



# NEW WHEEL ASSEMBLY DESIGN ON GRÉGOIRE-BESSON SP/SPML PLOUGH RANGE

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ON GRÉGOIRE-BESSON SP/SPML PLOUGH RANGE**

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## EXECUTIVE SUMMARY

Farmers are facing tougher competition every day as agriculture continues to become a more globally integrated industry. In order to face this pressure they must reduce their production cost and increase their efficiency. Tillage is one of the target areas for cost reduction as it consumes a lot of energy and time. Although ploughing is slowly losing ground to other tillage practices, many speciality crops, climatic zones and niche markets continue to require the use of ploughing as a key practice in their tillage system. Grégoire-Besson is committed to fulfilling the needs of these customers and helping them improve their profitability. Increasing efficiency by design is the main goal of this project. By looking at the weak areas of the existing SP/SPML plough range, new concepts to improve the rear wheel design will be created. A design methodology will be established based on the most recent scientific and engineering data and techniques. Finally a work schedule and cost analysis will be proposed. The ultimate goal of the project is to design a virtual wheel assembly prototype for Grégoire-Besson's SP/SPML plough range.



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## INTRODUCTION

Agriculture has experienced tremendous changes during the second part of the 20<sup>th</sup> century. Numerous technological and scientific developments during the post-war period have been widely adopted by farmers in developed countries to boost farm productivity and move agriculture from a subsistence activity to a globalized industry. Chemicals use has been one of the major changes, with a widespread utilization of pesticides to control crop pests and commercial fertilizers to balance crop nutrient inputs. Methods of doing field operations have changed, too. In North America, the last two decades saw the gradual replacement of conventional mouldboard ploughing with new conservation techniques such as no-tillage and minimum-tillage using chisel ploughs and discs. Europe is also experiencing a change of tillage practices, albeit at a slower pace than in North America. Many agronomists and machinery specialists have seen in this trend the potential extinction of ploughing as a tillage operation.

There are many factors making ploughing less attractive compared to conservation practices: high fuel cost, relatively slow work rate, high tractive force required, etc. Furthermore, ploughing is often blamed as one of the main cause of soil erosion resulting from the low amount of crop residue left at the surface. Although these concerns are totally justified, it is important to make some distinctions based on regional differences. Conservation practices are particularly well adapted to climates where large amounts of crop residue cover do not impede natural soil drying and warming; these dry and warm climates are mostly encountered in the American Midwest, the Canadian Prairies, Argentina, Brazil, South Africa and Australia. However many other important arable regions such as most of Europe and North Eastern North America experience high rainfalls and have relatively short growing seasons. In these cases, ploughing can be beneficial as part of a diversified tillage system.

The latter regions often receive large amounts of rain during harvest time, causing inappropriate soil conditions for harvest operations. Harvest often results in ruts and other soil damages which are best remedied by ploughing. In comparison to other primary tillage operations ploughing is the method that produces the best results

under wet conditions. Also, because it buries most crop residue, it leaves soil exposed for faster drying and warming. The burial of crop residue is also very important for some specialty crops (peas, beans) which must not be contaminated with soil. The fact that soil is completely moved to a depth of 150-250 mm also makes of the plough an excellent tillage instrument for roots and tuber crops (carrots, potatoes, etc.) which require a loose seedbed with not surface compaction.

In addition to the technical benefits of ploughing, the technique may soon make a come back in our fields as a method of reducing our dependency on chemicals, particularly pesticides. The European Parliament voted a new directive in 2007 calling for 50% reduction of active pesticide ingredients used in agriculture by 2017 (European Parliament, 2007). Ploughing is a method of choice to control crop pests and weeds. In particular, it is a very important and effective tool to control slug populations which are extremely damaging to wheat and oilseed rape crops.

Ploughing still has its place as a major tillage practice. However, to gain the most from the technique it is important to include it in an integrated sustainable farming system that includes tillage rotation, crop rotation and pesticides rotation.

As farmers have to compete in a global agricultural industry, it is important to have efficient equipments that will help reducing production costs and increase productivity. A major player in the tillage equipment industry in Europe and globally, Grégoire-Besson SA asked me to evaluate the current design of their SP/SPML reversible plough range and to produce a new wheel assembly design which has been demanded by customers in certain markets for a number of years.

## THE INITIAL PROJECT SELECTION PROCESS

I had multiple project ideas prior to beginning this project. They all had one common point: agricultural engineering was to be the cornerstone of any project I would undertake. Having a good background in soil conservation and a great interest in machinery design, I decided to contact Mr. Cyril Thirouin, eng., who I met a few years ago when he worked in Quebec. Mr. Thirouin is now head engineer for Grégoire-Besson in France. He initially proposed me to work on the design of a new disc harrow frame to be built in Canada; he also put me in contact with Simon Bourque, manager of Grégoire-Besson Canada in St-Hyacinthe. The first meeting with Mr. Bourque consisted of defining what the project would look like and evaluate the amount of work required. After this initial meeting, I started evaluating the possible design options for the frame of the machine using the existing technical drawings. During a second meeting with Mr. Bourque at Macdonald Campus, we came to the conclusion that the disc harrow design was not suitable for the design course. We made a list of projects of interest for the company: strip-tillage row unit, subsoiler frame and spring-reset system and reversible plough wheel assembly. After a few weeks, Mr. Thirouin and Bourque agreed to offer me the possibility of designing a new wheel assembly for ploughs. This project will be detailed in the following pages.



## **PORTRAIT OF THE COMPANY**

Grégoire-Besson SA is based in Montigné-sur-Moine, in Eastern France. It is a leader in tillage machinery in Europe and globally. Its product range includes mouldboard ploughs, disc ploughs, disc harrows, disc-tine cultivators, subsoilers, light cultivators and potato planters. In addition to its home base in France, the company also has international subsidiaries in the United Kingdom, Canada, Spain and Poland. It is a family-owned company, with Patrick Besson as the main shareholder and CEO of the company.

### **HISTORY**

The origins of the company can be traced back to 1802 when Mr. Grégoire started a small shop in Montigné (Grégoire-Besson, 2007). During the following century it evolved into a small farm machinery manufacturing shop. In the 1960's and 1970's, the company grows quickly due to the success of its products. During the last two decades, the company continued to grow and took over other tillage equipment manufacturers (tines and discs) to widen its products offer. In the last few years Grégoire-Besson also established itself as the leader for large tillage equipment by establishing new world records for the area ploughed in 2005 and for the area disced in 2007.

### **BUSINESS MODEL AND COMPETITORS**

Since Grégoire-Besson is a small company compared to giants like John Deere, CNH, Kuhn and Kverneland, it has established itself as a specialised company focusing on only one product type (tillage) for niche markets. It offers highly customisable machines that can be adapted to fit the specific needs of each customer. This highly adaptable product range also means that the company is able to fulfil the requirements of markets considered too small by large manufacturers. The main market for Grégoire-Besson is Europe. The main competitors of Grégoire-Besson are Kverneland (Norway), Kuhn (France) and Lemken (Germany). All product design is done in-house by the company's engineering department. Partnerships have been established with dozens of local firms for special services such as heat treatment and machining.



## PROBLEM STATEMENT

### PRODUCT BACKGROUND

As mentioned earlier, a reliable and innovative plough design is a key selling point for farmers who are always looking to increase their work efficiency while keeping operation and maintenance costs down. Grégoire-Besson's SP series ploughs were originally designed in the early 1980's (Thirouin, 2002). The original machine was designed to handle 4 to 6 furrows and the headstock was strong enough for tractors of 150 to 180 hp. During the years, farmers needs changed and the company responded by adding new equipments and options on the plough. For example, the range was expanded by adding 7 and 8 furrows models, new rock protection systems were offered and coulters were added as an option for regions like Eastern Canada.

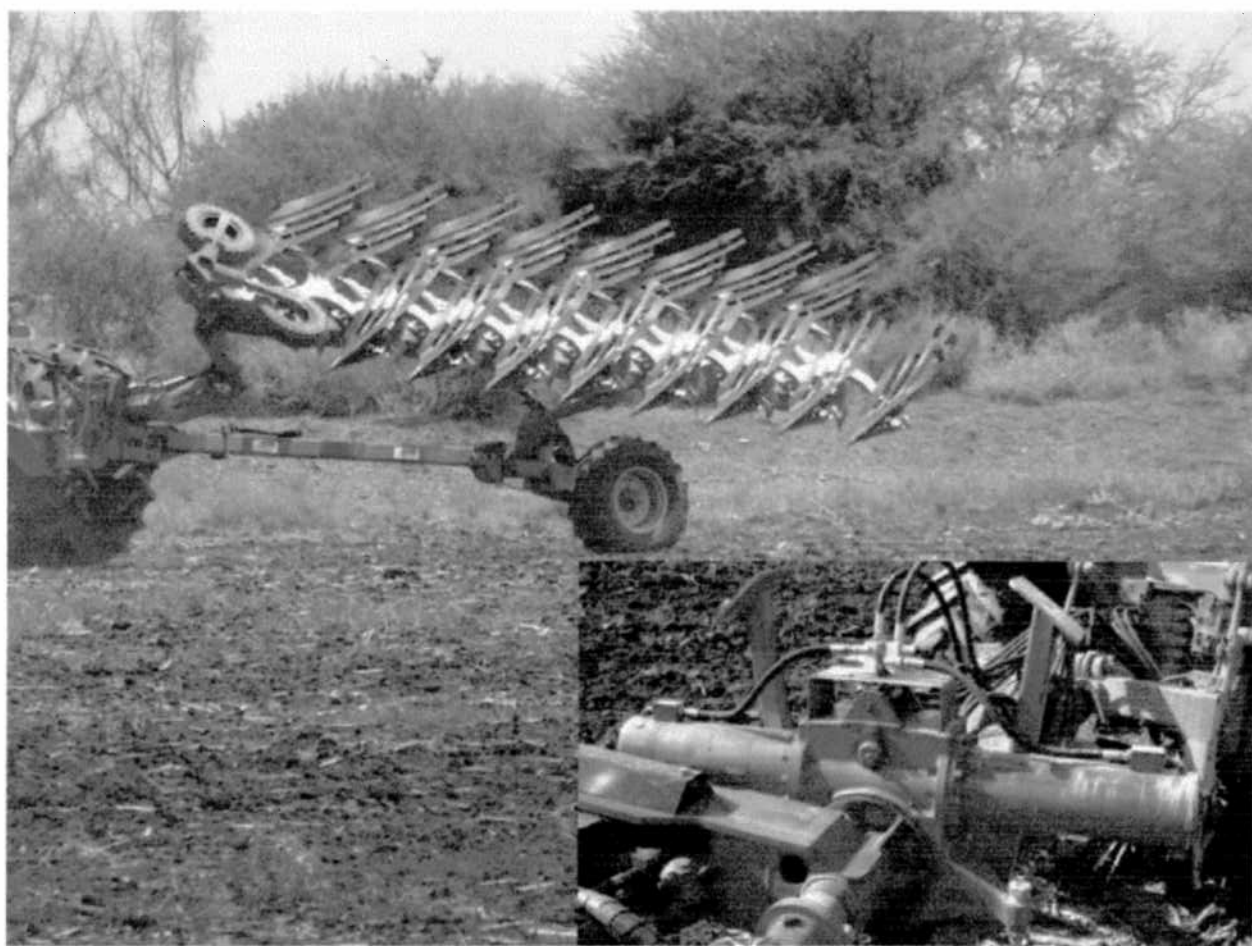
All these modifications to the original design showed some of the flaws of this design and forced the engineers to return to the drawing board to create an improved version of what is now Grégoire-Besson's flagship semi-mounted plough range. However, Grégoire-Besson is still looking at improving some weak points of the machine.



Figure 1: Top view of a Grégoire-Besson 7-furrow SPP9 plough (Thirouin, 2008).

## PROBLEMS DEFINITION

Grégoire-Besson requested me to investigate a few issues that are all related to the positioning of the transport/depth control wheel. One of the main problems encountered by users is the difficulty of the rack-and-pinion turnover mechanism to flip the plough from one side to the other at the headland (fig. 2). This problem is due to the large weight of the plough and its attachments (coulters, skimmers, gauge wheels, etc.). In addition, machines operating in Eastern North America and to a certain extent in Europe also have to deal with the added weight of wet soil and residue sticking to the mouldboards (Thirouin, 2000). This phenomenon is further emphasised by the long distance between the centre of gravity of the plough and the axis of rotation. This is a direct result of the positioning of the wheel in the middle of the plough: in order to



**Figure 2: SPMLB9 plough during the turnover process (Thirouin, 2008). Inset: Rack-and-pinion turnover mechanism (Steenbeek, 2007).**

accommodate the transport wheel between the plough Z-frame and the rotation axis (fig. 1) the latter must be moved farther from the Z-frame. This longer distance means that a greater torque is required at the turnover mechanism; in extreme conditions the design torque of the mechanism may be exceeded and the turnover process can only be done after removing some soil from the bodies.

Another impact of the positioning of the wheel is the behaviour of the plough in wet and hard soils. Many Canadian customers report that in very difficult conditions the tractor has very little control over the plough (Thirouin, 2000; Grégoire-Besson, 2004). This is mostly due to the positioning of the line of traction; a possible solution may be to put the wheel closer to the centre of gravity.

Another problem mentioned by many customers and outlined as the machine's weakest point by a renowned machinery magazine ("Vive la difference", 2008; Thirouin, 2002) is that the Z-frame can interfere with the wheel during the turnover process if the rear of the plough is not raised first. However, raising the backend to leave clearance for the Z-frame makes the plough unstable during turnover and increases the stress on the tractor linkage (Thirouin, 2002). Poor soil conditions on the headlands, such as ruts and holes, can also cause instability.

A design constraint also causes issues to customers who want to have a larger wheel to improve manoeuvrability: the current positioning of the wheel in the Z-frame limits tire diameter to less than 1100 mm. Many users would like to use 24R20.5 flotation tires ( $\varnothing$  1260 mm); this requires a repositioning of the wheel.

Finally, another issue with the current design is that with its current positioning, the rear wheel acts as a pivot point on the plough frame. When the tractor hitch is raised due to uneven terrain or when exiting a furrow, the plough pivots about the wheel and the bodies behind the wheel go deeper. In very wet soil conditions as encountered in Eastern North America, having a single on-land wheel is problematic as it sinks in mud, thus increasing the working depth at the back. Both of these conditions lead to an

uneven work depth and quality. A current user (Mr. Gerard Steenbeek) and a potential buyer (Mr. Warren Schneckenburger) of SP series ploughs gave me their opinion on the current product and suggested some improvements. Mr. Schneckenburger (personal communication, January 2008) suggests that the plough should have two wheels at the back: one in the furrow and one on land. This would allow a better depth control in wet soil conditions as the furrow wheel will be on hard soil.

## **MARKET CONSIDERATIONS**

Each market has different needs and the plough market follows the same rules. Most of the complaints and requests for improvements come from users and distributors in Canada and the Community of Independent States (CIS) (Thirouin, 2002). These markets are relatively small compared to the European market, but Grégoire-Besson wants to occupy this niche market. The technology developed to fit the needs of these two markets can also be transferred to European models if demand is sufficient. Current sales expectations for SP series ploughs are approximately 120 units per year globally, with 25 units exported in Canada. The limited size of the market means that we must ensure interoperability between the existing products and the new design to have as many common parts as possible between the two models.

## **CURRENT PRODUCT OFFER**

The current product offer from Grégoire-Besson and its competitors in the semi-mounted market consists of two main types of ploughs: centre-carriage ploughs (fig. 3) and single rear wheel ploughs (fig. 4). The latter has the largest sales volume. Centre-carriage ploughs are usually larger than single wheel ploughs. Since they do not have a direction system on the central carriage, they are not very manoeuvrable and their use is limited to larger fields. Single wheel ploughs are more manoeuvrable due to the wheel direction system and the smaller distance between the wheel and the tractor.

Single wheel ploughs, which are the main object of my project, are available in 2 configurations: mid-mounted wheel and rear-mounted wheel (fig. 5 and 6). Each one has its advantages and disadvantages, which are presented in Table 1.



Figure 3: Centre-carriage plough (G-B, 2007).



Figure 4: Single wheel plough (Thirouin, 2008).

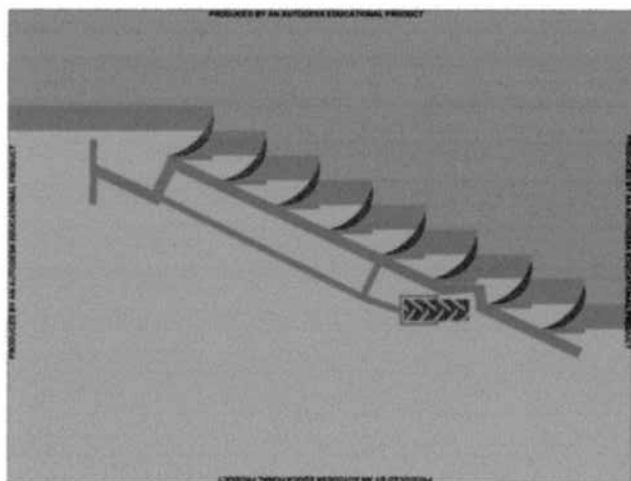


Figure 5: Mid-mounted wheel.

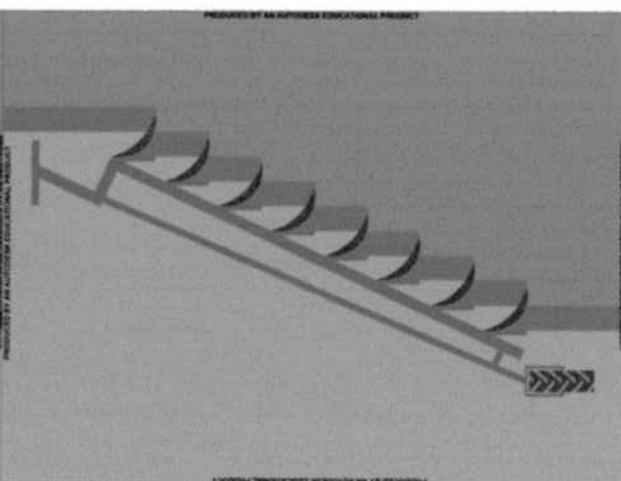


Figure 6: Rear-mounted wheel.

WHEEL TYPE	ADVANTAGES	DISADVANTAGES
Mid-mount	<ul style="list-style-type: none"> <li>- Wheel is within the working width</li> <li>- Highly manoeuvrable</li> </ul>	<ul style="list-style-type: none"> <li>- Complex Z-frame</li> <li>- Poor weight transfer</li> <li>- Uneven working depth</li> <li>- More turnover torque required</li> <li>- Unstable manoeuvres at headland</li> </ul>
Rear-mount	<ul style="list-style-type: none"> <li>- Good weight transfer</li> <li>- Good depth control</li> <li>- Larger tires can be installed</li> <li>- Lower turnover torque</li> </ul>	<ul style="list-style-type: none"> <li>- Requires reinforced stabilisation bar</li> <li>- Less manoeuvrable unless good direction system is fitted</li> <li>- Wheel is not within working width</li> </ul>

Table 1: Comparative chart for mid-mount and rear-mount plough wheels (Thirouin, 2002).

## PRELIMINARY IDEAS

After having defined the problems affecting the machine, the following step of the design process is to gather as much information as possible about the design topic and to make a list of preliminary ideas that may be applicable to solve the problem. I also followed the design process proposed by Krutz et al. (1984) in *Design of Agricultural Machinery*. One of the main recommendations of this design process is to gather information about current models and competitive models. I reviewed what is offered by Grégoire-Besson and its competitors and I started making a list of features and concepts which may be of interest. In addition, I decided to do a patent review to see what are the main innovative concepts used by plough manufacturers as wheel as see if some of my preliminary ideas are already patented and require a licence to use them.

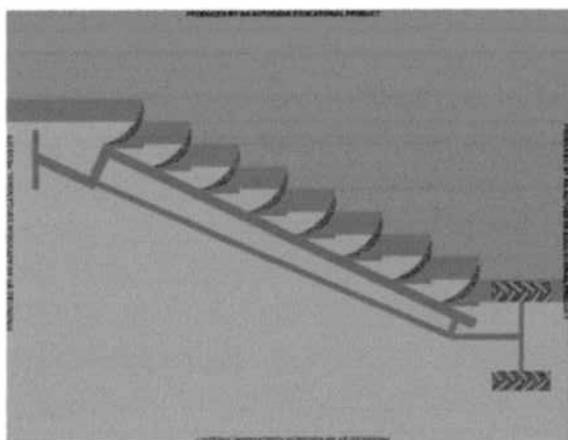
### PATENT REVIEW

I focused my search on European patents organisations because the vast majority of plough manufacturers are located on the Old Continent. I found numerous interesting ideas which may help me solve the problems enumerated earlier. Among the best discoveries, I found a design filed by Charrues Bonnel in 1990 which uses two wheels at the back of a reversible plough (commercialised as a “quart-de-tour” plough) (Bonnel, 1990). This concept is very similar to the centre carriage used on large reversible ploughs, but integrates a direction system on the wheels. A similar concept was developed in 1992 by Michel Bugnot (Bugnot, 1992), but the primary goal is to install tillage and seeding implements to have a one-pass tillage and seeding train. Finally I also found a patent issued to Kuhn SA in 2003 (Paugam, 2003) which describes a turnover system. I am mostly interested in how the rear wheel attaches to the stabilisation bar and this patent may give me some ideas for a possible design.

### PRELIMINARY RECOMMENDATIONS

Based on my product review and patent review, I decided to evaluate two designs of wheel assembly for the SP/SPML series ploughs. Since both designs have their advantages and disadvantages, I believe that it is important to model and compare both designs to see which one fits best to respond to Grégoire-Besson’s requirements.

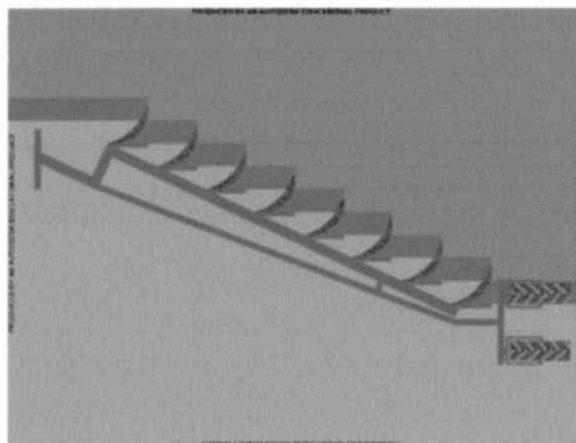
Both designs will have the same basic principle: they will have two wheels installed at the back, with one of them in the furrow and the other one on land. It seems to be the best option to control working depth accurately, increase stability and improve manoeuvrability. All these claims will have to be assessed once a preliminary design is made for each concept. One disadvantage of using two wheels at the back is that it increases the operating width of the machine considerably and limits on how close to a field edge the plough can work. One the primary goal of the design will be to minimize the working width of the wheel assembly. All these claims will have to be assessed once a preliminary design is made for each concept. The first design will consist of two wheels connected by a rigid axle (fig. 7). Such a concept has already been used on some Overum ploughs (fig. 8). The second concept will consist of two independent wheels connected to the frame via a specially designed frame (fig. 9).



**Figure 7: Rigid axle wheel assembly.**



**Figure 8: Rigid axle (Overum) (Thirouin, 2008).**



**Figure 9: Independent wheels.**



## SCOPE

My goal for the next following months will be to design all the components required to build my two concepts of wheel assemblies. This will involve calculation of all the forces applied on the assembly (weight of the machine, rolling resistance, etc.). Once the forces acting on main components will be calculated, I will have to go through a material selection process to find the best suited materials to meet technical and cost constraints. The following step will be to select the various components (bushings, bearings, hydraulic cylinders, fasteners and welds, etc.) according to loads and fatigue cycles. I will also have to design the hydraulic system controlling the assembly. Finally I will spend a major part of my time modelling components in Pro/Engineer Wildfire 3 (Pro/E) and assembling the components. Once a complete assembly has been designed I will be able to model how it reacts to external forces and I will be able to adjust the parameters of the direction system.

I will work closely with Mr. Thirouin and Bourque and I will seek their input at all the important stages of the design to make sure that my designs meet all the requirements and needs of Grégoire-Besson and its customers.

## RESULTS

The two virtual prototypes created with Pro/E will be evaluated on six main criteria: manufacturing cost, quality of depth control, machine stability, manoeuvrability, reduction of turnover torque required and physical dimensions. A qualitative analysis will be used to determine the importance and weight of each criterion. Of course, cost is likely to be the determining factor in the decision to proceed further in the development of this product (prototypes and field testing), but outstanding results in some of the criteria may offset the importance of cost as the determining factor.

The following section deals with the methodology I intend to use for the development and analysis of my design. These methods will be refined and adapted to the specific context of each component.

## METHODOLOGY FOR PROBLEM SOLVING

Due to the wide scope of this project, I chose to divide the theoretical part of my design in 4 different aspects: structural mechanics, material selection, mechanical components and hydraulic circuits. Of course these design categories are highly interdependent and cannot be considered individually; the distinction between the 4 theoretical sections is only a tool to simplify the analysis of the methods required. Once all the required theoretical information will be on hand, all concepts will be merged together. The following section will provide an overview of the theory required to analyse all aspects of this design process.

### STRUCTURAL MECHANICS

The first step of the design approach is to evaluate and analyse all the forces applied on the wheel assembly of the plough. Using basic mechanics techniques such as free-body diagrams it is possible to quickly summarize evaluate which equations must be used (Krutz, Thompson & Claar, 1984). External loads such as the weight of the plough are quite easy to calculate using manufacturing data (components weight, location of the centre of gravity, etc.). Soil rolling resistance  $R_r$  requires much more work and assumptions and can be derived using the approach developed by McKyes and Bekker (McKyes, 1985)

$$R_r = \left[ \frac{z + \delta_t}{d} \right] N$$

with sinkage  $z$ , tire deflection  $\delta_t$ , tire diameter  $d$  and load  $N$ ; also

$$R_r = \frac{\left( \frac{2N}{d} \right)^{\frac{n+1}{n}}}{(bk)^{\frac{1}{n}}} + \frac{\delta_t N}{d} = \frac{bp^{\frac{n+1}{n}}}{2k^{\frac{1}{n}}} + \frac{\delta_t N}{d}$$

with tire rpm  $n$ , tire width  $b$ , contact pressure  $p$  and terrain deformation exponent  $n$ . These equations will require assumptions about the soil types and properties. In addition tire characteristics (unloaded and loaded diameters, contact area, recommended operating pressure) must be obtained from tire manufacturers to

calculate accurate estimates of rolling resistance. It is important to note that we are looking for maximum values of rolling resistance.

The state of a stress is required to select materials as well as for the proper sizing of structural components. Stresses are divided in two main categories: simple loading axial stresses and combined biaxial stresses. While axial stresses are easily calculated with simple engineering formulas, Mohr's Circle represents a powerful tool to analyse more complex cases such as combined stresses and three-dimensional stresses (Juvinall & Marshek, 2006). If the stresses on a component are known, it is possible to determine the principal stresses, the principal directions and the maximum shear stresses. Mohr's Circle equations for combined stresses are (Juvinall et al., 2006)

$$\sigma_1, \sigma_2 = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\tau_{xy}^2 + \left(\frac{\sigma_x - \sigma_y}{2}\right)^2}$$

$$2\phi = \tan^{-1} \frac{2\tau_{xy}}{\sigma_x - \sigma_y}$$

$$\tau_{\max} = \pm \sqrt{\tau_{xy}^2 + \left(\frac{\sigma_x - \sigma_y}{2}\right)^2}$$

$$\sigma_\phi = \frac{\sigma_1 + \sigma_2}{2} + \frac{\sigma_1 - \sigma_2}{2} \cos 2\phi$$

$$\tau_\phi = \frac{\sigma_1 - \sigma_2}{2} \sin 2\phi$$

Since these equations only produce average stress values, it is necessary to calculate exact values at stress concentration points. Stress concentration regions are usually located around geometry changes (holes, fillets, notches). These regions exhibit much higher stresses so it is necessary to evaluate the maximum stresses in the regions to select materials and size components appropriately. There are two methods available for this: finite elements analysis (FEA), which requires sophisticated computer software, and stress concentration factors (Juvinall et al., 2006). The latter will be used

at the initial stages of design to approximate closely stress values, but I will try to make use of FEA on complete components to make sure that the stress concentration factors are appropriate. The theoretical stress concentration equation is (Krutz et al., 1984)

$$\sigma_{\max} = K_f \sigma_{\text{nom}}.$$

Values of stress concentration factor  $K_f$  for numerous geometries can be found in most advanced mechanics and component design textbooks.

Finally it will be necessary to calculate the turnover torque of the new designs to make sure that it meets the capacity of the current rack-and-pinion mechanism. The required torque is calculated by multiplying the weight of the plough by the distance of the centre of gravity from the rotation axis. The torque supplied by the mechanism is equal to the hydraulic force (area times pressure) multiplied by the radius of the pinion wheel.

## **MATERIAL SELECTION**

Selection of adequate materials is a very important step in the design process. Many factors must be analysed to come up with the best material for the operating conditions. Although I am likely to use the same materials already used on the existing machines, it is important to go through the selection process to make sure that the materials selected fit the application performance requirements. Material selection is based on using accurate material properties, which are available from ASTM, material suppliers and engineering textbooks. Ashby's material selection charts are also an excellent tool to start with. They are a graphical presentation of properties relationships for various materials. *Fundamentals of Machine Component Design*, by Juvinall and Marshek (2006) also explains very well the steps and criteria for material selection.

Some of the key performance characteristics involved in my design include strength, rigidity, durability, reliability, cost, weight, productibility and availability. The cost aspect is especially important: it must include the cost of the raw material as well as labour cost of machining it and overhead, to come up with a total cost of fabricated part. This means that selecting the cheapest material does not always result in a

cheaper fabricated part. The aim of the selection process is to achieve the best overall performance per unit cost. This is defined as the Selection Index (Juvinal et al., 2006)

$$\text{Selection index} = \frac{(\text{availability}) \times (\text{performance})}{(\text{cost})}$$

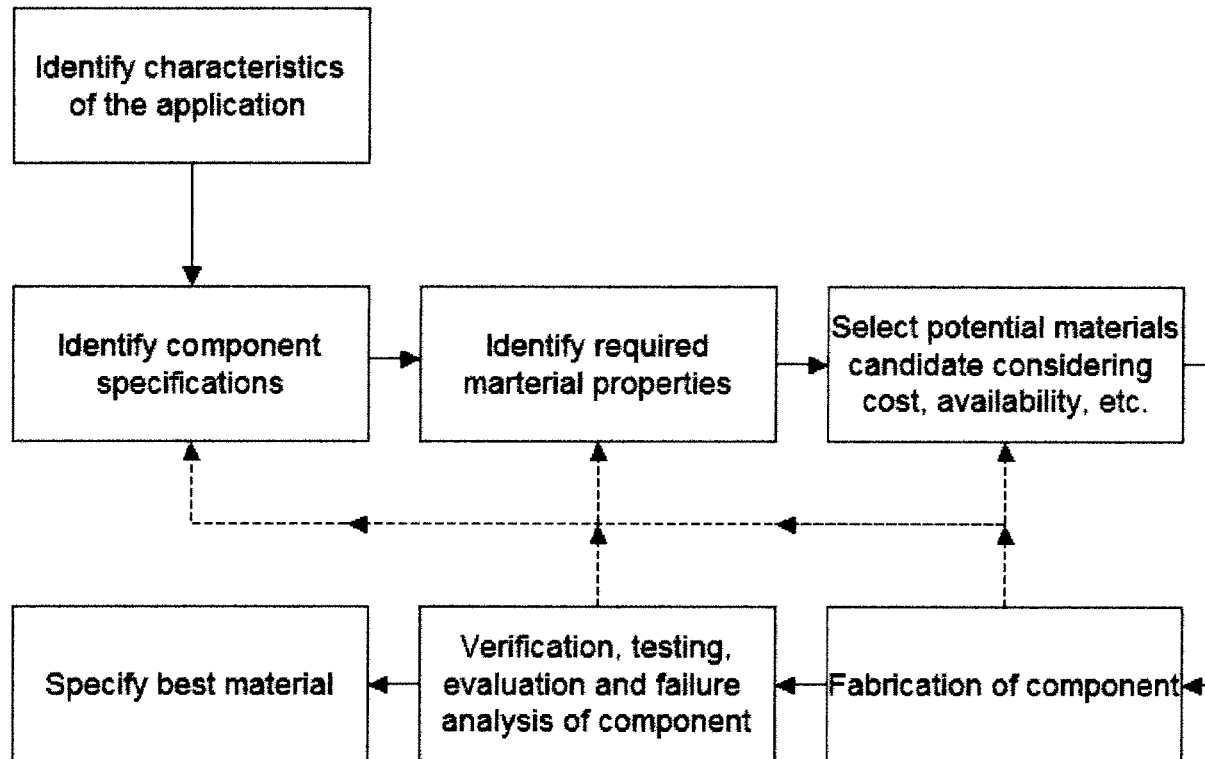


Figure 10: Material selection process for a machine component (Juvinal et al., 2006).

## COMPONENTS SELECTION THEORY

Selection of appropriate mechanical components will have a direct impact on the reliability of the wheel assembly. Since most of these components will not be designed and manufactured in-house, but rather purchased from external suppliers, it is important to evaluate appropriately which components fit best the proposed performance characteristics. This section deals specifically with threaded fasteners, bushings and bearings. Welding theory is also included in this section. A primary concern of components selection is to select components already in use on other machines manufactured by the company whenever it is possible. Having as many common parts as possible between models will ensure lower part cost and reduce the part stocks that have to be supported by the company and distributors.

The two types of fastening which will be used in this design are bolts and welds. Each one has its advantages and disadvantages: bolts can be installed and removed easily and non-destructively (Juvinal et al., 2006) whereas welds are permanent. However, one of the main disadvantages of threaded fasteners is their tendency to loosen and disassemble. This loosening issue has already been noticed on SP series ploughs (Thirouin, 2000). The problem has been sourced to inadequate bolts and lock nuts grading: the threads are too soft and give way when subjected to large forces. Surface treatments increase friction and provide resistance to loosening.

Because the wheel assembly is a highly critical component of the machine, threaded fasteners selection cannot be conducted arbitrarily. It is recommended to use a safety factor of 3 to 4 when using known materials subjected to uncertain stress conditions (Juvinal et al., 2006). The starting point for bolt selection is to use engineering judgement to select the appropriate steel grade and the associate stress concentration factor. Based on the nominal bolt load and the chosen safety factor, design overload is calculated and using (Juvinal et al., 2006)

$$\sigma = \frac{F_t}{A_t} K_f,$$

we find the thread area  $A_t$  of the bolt. Using standard bolt size tables, the proper size can be selected. Welding has the advantage of being less costly than threaded fasteners for joining machine members (Juvinal et al., 2006). However due to the permanent nature of welding it can only be used on main structural members. Proper selection of welding rod is important to make sure that the tensile strength of the weld is appropriate for the loading of the structural members.

Journal bearings have many advantages: they have very little service requirements, have a low cost and have simple enclosure requirements (Krutz et al., 1984). These plain bearings cannot be used anywhere however. Their use is limited to shafts with slow rotation speeds or not constantly rotating. This makes journal bearings well suited to pivots and articulations on the plough frame. The selection process for journal bearings is quite complex and requires numerous assumptions. Lubrication

conditions must be determined to ensure minimal frictional drag force. Diameter is determined by shaft size and length is chosen in accordance with application unit load  $P$ , where (Juvinall et al., 2006)

$$L = \frac{F}{P}.$$

Length to diameter ratio is necessary to calculate the bearing characteristic number  $S$ , defined as (Juvinall et al., 2006)

$$S = \left( \frac{R}{c} \right)^2 \frac{\mu n}{P}$$

(with pressure  $P$  and dynamic lubricant viscosity  $\mu$ ) which can be used to determine bearing clearance. Additional calculations can find the required lubrication rate and interval.

Rolling elements bearings are more expensive than journal bearings, but they are better suited to faster rotation speeds and high starting loads. The main area of use is the rear wheel. Adequate bearing type is based on the type of loading: radial, thrust or combination (Krutz et al., 1984). To select the appropriate bearing, we must look at the grade of precision, lubrication, enclosure and basic load (Juvinall et al., 2006). A design life and reliability factor must also be specified. In the case of this plough, the design life is estimated at 5000 hours and 90% reliability is required. Application factors  $K_a$  must be selected based on the type of application and bearing. Bearing rated capacity  $C_{req}$  is calculated with (Juvinall et al., 2006)

$$C_{req} = F_e K_a \left( \frac{L}{K_r L_r} \right)^{0.3}$$

with equivalent force  $F_e$ , design life  $L$  for a radial load, life adjustment reliability factor  $K_r$  and rated capacity design life  $L_r$ . Then using standard bearing sizing charts, we find the appropriate bearing for the type and size of loading.

## HYDRAULIC CIRCUITS DESIGN THEORY

The hydraulic circuits controlling the wheel assembly are a crucial part of the design. Hydraulic components will be used to control the lifting and lowering of the plough and to control the direction system. The latter part is particularly important as the quality of the direction system will determine how manoeuvrable the plough is (this is a key point for design success).

The process of designing a hydraulic circuits starts with an analysis of job requirements (Burton & Bitner, 2008). In this particular case we must analyse the load to determine what is the required velocity profile, the burden and burden profile and the hydraulic force profile. These physical system characteristics help to determine the size of actuator required to perform the job. In addition actuators must be sized to be compatible with current tractors oil flow and operating pressure. Next is to establish flow and pressure profiles to ensure that the system will work within tractor operating constraints at all times. In order to determine complete system efficiency, operating horsepower must be calculated.

After all these system characteristics are known, it is possible to draw a hydraulic circuit. At every important part of the circuit, pressure, flow, and horsepower profiles must be plotted to ensure that the circuit is sufficiently efficient. If efficiency is too low, the circuit must be redesigned to reach acceptable efficiency. Because of the importance of the hydraulic system in this design, both from safety and machine performance points of view, we cannot redesign by compromising on design constraints (Burton et al., 2008). Once the circuit has acceptable performance characteristics, the final step is to select system components (actuators, valves, hoses, accumulators, etc.) based on performance and cost.



## SOURCES OF INFORMATION

The technical and theoretical information for this project comes from a wide variety of sources. I obtained some information about problems and suggested improvements from current and potential machine users. Company internal reports are also a tremendous source of information: all warranty claims are analysed and the company keeps extensive records. Grégoire-Besson also supplied me with excellent reports dealing with operating conditions in potential markets. Finally much of the theoretical aspect of this design comes from engineering standards (ASTM, ASABE), engineering textbooks and course notes. A list of additional design references can be found after the reference section (page 35).

## WORK SCHEDULE

### WORK FLOWCHART

The following flowchart depicts an overview of the complete design process from the project selection and brainstorming process up to the final design delivery to Grégoire-Besson.

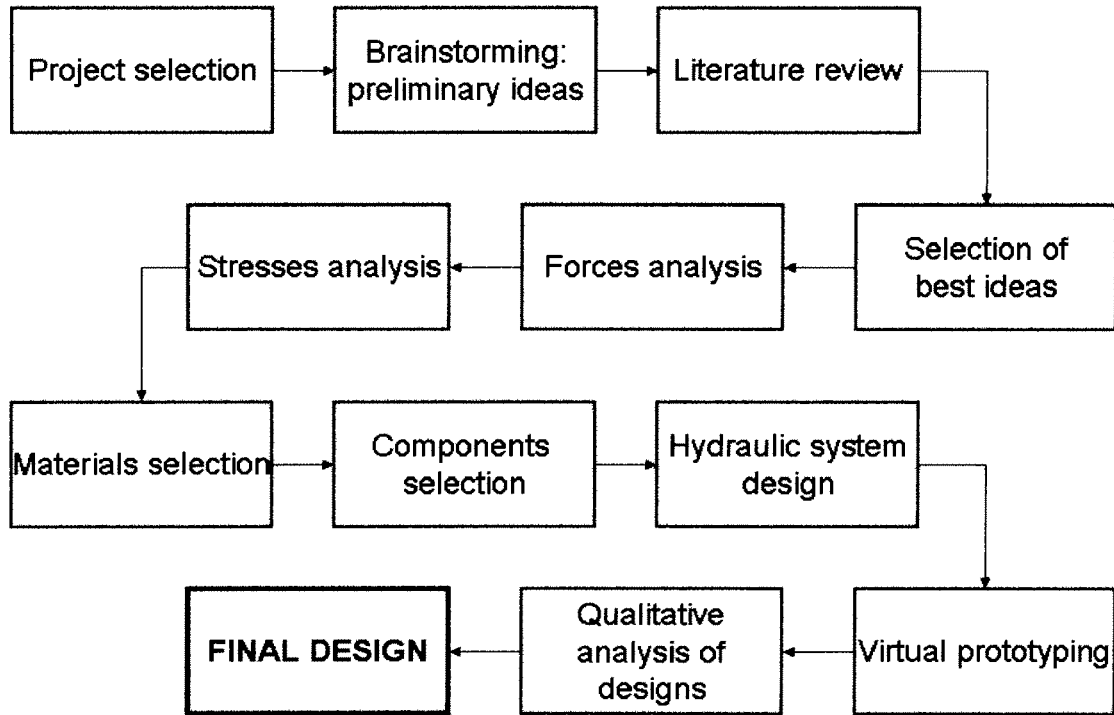


Figure 11: Complete design process flowchart.

### ESTIMATED WORK TIMES

Table 2 shows the estimated time required to complete each step of the design. The schedule indicates tentative dates of completion of each step of the design and is subject to change based on unforeseen time and design constraints. It is based on course requirements and additional requirements by Grégoire-Besson. Part of the design work will be conducted during summer time as part of an internship at Grégoire-Besson Canada in St-Hyacinthe.

MONTH	TASK	TIME (H)
May 2008	▪ Analysis of current design (Pro/E)	5
	▪ Evaluation of forces on wheel assembly	10
	▪ Modelling of turnover forces based on plough configuration (create Excel program)	12
June 2008	▪ Qualitative analysis of SP series plough and competitive designs	10
	▪ Marketing analysis	10
July 2008	▪ Stress analysis in structural components of the 2 concepts	8
	▪ Finite elements analysis of stresses	10
	▪ Material selection	5
August 2008	▪ Hydraulic system design	10
	▪ Hydraulic components selection	3
	▪ Mechanical components design and selection	15
September 2008	▪ Technical drawings and virtual prototyping (Pro/E)	40
October 2008	▪ Optimisation of direction system	10
	▪ Qualitative analysis of design options	5
November 2008	▪ Final design report development	20
	▪ Final presentation development	6
December 2008	▪ Report submission and presentation	1
<b>TOTAL</b>		<b>180</b>

**Table 2: Proposed work schedule and time requirements.**

## COST ANALYSIS

At this stage of the project, it is not possible to evaluate the total cost of the wheel assembly (materials, work, design, etc.). However it is necessary to conduct a financial analysis of the cost of the design process itself to make sure that this cost meets the company's financial objectives in research and development. An accurate analysis of this cost is necessary as this investment in R&D will be reflected on the final cost of the product.

The data used to calculate the various hourly rates are based on industry standards for medium engineering firms in Canada. However it should be noted that these references are for consulting firms doing work for external customers. I assumed that they are equivalent the rates used in manufacturing firms. Rates and fees are given in Table 3. Rates for engineers and technicians include administrative fees (secretaries, accounting, legal fees, office supplies, etc.).

ITEM	HOURLY RATE (CA\$)
Engineer	75.00
CAD technician	32.00
Computer modelling (Pro/E)	10.00
Computer modelling (FEA)	10.00
Travelling	0.50 per kilometre
External consulting	75.00

Table 3: Rates and fees for design.

The cost of each step of the design is based on the work schedule presented in Table 2. In addition 25 hours of work are assumed for this first part of the design process and 5 hours of work is added for external consultants. Table 4 details the budget of the design process.

TASK	ITEM	TIME (H)	TOTAL COST (CA\$)
Preliminary design process	Engineer	25	1875.00
Analysis of current design (Pro/E)	Engineer	5	375.00
Evaluation of forces on wheel assembly	Engineer	10	750.00
Modelling of turnover forces based on plough configuration	Engineer	12	900.00
Qualitative analysis of SP series plough and competitive designs	Engineer	10	750.00
Marketing analysis	Engineer	10	750.00
Stress analysis in structural components of the 2 concepts	Engineer	8	600.00
Finite elements analysis of stresses	Engineer	10	750.00
	FEA software		100.00
Material selection	Engineer	5	375.00
Hydraulic system design	Engineer	10	750.00
Hydraulic components design	Engineer	3	225.00
Mechanical components design and selection	Engineer	15	1125.00
Technical drawings and virtual prototyping (Pro/E)	CAD technician	40	1280.00
	Pro/E software		400.00
Optimisation of direction system	Engineer	10	750.00
Qualitative analysis of design options	Engineer	5	375.00
Final design report development	Engineer	20	1500.00
External consulting	Consultant	5	375.00
Travelling fees	-----	500 km	250.00
<b>TOTAL (CA\$)</b>			<b>14255.00</b>

Table 4: Design process budget details.

It is quite easy to find the estimated cost per unit sold. Assuming that 25 units are sold every year, that the design is used during 5 years before being replaced by a newer design (amortization period of 5 years), and estimating the interest rate at 6%, the total research and development cost per unit sold is approximately CA\$135.00.

## CONCLUSION

The research done for this design proposal showed that there is a growing potential market for an upgraded version of the SP/SPML plough range. Furthermore, the design concepts selected at the end of the brainstorming and analysis process will help solve numerous issues that have been observed the manufacturer and machine users and they will ultimately make the machine a more efficient tillage tool. The methodologies outlined in this proposal will be the base point for the next steps of the design process which will be conducted during summer and fall 2008. The outcome of this extensive design process will be a complete virtual prototype with specifications for each component. A real-life working prototype would be ideal for field testing and further analysis of the design, but due to time constraints it is unlikely that a prototype be built before December 2008. However if the concepts meet all the requirements of Grégoire-Besson and after further market analysis, working prototypes will probably be built for field testing in 2009.



## ACKNOWLEDGEMENTS

For their suggestions and support already given and promised for the future of this project, I would like to extend my appreciation to Mr. Cyril Thirouin of Grégoire-Besson and Mr. Simon Bourque of Grégoire-Besson Canada. Their cooperation was essential to the success of this project. Also I would like to thank Dr. G.S.V. Raghavan for his guidance and help.



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## **APPENDIX A**

### **GRÉGOIRE-BESSON SP/SPML SERIES PLOUGH BROCHURE**



P SPML compact



high output

## SINGLE WHEEL PLOUGH



WE'RE MOVING FORWARD WITH YOU

www.gregoire-besson.com



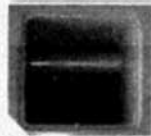
WE'RE MOVING FORWARD WITH YOU

- Simplicity
- Performance
- Flexibility

### Simplicity for a long life

For the long life of the frame (180x180x10), it is fabricated to the minimum, to keep the mechanical qualities of steel intact.

After drilling the tube bushes are welded in to insure the rigidity of the frame. The way of manufacturing, with the use of welding parts together as much as possible, reduces the risk of loosening, to obtain the best life of your implement.



**A unique design for more performance:**  
Unique frame design of the compact range makes it possible to insure a better performance from your tractor. The rear position of the depth wheel is totally integrated to the frame, to allow optimum traction with minimum strain. The lateral pressure is reduced due to a better alignment of the plough behind the tractor. Along with the advantage of being lighter, there is also less wear on the landings. Lower levels of gravity ensure a safe transport position with a high level of comfort.

Front, turner, adjustment, is operated, either with a conventional transmission with a hydraulic oiler control. The hydraulic adjustment of the front furrow allows you to change the furrow complexity in difficult conditions.



SP9-SPW9  
In furrow semi mounted plough

150-300 Hp



SP compact ploughs are equipped with a self steering depth/transport wheel. This allows easy manoeuvres on the headlands or in transport position.

The wheel support is linked to the turnover mechanism, in accordance to reduce the stress on the wheel. The wheel stays parallel to the furrow for less pulling requirements.



### Plough easy to modify

SP Compact range has been designed, to be able to offer a product which will follow the development of your farm. This plough has the possibility to be equipped with 2 additional furrows. Patent from Grégoire-Besson makes it possible to add an extra furrow before the depth wheel, to allow the best possible traction.

Due to the design of the frame, it will be possible to fit tyres with a wide diameter. The plough will pass over the obstacles without problem, and will increase the comfort in transport.

SP9 - SPW9

	180 x 180 mm			
	5	6	7	8
	100 ou 114 cm			
	71 / 76 / 81 cm			
	B, Y, Z			
	12-20" / 14-22"			
	2500	2800	3100	3400
	140-180	160-190	190-240	240-270

## These models have some common design features which make : Gregoire Besson ploughs well know :



**Headstock 110°**  
The headstock is linked to the plough by a cast steel cardan, which allows a turning angle of 110°.

The cardan can be equipped with a hydraulic compensation cylinder, which if act directly on the top link. With this system, you can reduce the effort of the tractor up to 30%.

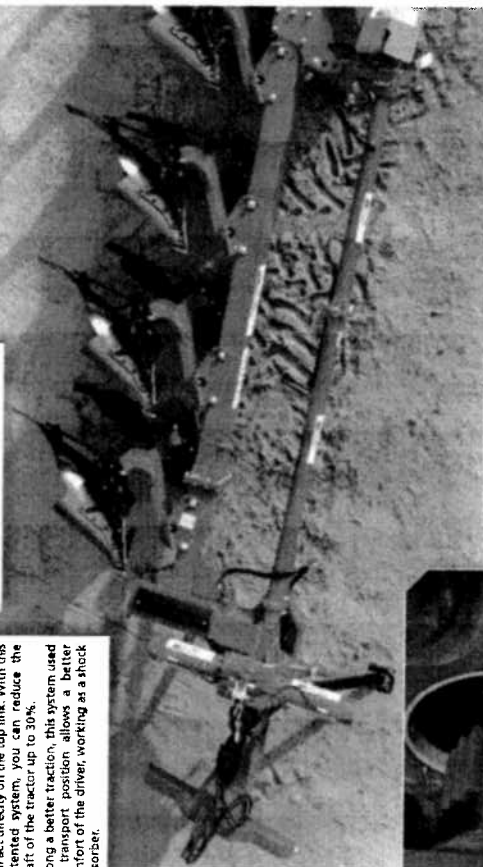
During a better traction, this system used in transport position, allows a better effort of the driver, working as a shock absorber.



**Headstock with various hitches**  
All the single wheel semi mounted ploughs are available with some hitches with various options. For example: hitch, quick coupler cat II, III or IV, ...



**Cast steel body support**  
To ensure a good resistance in the time, the body support is welded cast part. The mouldability of the steel allows to adapt its solidity by absorption of the shocks. With its fleeing contour of the body, the residues are evacuated easily.



**Stable and comfortable turnover system**

Pinion and pinion mechanism, operated by two hydraulic cylinders ensures constant, precise and smooth operation during turnover operations. This system developed by Gregoire-Besson is now well known in the world for his high level of reliability and his low cost of maintenance.

Equipped with some cylinders of 35 T, this system makes possible to turn the plough easily and without shock loads for the tractor and the plough.



**Unique design of the frame**

Specific design of the frame allows easy turnover due to a better position of the wheel. As the wheel is totally integrated to the frame, the plough becomes more easy to pull.

It is also possible to equip the plough with wider tyres (up to 1220 mm), for a better comfort and also a better control of the working depth in wet conditions (for example). This modification allows the SP and SP1 ranges, to take out the wheel mark by the rear furrow.

## A great choice of safety devices to adapt to all the conditions



**A safety bolt for the heavy soils (B)**

This type of safety is suitable for implements working in ground, without stone and in light, medium, and heavy soils without rocks. During the shearing of the soil, the bolt is sheared and is cleared away from the obstacle.

Depending on the conditions, there is a choice of bolt resistance (8.8 or 10.9).



**A hydraulic safety high performance (Y)**

Hydraulic safety device Gregoire-Besson is assembled on 4 ball joints. Each element can move from top to bottom, and from left to right without the articulation being damaged.

This system of safety uses a double linkage and a cylinder fixed on the end of the element.



**A HD hydraulic safety device (Z)**

This system of safety uses a double linkage and a cylinder fixed on the end of the element. In comparison of the Y system, Z hydraulic device is using ball joint on the articulation, to allow more flexibility in heavy soils.



**Working width adjustable manually or hydraulically (Wrange)**

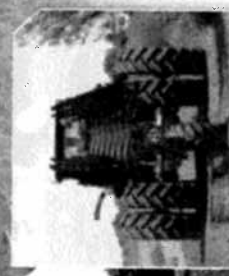
**SP9 / SPML9** : Adjustment of turning width from 12m to 20m or from 14m to 22m, according to the interbody clearance 100 or 114 cm.

**SP109 / SPML109** : The working width adjustment system uses a double external linkage. This system reduces considerably the stress on the mechanism. It is then possible to regulate the working width in all positions. The linkage can also be easily reached for maintenance and adjustment. The system is greased from the top. The pinion and pinion are greased which ensures great reliability of the system.



**Stability during transport**

A lower centre of gravity makes it possible to offer a plough much more stable in transport or during heavy operations. A plough more stable = more comfort and less mechanical stress for the plough and the tractor.





**Adaptability  
Ergonomic  
Reliability**

**Possibility to work on-land and in-furrow**  
Depending on the soil conditions or the type of tractor, it is important to keep the possibility to change your plough from the on-land to in furrow position, and reverse. The SPML 9 Compact range is offering this possibility, and in a few minutes the plough can be changed. Again, this specification makes your Gregoire-Besson unique and adaptable.



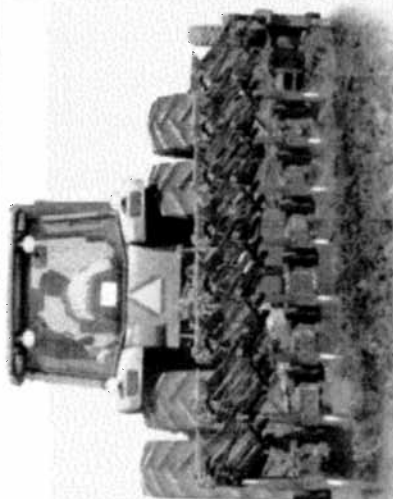
SPML 9 - SPML 9WS

	180 x 180 mm			
	5	6	7	8
	100 ou 114			
	71 / 76 / 81 cm			
	B, Y, Z			
	12-20" / 14-22"			
	4200	4500	4800	5100
	150-170	170-200	200-240	240-280

## SPML9-SPML9WS

In furrow/On land semi mounted plough

150-290 Hp



### Researched ergonomics makes easy use.

The latest research has been designed to make the ploughing operation easier and more efficient. The plough is designed to be used in a variety of conditions, from the most difficult to the most favorable. The plough is designed to be used in a variety of conditions, from the most difficult to the most favorable. The plough is designed to be used in a variety of conditions, from the most difficult to the most favorable.

The high side adjustment of the front frame allows the plough to follow the first turning movement in a variety of conditions. Also the height can be easily modified to work on land or in furrow. In the on land position, the plough will be suitable for tractors equipped with low, medium or full track traction.

### Reliability is priority

To ensure perfect reliability, the SPML 9 range, has been designed with a specific stabilisation frame. The turnover system track and pinion allows a comfortable and precise turning of the plough, which will contribute to a better long life of your investment.



**Original wearing parts of Gregoire-Besson: guarantees output in all fields.**

Original wearing parts of Gregoire-Besson are of higher quality with thermal treatments 180 kg. As well as their design, these spare parts were considered for an optimum use, offering to you low cost wearing part.

**Reinforced share**  
The ploughshares are reinforced this makes it possible if necessary to work without points.



**Reversible landside**  
The landside has 4 positions for an optimum use of the part.

A landside supplement has been developed to increase the life of the landside.



**To optimize the wear of the point**  
The point "three holes" (4 positions) is a system specific to Gregoire-Besson, which allows the use of the part to the maximum. The part is also less aggressive which is very useful in stony conditions.



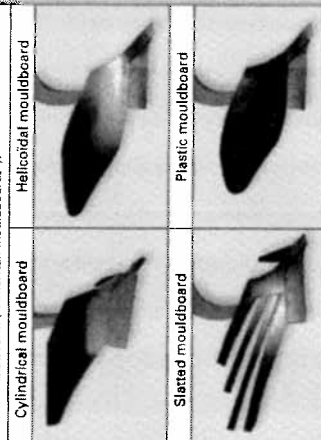
**Bar point self-sharpen**

This part has the advantage of being adjustable (multiposition) and reversible. This system makes it possible to deepen the point independently from the share. The part is guaranteed against breaking and deforming.

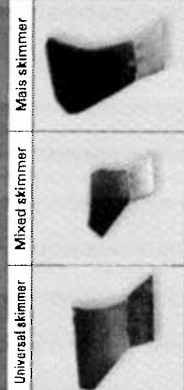


**A broad range of mouldboards to suit all the conditions**

Mouldboards are mainly characterised by their length and shape. To adapt to all the conditions of use, Gregoire-Besson offers a broad choice of mouldboards: "short", "long", "full", "slatted", "helicaloid", "cylindrical" or "mixed form" ("American mouldboards").



**To choose a skimmer according to the volume of residue to be hidden**



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