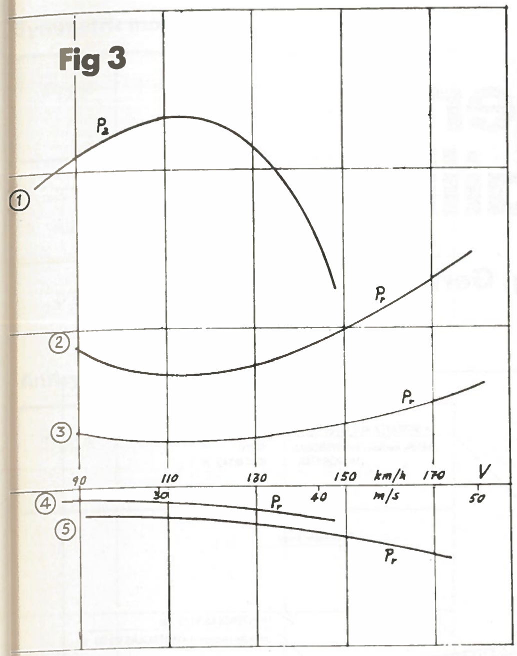
Fig. 3 shows the ample variation with airspeed of the "power-available", $P_a = \eta P$, when a fixed pitch propeller is adopted. A variable pitch propeller would practically yield a constant value of the power

Table III Performance Data

Tow Plane		POLYT 5	ESS-GAI	PIK 23
V_{NE}	km/h	232	300	281
Max. speed for airbrake extension	km/h	120	-	-
Max. speed for airbrake extended	km/h	165	-	-
Stalling speed	km/h	72	78	87
Rate of climb at sea level				
Solo	m/s	8	10.8	5.8*
Single seat glider	m/s	5	6.5	3.8*
Two seat glider	m/s	4	4.5	2.9*
Take-off distance to 15 m	m	140	115	320
Landing distance from 15 m	m	280	214	150

*75% power

Fig 3



① $P_a = \eta P$ (P = 180 hp, η_{max} = 0.65)
② Robin DR-400 (W = 760 kg, W/S = 55.9 kg/m²)
③ o/p motorglider (W = 660 kg, W/S = 55 kg/m²)
④ old-type single-seat glider (~Ka-6, W = 300 kg)
⑤ overloaded training two-seat glider (W = 750 kg)

available in the speed range of 90 to 150 km/h, greatly improving the tow rate-of-climb at low or high towing speed. Again, higher costs are the counterbalance of this benefit.

Other requirements and recommended features:

(1) Noise level limitation (65 dB(A)).
(2) STOL characteristics: e.g., take-off run within 300 m towing two-seat gliders.
(3) Fast descent: airbrakes or high deflection flaps with high operating and limit speeds.
(4) Reduction of risk of up-sets: tow-line attached close to a/c C.G. or increase of elevator power.
(5) Visibility in flight over 360° and vertical.
(6) Forward visibility on the ground.
(7) Efficient engine cooling during take-off and climb.
(8) Reduction of engine cooling during descent.
(9) Quick initial acceleration.
(10) Close turning manoeuvrability on the ground.
(11) Retraction of tow-line.
(12) Ease of maintenance: cowlings easy to remove; spark plugs simple to get at and change; strong simple landing gear; easy access to wheel brakes.
(13) Reduction of overhaul costs: no fabric (high re-covering costs); 4 rather than 6-cylinder engine; fixed pitch propeller.
(14) Rudder trim.
(15) Fuel system: simple, minimum chance for pilot error, minimum of tank selection during flight, accurate fuel level indication, simple re-fueling (no ladders).
(16) Engine protection from dust.
(17) Comfortable seating.
(18) Easily accessible tow release.
(19) Engine to be operable on MOGAS fuel.
(20) Ease of take-off in cross wind conditions.

Reference

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[2] Jane's – All the World's Aircraft, 1973/74.
[3] Technical documents by VALMET OY.
[4] Jane's – All the World's Aircraft, 1983/84.
[5] P. Morelli – "Some General Considerations on Sailplane Aerodynamic Design" – OSTIV Publ. III.