Increasing aircraft design flexibility – The development of a hydrostatic transmission for gliders with self-launching capability

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Abstract

This paper gives an overview of existing motor gliders and hydrostatic power transmissions. It shows the potential benefits of a hydrostatic power transfer for gliders with self launching capability, the required system properties and its limitations. Furthermore a preliminary system setup is described to demonstrate the challenges associated with this application. At the end a selection of unconventional airplane designs is discussed that could be realized by using a hydrostatic transmission in the propulsion system.

Keywords

glider with self-launching capability; hydrostatic transmission; propeller position; design flexibility; mechanically decoupled transmission

Contents

Nomenclature

AR	Aspect ratio
b	Wing Span
$\bar{c}$	Geometric Wing Chord
C_D	Drag Coefficient
C_L	Lift Coefficient
Δ	Delta
D	Drag
GR	Glide Ratio
L	Lift
MTOM	Maximum Take-Off Mass
n	Rotational Speed
P	Power
P_c	Climb Power
P_{req}	Required Power
$P_{req,h}$	Required Power for horizontal Flight
p	Pressure
Q	Flow Rate
RPM	Revolutions per Minute
S	Wing Reference Area
T	Thrust
V	Displacement per Revolution
v_h	Velocity in horizontal Flight
W	Weight (Force)
w	Climb Rate

1. Introduction

Today there is a variety of motor gliders available that allow a combination of independent flight operation with medium to high gliding performance at different levels. At the top end are high performance gliders with a fully retractable propulsion system. This allows independent take off, climb and cruise flight, but also ensures a high aerodynamic performance during the gliding phase. These airplanes are called gliders with self-launching capability.

They feature a combustion engine and an extendable pylon mounted propeller behind the cockpit. In the powered flight mode the propeller is extended above the fuselage. The power transfer from the engine to the propeller is commonly realized by a belt drive. There is no clutch to mechanically decouple the engine shaft from the propeller. Therefore the propeller has to be extended before starting the engine. This is particularly important for in-flight engine start, as an extended propeller significantly increases the drag as long as it does not create any thrust.

Due to the limited flexibility of the belt drive the propeller position is defined by the combustion engine's place of installation, as the extended propeller needs to be situated in-line with the combustion engine shaft. With the very limited space available in a high performance glider, the only position to install the engine is behind the cockpit. To ensure a clean aerodynamic shape for gliding, the propeller and the pylon need to be fully enclosed in the fuselage. So the available space in the aft fuselage limits the propeller diameter. For efficiency reasons a large propeller diameter would be desirable [1].

2. Motor Gliders

The historical background for motor gliders is leisure flying, which still is the main application. Although not reflected in the German aircraft registration regulations, there are two fundamentally different configurations and thus, purposes: high performance and touring motor gliders. The German registration features the letter “K” behind the national letter “D”, e.g. D-KXYZ. The applicable certification specification is the EASA CS-22 [2].

Table 2.1: Motor glider properties and performance

	DG 1001 T [3]	ASH 25 EB 28 [4]	Stemme S10 [5]	Super Dimona [5]
Type	Sustainer	Self Launching	Touring	Touring
Seats	2 (tandem)	2 (tandem)	2 (side by side)	2 (side by side)
Max. Power [kW]	22	45	85	85
Max. Take Off Mass [kg]	780	810	850	770
Wing Span [m]	18	28	23	16
Aspect Ratio	19	45	28	17
Max. Glide Ratio	1:45	1:60	1:50	1:27
Max. Climb Rate [m/s]	1,5	2,6	4,2	5,4

Both classes feature the most common airplane configuration – not considering the propulsion system – with the wing providing lift close to the overall center of gravity. A horizontal stabilizer at the tail provides longitudinal stability. Lateral stability is achieved by a vertical stabilizer also at the tail. The stabilizers are usually combined to an empennage, where a T-tail is widely used – especially for high performance gliders.
High performance gliders can be found as single and twin seaters, the latter in a tandem arrangement. Touring gliders are mostly two-seaters with both occupants sitting side by side.

The high performance class comprises gliders that are equipped with a propulsion system to increase the operational flexibility and to avoid outlandings. Depending on the system these gliders are self-launching or are limited to in-flight engine operation. The latter use a so called sustainer engine. Both types have in common that the propulsion system consists of an internal combustion engine and a propeller behind the cockpit. The complete propulsion system can be retracted into the fuselage to keep the high aerodynamic performance of the base-line glider. For long range flights a saw tooth flight profile is applied. It consists of a phase of powered climb, which is succeeded by a descent with a retracted propulsion system. This is then again followed by a powered climb and so on. The ranges that are achieved by flying a saw tooth profile are significantly larger, than those with a continuous engine operation in level flight [6] and [7].

Whereas gliding is the main purpose of high performance motor gliders – leading to relatively short engine operation – touring motor gliders are mostly operated in the powered flight mode. With the engine installed in the nose in front of the cockpit, their propulsion system features the same characteristics as these of single engine propeller aircraft. However, touring gliders, like the Scheibe family members [8], are also used for gliding with the engine shut down and the propeller turned into the minimum drag position.

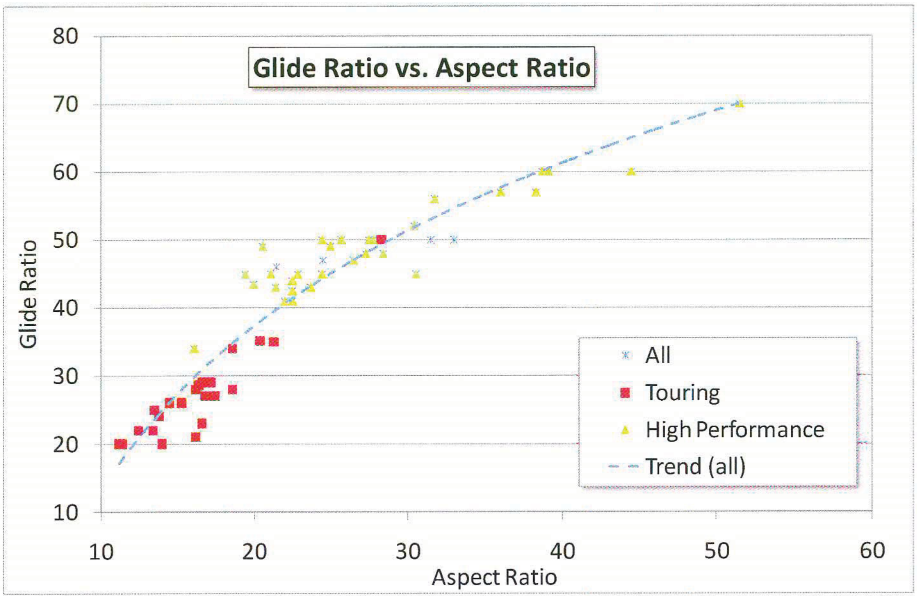


Figure 2.1: Maximum glide ratio vs. aspect ratio for motor gliders

Next to the propulsion system, another important difference between touring and high performance gliders is the wing aspect ratio. At a given wing area a large aspect ratio leads to a small geometric wing chord and to a large wing span, posing challenges regarding structural and flight control system installation aspects. In-flight agility is also affected, and ground handling is getting a more important issue.

$$AR = \frac{b^2}{S} = \frac{S}{\bar{c}}$$

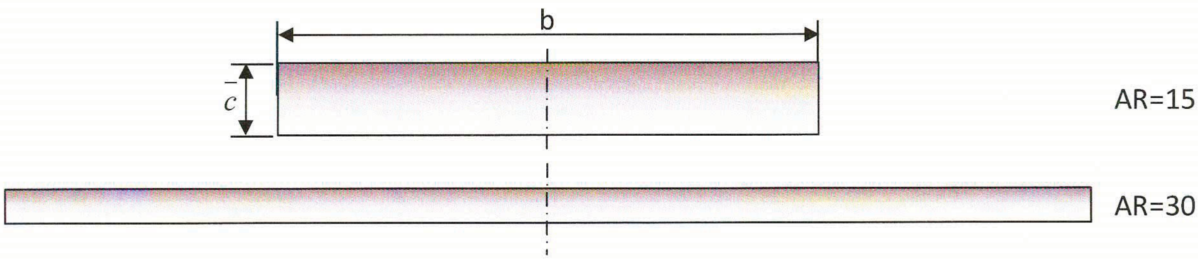


Figure 2.2: Aspect ratio comparison for wings with the same area

The aerodynamic performance of an airplane is expressed by its glide ratio GR. Figure 2.1 shows that there is a close relation between the aspect ratio of the wing and the maximum glide ratio. It also makes clear, that – with one exception, the Stemme S-10 (compare Table 2.1) – touring gliders have a significantly smaller glide ratio than high performance motor gliders.

$$GR = \frac{C_L}{C_D} = \frac{L}{D}$$

In horizontal flight at constant speed, when lift is equal to the weight force, and thrust is equal to drag, the glide ratio represents the ratio of weight force to thrust. Hence, the required thrust can be derived from the glide ratio and the weight of the airplane.

$$T = \frac{W}{GR}$$

For the combination of an internal combustion engine with a propeller it is more meaningful to state the required power, here without considering any losses.

$$P_{req,h} = \frac{W}{GR} \cdot v_h$$

It becomes obvious, that at a given velocity the power demand decreases with an increased glide ratio. The weight influences is linear, so a heavier aircraft requires correspondingly more power.

The maximum climb rate is an important parameter for take-off and for the overall performance assessment, e.g. to minimize the time to reach the initial gliding altitude. In the power equation the climb rate adds another linear factor.

$$P_{req} = P_{req,h} + P_c = W \cdot \left(\frac{v_h}{GR} + w\right)$$

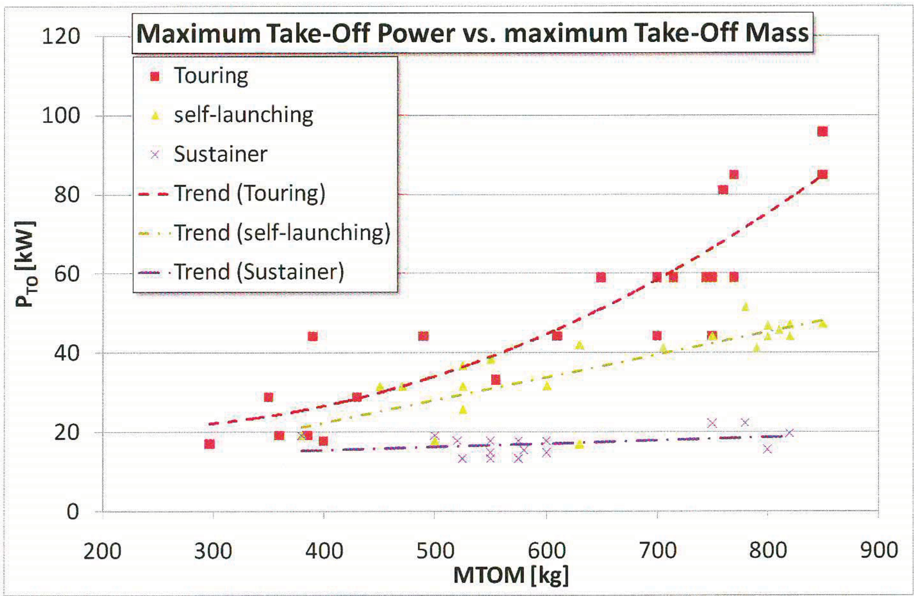


Figure 2.3: Maximum take-off power vs. maximum take-off mass

The comparison of the installed maximum take-off power for the different glider types in Figure 2.3 shows, that touring gliders have generally the most powerful engine, followed by self-launching high performance types. As touring gliders are also used for towing, the stronger engines are not only reflecting the smaller glide ratio but also the need for higher climb rates.

The sustainer engine offers the least available power, reflecting the fact, that there is no need for a high climb rate at take-off.

2.1. Touring Motor Gliders

Closest to general aviation airplanes for leisure flying is the touring class motor glider. It features a usually in the nose installed engine that drives a fixed or constant speed prop and a wing with – compared to other general aviation airplanes – a high aspect ratio. This leads to a relatively low power demand in cruise flight and allows leisure flying at reasonable costs. Figure 2.4 shows the Diamond HK36 Super Dimona, a popular touring motor glider.

Figure 2.4: Diamond HK36 Super Dimona towing a glider, picture with kind permission of Diamond Aircraft [9]

One of the first touring motor gliders was the Fournier Sportavia RF-3, a single seater with a 29kW engine and a maximum take-off mass of 390kg. Its first flight was in 1963.

2.2. Gilders with Self-Launching Capability

Based on conventional gliders without engine this type features a propulsion system that is installed behind the cockpit. It offers high operational flexibility with maximum gliding performance. In many cases the complete propulsion system can be removed, so the airplane can be utilized like a conventional glider, avoiding possible drawbacks in a competition, especially regarding water ballast loading.

The propulsion system consists of the engine, a propeller pylon, the – usually fixed pitch – propeller, the power transfer and an extension mechanism. Due to their low mass and simplicity two-stroke reciprocating engines, with water or air cooling, are most commonly used. An exception is the Wankel engine powering the Alexander Schleicher self-launching gliders (Figure 2.5). Its total mass of 27,8kg, combined with the very compact shape and a maximum take-off power of 40,4kW makes it ideally suited for this purpose [10] and [11]. To house the propulsion system the fuselage has to be cut open behind the wing to accommodate an engine compartment. It is closed during gliding by two doors. The engine compartment also contains the fuel system. Fuel tanks can be installed in the fuselage or in the wings. Typically the fuel quantity lies around 20liter for fuselage installed tanks. Due to the highly tapered fuselage behind the wing, the propulsion system installation poses significant challenges with respect to structural and space aspects. Also, the addition of mass behind the wing affects the center of gravity location, leading to tighter weight and balance restrictions compared to the baseline model without engine.

Figure 2.5: Alexander Schleicher ASH 31 Mi high performance self-launching glider with extended propeller, picture with kind permission of Alexander Schleicher Flugzeugbau [11]

Depending on the propulsion system, the engine is either totally fixed in the engine compartment or tilts upwards with the propeller pylon. The latter is used for direct engine cooling, whereas a fixed engine requires a separate cooler in the propeller slip stream. To transfer the power from the engine to the propeller, and to adapt the engine shaft rotational speed to an RPM suitable for the propeller, a belt drive is employed. In most cases a toothed belt is used. DG-Flugzeugbau however has opted for five V-Belts in the DG-1001M aiming at the reduction of noise and vibrations [12]. The Alexander Schleicher tooth belt transmission features two tensioner pulleys that assure proper belt tension when the propeller pylon is extended. While retracted the belt tension is released. An electric screw jack actuator, countered by a gas spring, moves the pylon for extension and retraction. Before retraction and closing of the engine compartment doors, the propeller is arrested in a defined position. There are also extension mechanisms with a hydraulic actuator.

As there is no clutch in any of the standard designs, the propeller has to be fully extended before engine start-up. While not problematic on the ground, it can play in important role in flight. With the propeller fully extended, there is a period when the propeller does not produce any thrust. In fact, it incurs significant drag. This leads to an increased sink rate by a factor of three according to [6]. That means, in case the engine does not rev-up, or the power transfer to the propeller fails, the time available to identify a potential outlanding area is significantly reduced. This condition is further aggravated by the common practise to extend the propeller at an altitude as low as possible. A decoupling of the engine shaft and the propeller would be desirable, to permit starting the engine without extending the propeller. This would avoid the drag penalty in the case of a drive train failure and might also avoid the loss of points in a competition. The pilot could start-up the engine at a higher altitude without decreasing the airplane's performance, thus increasing the safety margin.

Figure 2.5 shows the ASH 31 Mi in powered flight. The propeller disc above the fuselage leads to a thrust vector with a significant lever around the aircraft center of gravity, resulting in a nose-down pitching moment. This has to be counteracted by trimming with the elevator (or the complete horizontal tail or a trim tab).

2.3. Gliders with Sustainer Engine

From a propulsion system installation point of view, gliders with a sustainer engine are comparable to gliders with self-launching capability. The complete propulsion system can be retracted into the fuselage for gliding and propeller disc is located above and behind the cockpit in the powered flight mode. As a sustainer engine is mainly intended to prevent outlandings, it does not need to provide power for an independent take-off. Therefore the engines are considerably smaller, lighter and simpler than those for self-launching gliders (compare Figure 2.3). Their maximum power lies in the area of 20kW. Further significant differences in the propulsion system comprise the installation of the engine on top of the extendable pylon and in many cases the lack of an electrical engine starter. The latter leads to the obligation for a wind milling engine start-up in flight, which is associated with an altitude loss of 70m to 140m.
Gliders with sustainer engines are launched like conventional gliders by means of a winch or a tow plane.

3. Hydrostatic Power Transmission

Nominal pressures of hydrostatic power transfer systems can vary between less than 100 and up to 1000bar for special applications. Transport aircraft hydraulic systems are traditionally designed for a pressure of 207bar (3000PSI) [13]. In contrast, the Airbus A380 features a 345bar (5000PSI) hydraulic system, which leads to mass savings of more than 800kg, compared to the standard operating pressure [14]. For industrial application a wide range of components is available for a maximum continuous pressure of 420bar.

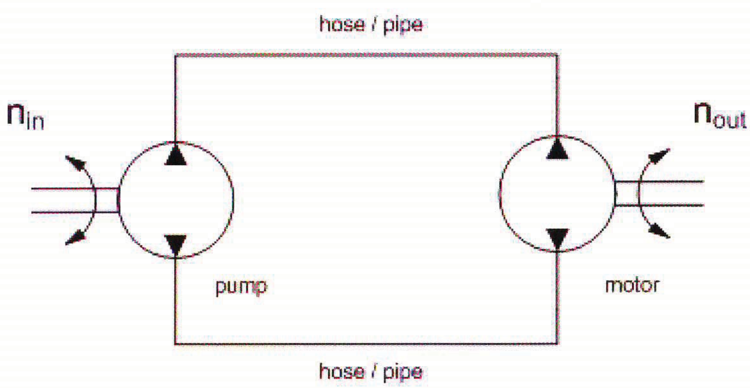


Figure 3.1: The sketch of a simplified closed loop hydraulic circuit.

A simplified closed loop hydraulic circuit, shown in Figure 3.1, consisting of a pump and a motor can be used in principle as a gear box. Depending on the ratio of the displacement of pump and motor a constant transmission ratio can be realized, also adjustable transmission ratios when one or both components feature a variable displacement.
The pressure in the system depends on the torque of the motor. The size of the components is related to the maximum pressure, for example 420bar and the displacement. Hydrostatic

transmissions belong to the group of form-closed transmissions, but in reality internal leakages cause a little loss of the motor speed. In addition a small loss of pressure, caused by friction and throttle effects is inevitable. Both affect the overall efficiency of the transmission which will be around 85%.
Pump and motor can be connected with hoses. The position of both main components can be chosen freely. This is one of the main advantages. Most hydrostatic drives can be used in both directions of motion and in both direction of torque (four quadrants). So both lines can be the pressure lines. The volume to power ratio (m^3/kW) and the mass to power ratio (kg/kW) of a hydrostatic transmission are smaller than in an electric transmission system, but larger than for a mechanical gear.
Apart from the main components pump and motor it is necessary to have a feed pump and a flushing valve to control the volume of the oil in the circuit, which is shown in Figure 4.3. Also the heat has to be cooled in an air-oil heat exchanger. The cooler, the feed pump and the flushing valve are connected via check valves always to the low pressure lines. Pressure valves limit the maximum pressure in case of an over-torque at the motor shaft. Also a reservoir for the oil must be installed.
Hydrostatic transmissions are used in many different technical systems. For example: winches, drives of excavators and caterpillars, motorcycles, lawn movers, agriculture machines and hydraulic test rigs for gear boxes. The power can be more than 1000kW, but also small drives with just a few kilowatts are realized.

4. Hydrostatic Propeller Drive

The idea of a hydrostatic power transmission for a motor glider is not new. Still, there has yet to be a successful development and application. The basic lay-out would comprise a pump, flanged directly to the combustion engine shaft and the hydro motor (motor in the following) with the propeller attached to its shaft, as main components. Adapting the rotational speed between the engine shaft and the propeller can be realized by selecting the appropriate displacement for the pump and the motor. There would be no need for an additional mechanical gear.
A glider with self-launching capability seems quite suitable to demonstrate the general system feasibility. An intermitting engine operation suggests that a potential efficiency disadvantage would not be too problematic. An application for a sustainer type does not seem promising, as this type's main construction principles is simplicity. For a self launching glider even the likely addition of mass is not necessarily a problem. As it is common practise to load water into the wings to increase the wing loading, minimizing the overall mass is not a main driver. More important is however the mass distribution, reflecting the limited load carrying capacity of the engine compartment, and the desire for a maximized loading flexibility. As mentioned above, even current propulsion systems can negatively affect the available center a gravity range. So adding mass behind the cockpit would aggravate this effect.

4.1. Benefits

As mentioned above, the propeller has to be extended to start-up the engine in conventional systems. Once the propeller is in place, the drag is significantly increased, leading to an – up to three times larger – sink rate. In case the engine does not rev-up, or the power transfer is interrupted, the time frame for the pilot to identify a suitable landing field and to perform a stable approach becomes critical. Therefore, it would be desirable to start the engine while still gliding without extending the propeller. Firstly one could do so at a higher altitude, without ultimately ending a successful gliding flight. In case of a malfunction there would be more altitude and thus time available to prepare an outlanding. Secondly, even if the engine is not started at a higher altitude, the clean aerodynamic shape would increase the margin for the landing preparation.

With a hydrostatic transmission a simple valve set-up could incorporate an idle circuit that decouples the propeller from the engine shaft. Once the engine runs the fluid could flow in a closed circuit for a certain time. This would also allow pre-heating the hydraulic fluid after a long flight in cold temperatures.

Ultimately a hydrostatic power transmission with an integrated idle circuit would be beneficial for flight safety.

Another aspect, affecting the whole airplane and propulsion system configuration is the lack of a rigid mechanical connection between the engine shaft and the propeller hub. The currently employed belt drives have a very limited flexibility and therefore force a propeller position in line with the engine shaft. This basically means that today the propeller position is defined by the installation space requirement of the engine. A hydro motor could be installed at any desired point in the airplane, as it could be connected by flexible hoses, or shaped pipes. The high power to weight ratio of hydraulic machines and their compact shape offer good installation opportunities.

If there are constraints regarding the possible propeller diameter, the hydrostatic transmission would easily allow a power split, to drive two (or more) propellers with one engine.

As the internal losses are absorbed by the fluid, a single heat exchanger can be utilized to dissipate this energy, reducing the need direct cooling of the hydraulic machines. The central heat exchanger could be placed in the propeller slip stream, to increase its efficiency.

By adding configuration flexibility the hydrostatic power transmission increases the number of degrees of freedom in airplane and propulsion design, with the option to keep proven components, such as the combustion engine.

4.2. Technical Requirements

Initially the goal is to optimize a closed loop hydrostatic transmission with a fixed displacement pump and motor. As the glider manufacturer Alexander Schleicher is one of the project partners, the propulsion system applied in their airplanes defines the design parameters such as power and rotational speeds. The overall mass and the efficiency in the design point of operation are identified as the most critical system properties.

Table 4.1: Basic performance parameters for the hydraulic transmission conception [10], [15] and [16]

P_{max}	40,4kW
$RPM_{in,max}$	7750
$RPM_{in,cont}$	7100
$RPM_{out,max}$	3000

Table 4.1 shows the basic performance parameters that need to be considered for the transmission design. The maximum power and the input values, such as maximum and maximum continuous rotational speed are given by the engine. The propeller defines the maximum output RPM.
As the availability of a suitable pump and motor is decisive for a potential realization, a market survey was done. Figure 4.1 shows the results for pumps as a comparison of design rotational speed and maximum power. Here, the design point is at 7750RPM and 41kW. Suitable pumps need to be to the right and above that point. It is obvious that only bent axis machines with a constant displacement offer the required performance.

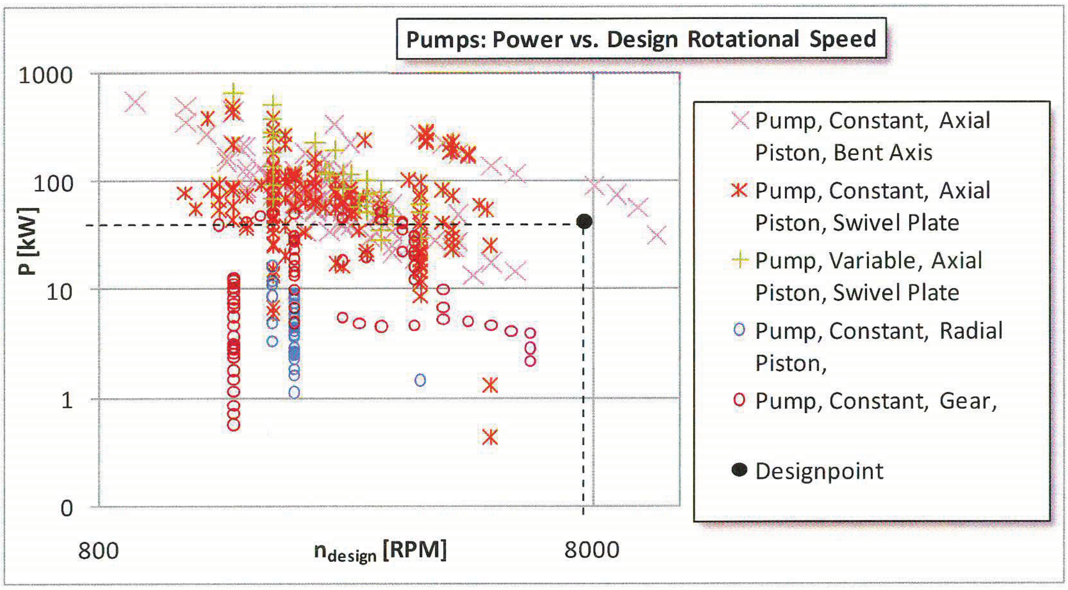


Figure 4.1: A selection of available pumps, showing hydraulic power capability as a function of shaft RPM

To transform the high input RPM to a suitable speed for the propeller, the correct ratio between the pump and motor displacement has to be calculated with the following equation.

$$\frac{n_{in}}{n_{out}} = \frac{V_{Motor}}{V_{Pump}}$$

In this equation n_{in} is the input RPM (the rotary speed of the engine), n_{out} is the output RPM (the rotary speed of the propeller) and V is the displacements of pump and motor.
Without considering losses the ratio of the displacements of pump and motor are anti proportional to the respective shaft RPM. To assure a propeller speed lower than 3000RPM the motor displacement has to be at least 2,6 times larger than the pump's.

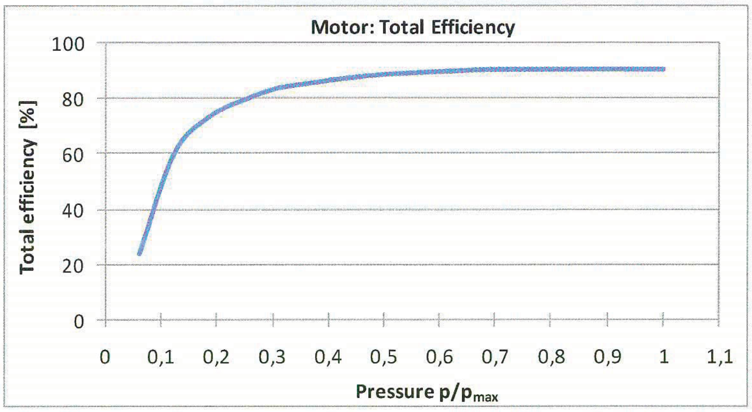


Figure 4.2: Exemplary function of the total efficiency of a motor vs. the relative pressure difference

Assumingly the two hydro-machines (pump and motor) have the highest impact on the overall system efficiency. Figure 4.2 shows how the overall efficiency of the motor depends on the system pressure difference. At about 50% and more of the maximum pressure the achieved efficiency lies around 85 to 90%. Similar values can be expected for the pump. As the rotational speed has a similar influence as the pressure difference, the selection of both components can greatly affect the overall performance of the transmission. The estimate is that a value of 80 to 85% is achievable.

4.3. Preliminary Layout

By defining the most important system parameters, like design pressure and flow rate, the required displacements for the machines can be derived. To transfer a given power P a certain flow rate Q at a certain pressure difference Δp has to be provided by the pump.

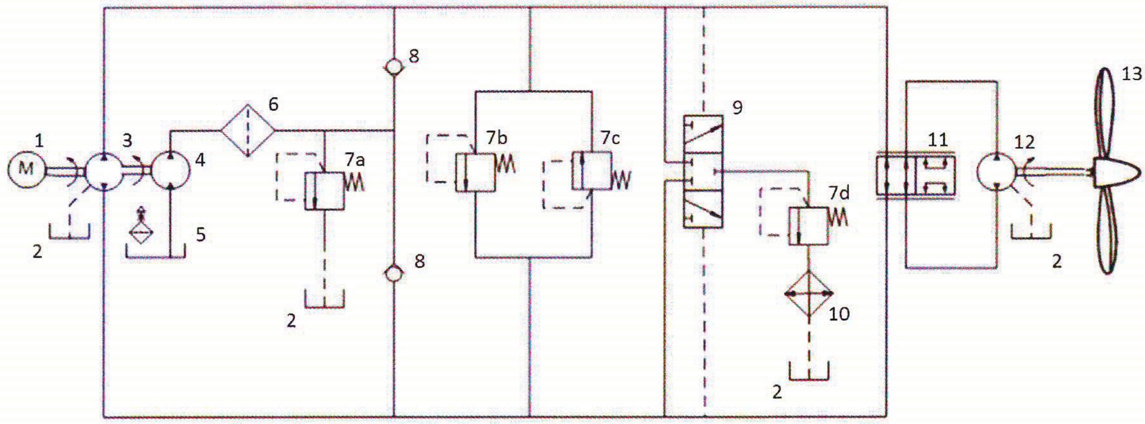
$$P = \Delta p \cdot Q$$

By increasing the pressure, the flow rate can be reduced, also reducing the overall fluid volume. For overall mass reasons a relatively high pressure seems advantageous. Not only is the fluid mass reduced, but also the size and thus mass of the pump and motor.

$$Q = V \cdot n$$

From the market survey a suitable pump with a displacement of 10ccm was identified. At the maximum rotational speed of 7750RPM – without considering any losses – the resulting flow rate is 77,5ltr/min. This yields a pressure difference of approximately 320bar (4640PSI) to achieve the 41kW transfer power.

From the pump displacement a minimum motor size of 26ccm can be derived by using the above calculated ratio of 2,6. The selected unit has a displacement of 28ccm. It is estimated, that the two selected units lead to a combined efficiency of around 84%.



Position	Name of the Part	Position	Name of the Part
1	combustion engine	8	Non-return valve
2	drain losses / cooling flow	9	flushing valve
3	main pump	10	oil cooler
4	charge pump	11	idle valve
5	oil reservoir	12	motor
6	oil filter	13	propeller
7a-d	pressure relief valves		

Figure 4.3: Principle lay-out of a hydrostatic transmission with idle valve

A preliminary system lay-out is shown in Figure 4.3. It is characterized by a closed loop design and an idle valve at Position 11 (P. 11) to disconnect the motor (P. 12) from the fluid flow and to allow a slow power transfer to the propeller (P. 13) to avoid sudden load changes. The shown system allows forward and backward power transfer, which means that there is still the possibility to start the engine (P. 1) by wind-milling. In case the power direction changes, the motor would act as pump and vice versa.

A charge pump (P. 4) is required to assure that the minimum pressure does not drop below the required suction pressure for the main pump (P. 3). It also compensates for case drain losses of the machines and for the fluid volume that is taken from the low pressure line for cooling. The charge pump sucks oil out of the oil reservoir (P. 5), which in turn is refilled by the case drain and cooling fluid flow (P. 2). In order to minimize the system mass, it is planned to reduce the tank volume to 8 to 10 liter. A conventional system would feature at least a 40 to 60 liter tank. The two pressure relieve valves (P. 7b/c) protect the system from over pressure. It is advantageous, or better, required, to provide a pressure of at least 10bar to the main pump on the suction side, to prevent cavitation. The pressure relieve valve in the flushing line (P. 7d) is defining the low pressure level in the main circuit. To be protected from overpressure the heat exchanger (P. 10) is installed downstream of that valve.

As there is hydraulic power available, it makes sense to use a hydraulic cylinder for engine extension and retraction. From the currently used electric actuator specification the required cylinder can be roughly calculated. By using the low pressure of for example 15bar the required piston diameter would be 32mm. To achieve the same extension speed as the electric actuator a flow rate of 1,28ltr/min would be needed. So the charge pump would have to provide 32W. The extension mechanism is not incorporated into the hydraulic system lay-out yet, but considering the above outlined power demand it seems feasible using the charge pump as power source.

4.4. Limitations and Drawbacks

There are some obvious hurdles that stand against the utilization of a hydrostatic gear in a self-launching glider. One is certainly the mass issue. Although, as stated above, one could justify a weight penalty for performance reasons, it still has negative influences on weight and balance considerations. The aim of 25kg for the complete hydrostatic power transfer might be hard to achieve.
Another factor is that while the belt drive is a relatively simple and efficient power transfer, a hydraulic system is a lot more complex and will lead to less available power at the propeller.
At a later stage, if the technical feasibility can be confirmed, certification requirements and costs may still stand against the planned application.

5. Potential Glider Designs

The increased flexibility of positioning the propeller independently from the combustion engine offers opportunities for a variety of unconventional aircraft configurations. Currently it seems that for competition and leisure flying there is no need to significantly change the proven configuration, maybe apart from a propeller installation in the nose.
However, if the desired flight profile differs from the mission of a self-launched high performance glider the option to relocate the propeller and/or the engine can be advantageous. As the hydraulic transmission easily allows splitting the power even the application of multiple propellers, driven by a single engine can be realized.
There are a number of aspects that need to be considered when selecting the position of the propeller. Among these are for example: propeller efficiency, crash behaviour, dangers to the pilot in case he or she has to exit the cockpit in flight, noise, influence on the airplane aerodynamic during gliding, required structural reinforcements and consequences on weight and balance affecting longitudinal stability. The following subchapters give some ideas about potential configurations. The outlined characteristics are certainly not comprehensive, but they can give an impression of the influences of the propeller installation.

5.1. Propeller in Front of the Cockpit

Considering the propeller installation of today's high performance motor gliders, a nose mounted propeller would offer several, however not only, advantages.
Mounting the propeller in the nose would apply the associated loads directly into the fuselage structure, avoiding their redirection through a propeller pylon. As the thrust vector would be directed through the airplane's center of gravity there would be less, if any, need for trimming the elevator in case of power setting changes.
Looking at the structure behind the cockpit, moveable air inlets could provide sufficient cooling for the engine. Therefore the fuselage cut out, which might still be necessary for engine installation purposes, can be closed by load carrying panels. This would again lead to a closed profile, which has a significantly higher torsional stiffness than an open profile.

Figure 5.1 illustrates the need for a high landing gear to assure sufficient ground clearance for the propeller. A single main gear would no longer be suitable to avoid additional wheels with long struts on the wing for balancing. Consequently there would need to be two main landing gear legs, forming a wheel track as large as possible for stability reasons. The latter is particularly important considering the large wing span of higher performance gliders.

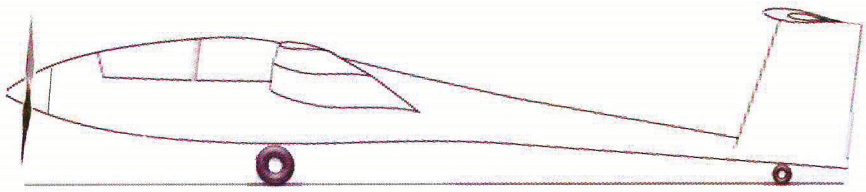


Figure 5.1: Suggested configuration of a tandem seater high performance motor glider with propeller in the nose

To incorporate a foldable propeller, the nose section has to be strengthened and most likely extended.
Due to the required modifications to the entire aircraft, it does not seem like an option to equip an existing high performance glider with such a propulsion system. Rather a complete new design or a particular derivate of a current model would be required.

The twin seater Stemme S10 (compare Table 2.1) is an example of a motor glider with a very high glide ratio and a propeller in the nose. Untypical for touring motor gliders, its engine is installed behind the cockpit. The power transfer to the propeller is realized by a carbon shaft running through a tunnel between the two seats [17].
There is also a glider with sustainer engine that makes use of a nose installed propeller. It is the electrically powered LAK 17b FES. In contrast to the S-10, its propeller is not completely covered in a nose cap during gliding, but folds backwards against the fuselage [18] and [19].

5.2. Propeller in the Tail

There are examples of motor gliders with a propeller in the tail. Both positions, in front and aft of the empennage were realized. A vertical tail mounted propeller can be relatively large, as there is no need for a fuselage cut-out and ground clearance can be assured, just by the height of the vertical tail. In case of a propeller in front of the empennage ground clearance is not an issue at all.
Installing the propeller in the tail has significant consequences for the tail structure. The propulsive and reaction forces need to be directed through the fin into the fuselage. Looking at the intersection of the empennage with the rear fuselage tube (Figure 2.5), current designs feature a weak spot here.
Due to the short distance between the propeller and the lifting and control surfaces of the tail, it is very likely that the power setting affects the airplane's controllability and stability.

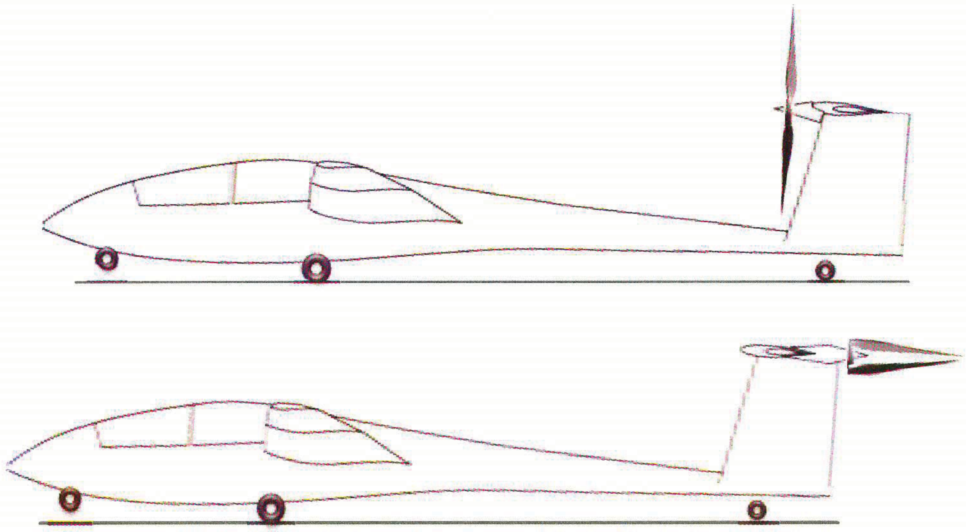


Figure 5.2: Suggested configurations of a tandem seater with propeller installation in the tail

From an aerodynamic point of view, the installation aft of the stabilizer seems better. Here the propeller can be folded out of the free air flow to reduce its drag. The Sunseeker ultra light electric motor glider features a foldable propeller in the tail [20]. At the Institute for Aircraft Construction (IFB) of the University in Stuttgart, Germany [21] two gliders with a propeller installation shown in Figure 5.2 were designed and built, or are currently under construction. The Icaré II is an electrically powered high performance single seater with a 12kW motor and the propeller aft of the tail. Also electrically powered is the e-genius, which can be categorized as a touring motor glider. It features an electric motor on top and in front of the vertical tail.

5.3. Twin Prop

As a hydrostatic power transfer allows splitting the available power to two (or more) motors, a configuration featuring multiple propellers could be realized. Smaller propellers could be utilized, to avoid some drawback of the above described configurations.

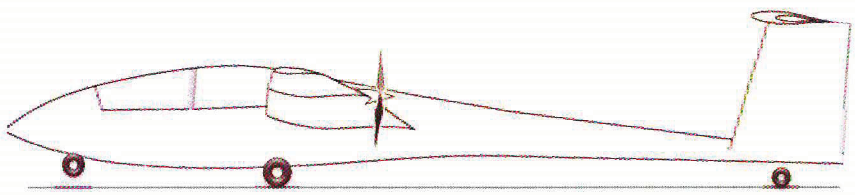


Figure 5.3: Suggested configuration of a tandem seater with two propellers installed in the wing trailing edge

Like for the configuration shown in Figure 5.2, bottom a foldable propeller could be used to lower the drag in the gliding mode.
The AeroVironment Global Observer, a high altitude long range and endurance unmanned air vehicle (UAV), features an internal combustion engine with its power being distributed to four propellers [22]. In this case however, an electric power transfer is employed.

6. Conclusion

The research on hydrostatic transmissions, motor gliders and the currently available hydraulic components suggests that it is technically feasible to design and build such a system for the application in a glider with self launching capability.

A hydrostatic transmission between the engine and the propeller has the potential to overcome disadvantages of the currently used belt drive transmissions. To decouple the engine from the propeller, a preliminary lay-out comprises a valve controlled idle circuit. Herewith flight safety can be increased.
From an installation flexibility point of view, the hydrostatic transmission allows an installation of the hydro motor at almost any position in the airplane. This leads to the possibility to place the propeller independently of the combustion engine, opening new options for motor glider designs.

It still has to be shown, that a hydrostatic transmission can actually improve motor glider characteristics, or offers a significant benefit for other airplanes with a similar flight profile. An application in a UAV could prove more promising than in manned gliders for leisure flying.

Funding of the research is provided by the German Federal Ministry of Education and Research to which the authors herewith express their acknowledgement. We are also very thankful for the support provided by our project partners Alexander Schleicher Flugzeugbau (Poppenhausen, Wasserkuppe), the Institute for Fluid Power Drives and Controls at the Aachen Technical University and GL Hydraulics (Aachen).

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