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Solving Power Balance Problems in Single-Traction Tractors Using PTractor Plus 1.1, a Possible Learning Aid for Students of Agricultural Engineering

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Abstract: Tractors are used to perform jobs that require different types of agricultural tools to be attached to their rear, to their front, or both. These tools may need to be dragged, towed, or suspended above ground, and sometimes require a power supply; this is usually obtained via a hydraulic system or from the tractor's power take-off system. When tractors have to work with such tools on different types of soils and on different slopes, the need arises to calculate the power the tractor engine will have to produce. In the classroom, this is normally calculated manually with the help of a calculator. This work, however, describes a computer program (written in Delphi and operating under Windows) that rapidly solves the most common types of power balance problems associated with single-traction tractors. The value of this software as a learning aid for students of agricultural engineering is discussed.

Keywords: improving classroom teaching; simulations; teaching/learning strategies

1. Introduction

The use of new technologies in teaching has, currently, a very important place in the field of education [1]. Thanks to its use, it is possible to extend teaching to students regardless of their level of knowledge, schedule availability, location, or other limitations [2].

Agricultural Engineering university studies are undergoing great changes and improvements, thanks to the use of these technologies. Thus, it has been demonstrated the improvement in the development of agricultural engineering class sessions by using the flipped classroom learning environments (combination of the conventional and virtual teaching) [3]. Other authors proposed the implementation of distance-learning in engineering studies and use it for the benefit of increasing their attractiveness [4].

Among the important advances that have been made in the teaching of engineering and the use of new technologies [5], the following stand out: the tools for simulation of crop growing in agricultural [6], the use of devices to support the crop growing, advising, for example, the need of irrigation or fertilization [7,8], the use of supervisory control and data acquisition systems (SCADA) for the installation design, as drip irrigation systems [9], the use of software of finite element analysis (FEA) for the simulation of structural components of vehicles and machinery [10], the implementation of collaborative computer-aided engineering (CAE) for collaborative tools that allow the integration of different engineering specialties [11], the use of interactive exercises (using software), the use of information in real time, the use, by students, of graphics software for modelling or a virtual reality system for engineering laboratory education [12,13], the combining of attending theory classes with web-based learning and the use of software for solving problems (even in examination situations) [14,15], the use of tools for videoconferences between professors and students, also allowing group classes online [16,17], the use of augmented reality in order to improve the learning results [18,19], and the use of IT tools in the laboratory as a learning aid [20]. In addition, the use of web-based technologies, such as Moodle, as a support to traditional teaching [21,22].

In agricultural engineering, a main aspect is the knowledge of the machinery and equipment used [23]. The tractor is a vehicle widely used in several tasks. The technological development has also contributed to numerous advances in this type of agricultural vehicle [24], such as, for example, improvements in steering systems [25], the development of hybrid tractors [26], the use of algorithms and simulation to improve the suspension systems [27], or the use of a sensor to control the wear of some elements [28].

Therefore, during university studies in this specialty, students must acquire the knowledge for the design and calculation of the main parameters related with the tractors. One of these parameters is the engine power of an agricultural tractor [29]. One way to obtain the torque and power values of a tractor's engine is through the use of a dynamometer [30]. Also, some software solutions have been developed for these and other types of calculations [31], and mobile applications, which are a complement to the study of tractors [32].

This work describes the development and use of software that students could use to check their manually-produced solutions to problems on the behaviour of single-traction tractors in the field. Tractors are used to perform jobs that require different types of agricultural tools to be attached to their rear, to their front, or both. These tools may need to be dragged, towed, or suspended above ground, and sometimes require a power supply; this is usually obtained via a hydraulic system or from the tractor's power take-off system [33]. When tractors are working with such tools on different types of soils and on different slopes, the problem arises of calculating the power the tractor engine needs to produce [33,34]. Traditionally, such problems are tackled using the nomenclature described in Table 1 and the equations shown in Figure 1.

This calculation, therefore, demands knowledge of certain physical characteristics of the tractor–tool–soil system, and the resistance to movement caused by the weight supported by each of the tractor's wheels. The software developed takes all these variables into account, and can determine the power required of the engine under a wide range of work conditions. The value of this software as a learning aid for students of agricultural engineering is discussed.

Table 1. Nomenclature used.

Symbol	Magnitude	Symbol	Magnitude
$\mathbf{N_e}$	Effective power of the engine	$\mathbf{p}$	Pressure in the hydraulic system
$\mathbf{N_T}$	Power transmitted	$\mathbf{q}$	Hydraulic flow
η_m	Mechanical yield of the transmission	η_g	Overall pump performance
$\mathbf{N_{s.e.}}$	Power consumed by the electrical system	$\mathbf{T}$	Moment of the power take-off system
$\mathbf{N_h}$	Power consumed by the hydraulic system	ω	Velocity of power take-off
$\mathbf{N_{t.d.f.}}$	Power supplied by the power take-off system	$\mathbf{U}$	Peripheral forces in drive wheels
$\mathbf{N_U}$	Usable power	$\mathbf{R}$	Resistance to movement
$\mathbf{N_\rho}$	Power losses in movement	$\mathbf{V_t}$	Theoretical velocity
$\mathbf{N_\alpha}$	Power associated with the slope	$\mathbf{V_R}$	True velocity
$\mathbf{N_a}$	Power associated with acceleration	$\mathbf{P_T}$	Cross-sectional weight of the system
$\mathbf{N_\sigma}$	Power lost due to sliding	$\mathbf{F_i}$	Inertia of acceleration
$\mathbf{N_Z}$	Power transferred to the towing bar	$\mathbf{Z}$	Force associated with the towing bar
$\mathbf{V}$	Volt	$\mathbf{I}$	Ampere
η_b	Bar yield (Z)		

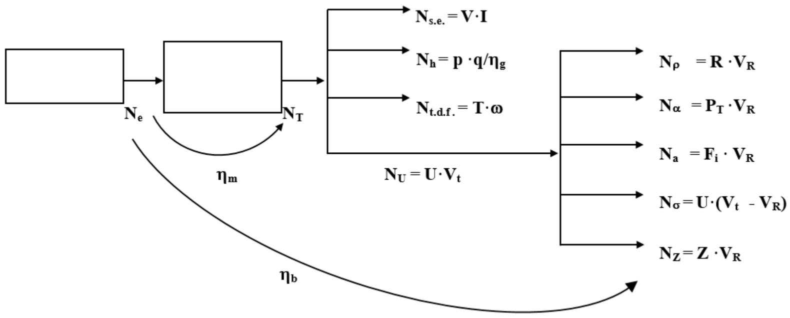


Figure 1. Power balance for a single-traction tractor.

2. Materials and Methods

A series of algorithms was produced that contemplates the majority of power-requirement situations encountered in the normal use of single-traction tractors. These situations were catalogued by examining the questions given in exercises and examinations to students of agricultural engineering at the University of Almería, Spain, in recent years. These algorithms were incorporated into a program designed to calculate the power required of the tractor engine in different scenarios. The program was written in Delphi [35], a high level language, and compiled to generate a file executable under the Windows operating system. The flowchart of the program is showed in Figure 2, where each step of the diagram is explained below in this section.

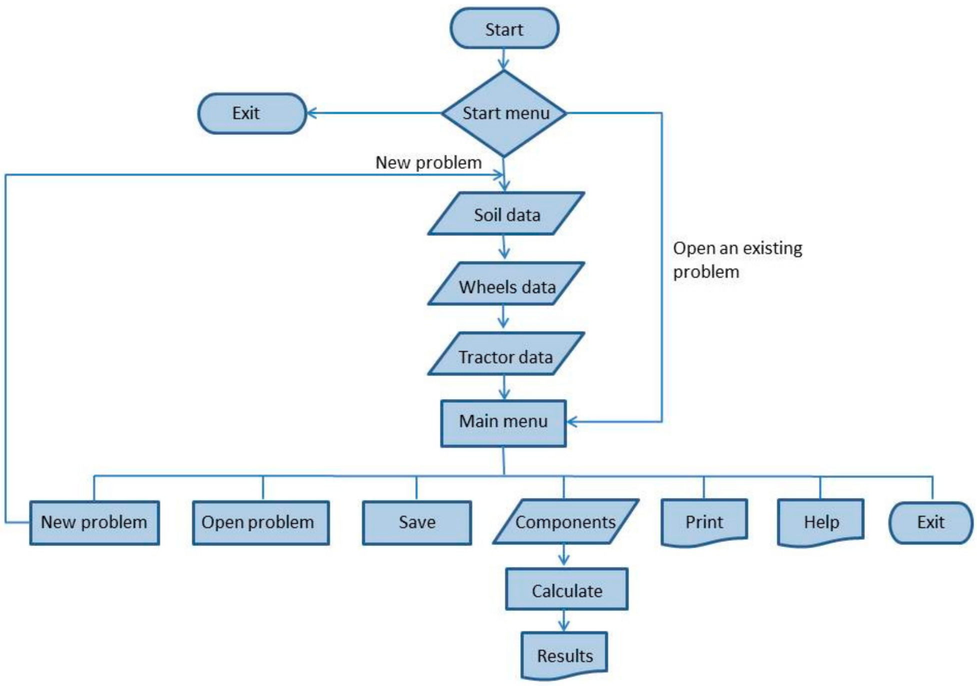


Figure 2. Program flowchart.

2.1. Start-Up Window

On starting the program, a window (Figure 3) appears that allows the user to choose between two options: to begin work on a new problem, or to re-open a saved problem. If desired, the program can be exited at this point by pressing the EXIT button.

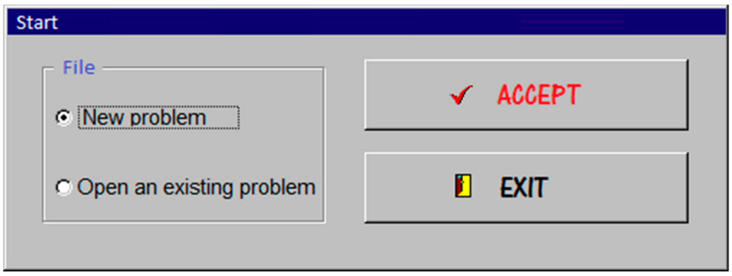


Figure 3. Start-up window.

2.2. Soil Data

If the "new problem" option is chosen, a new window appears (Figure 4) for the incorporation of data pertaining to the soil over which the tractor must move (maximum specific resistance of the soil and slope). If these data are not required for the solution of the problem, values of 0 are entered. When all data have been entered, the ACCEPT button is pushed.

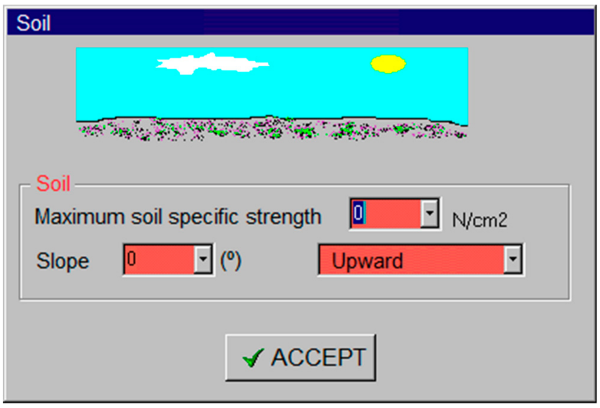
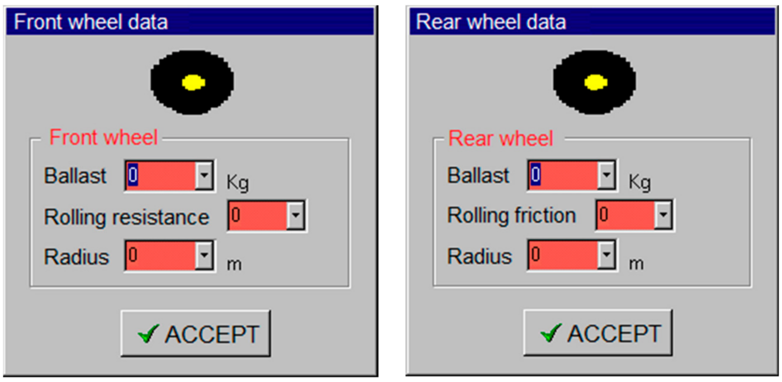


Figure 4. Soil data input window.

2.3. Data Pertaining to the Forward and Rear Wheels

Once the soil data are entered, a new window (Figure 5) appears for the introduction of data pertaining to the front wheels of the tractor (forward ballast, the coefficient of rolling resistance of the front wheels, and the front wheel radius). When this has been done, the ACCEPT button is pushed. A new window, similar to the last one, then opens for the rear wheel data to be introduced. The operator then proceeds as above.



(**a**) (**b**)

Figure 5. Tractor wheel data input window; (**a**) Front wheel; (**b**) Rear wheel.

2.4. Chassis and Engine Data

Once the above data have all been introduced, a new window (Figure 6) opens to allow the introduction of the chassis and engine data; this includes the distance between the axels, the tractor's centre of gravity, its weight, the power loss in the hydraulic system, the power reserve of the engine, the mechanical yield of the transmission, power loss in the electrical system, the theoretical velocity of the tractor, the true velocity of the tractor, and coefficient of sliding friction. In the velocity section of the window, two or three of the requested values should be introduced. A value of 0 is introduced if the true value is unknown. The CALCULATE button is then pushed for the unknown value to be determined from the data provided. The ACCEPT button is then pushed. If the values introduced are clearly incorrect (e.g., a true velocity higher than the theoretical velocity has been entered) a message to this effect will appear. Any errors can then be corrected before pushing the ACCEPT button again.

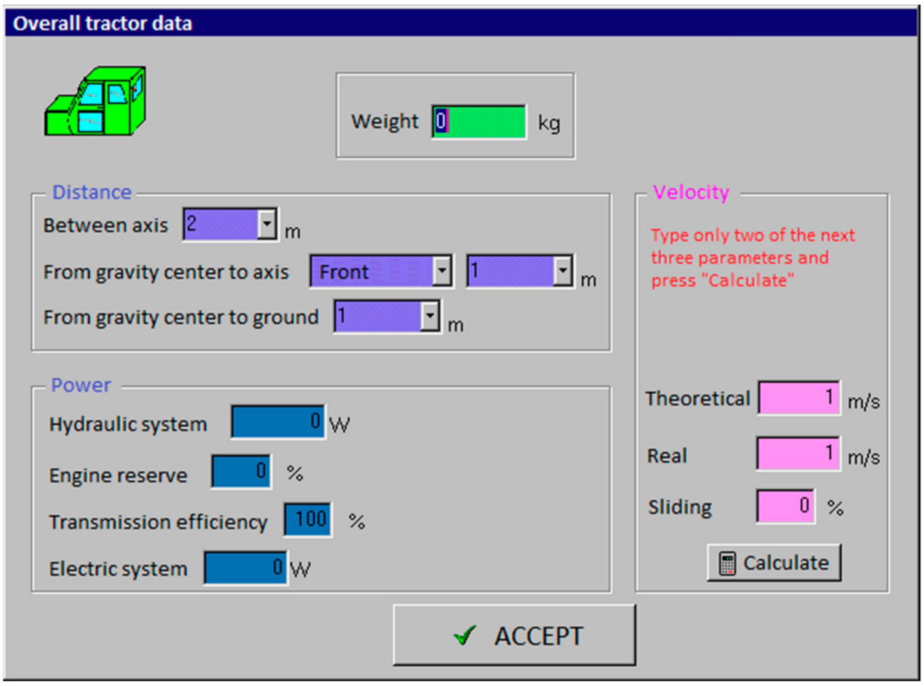


Figure 6. Chassis and engine data input window.

2.5. Main Window

When the above step has been completed, a new window (Figure 7) appears. This allows the machinery (e.g., fertilizer spreader, drill, pulveriser, mould board plough, trailer, etc.) to be connected to the tractor (either at the front or rear) to be introduced.

A desired tool is selected from the options by clicking on it and dragging to the picture of the tractor. The virtual tractor can take a maximum of one suspended or dragged tool and two forward tools; no more can be added, but choices can be changed. To eliminate a tool, all that is required is to drag it from virtual tractor and drop it in the recycle bin. The tool selection options will then become active again. The data for the attached tool can then be introduced by clicking on the "TRACTOR COMPONENTS" dropbox and choosing the tool selected; a data input window will then appear. These data can be modified by performing the process again at any time.

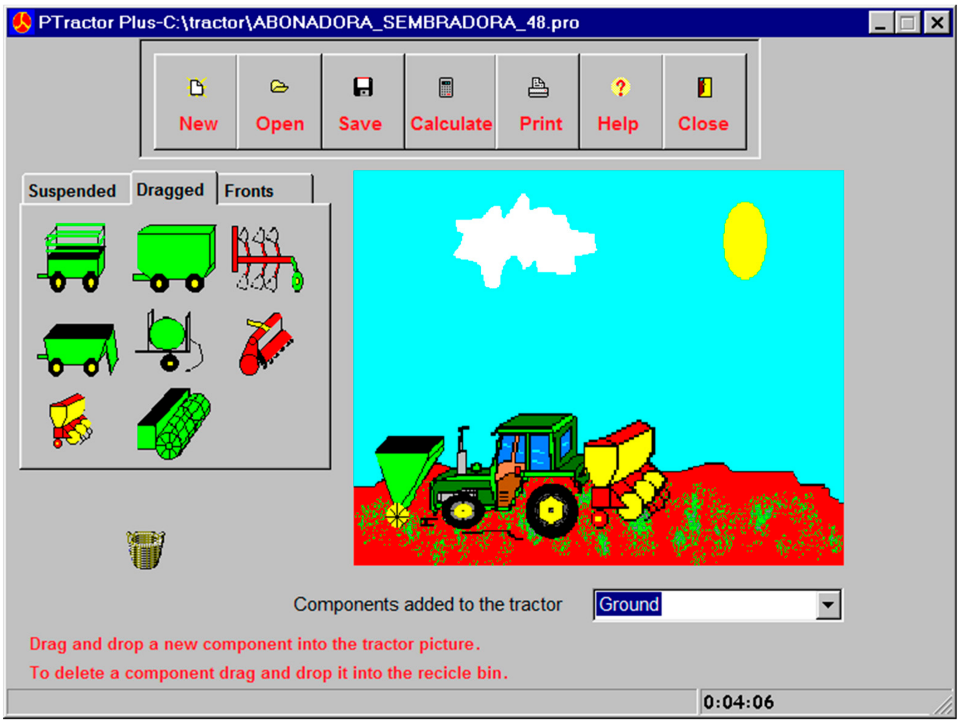


Figure 7. Main window.

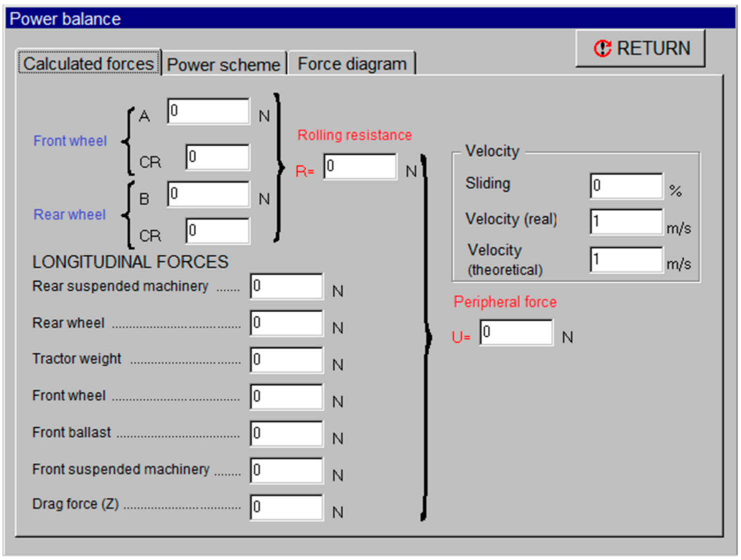
2.6. Visualizing the Results

To see the results (Figure 8), the user only needs to do the following:

(a) Press the CALCULATE button in the main window. A window will then appear with all the results.

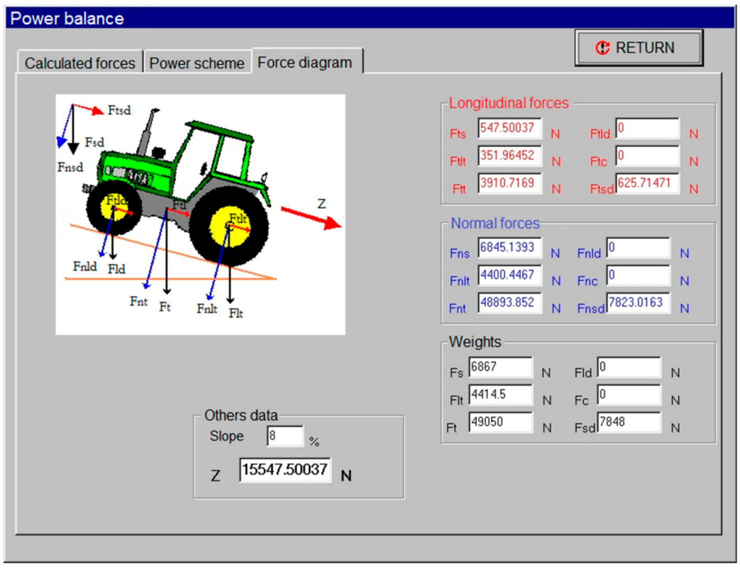
(b) Clicking on a result will cause a window to appear with the formula used to obtain that results. To move between the different types of result, the user need only click on the different tabs.

(c) To return to the main window, the RETURN button is pushed.

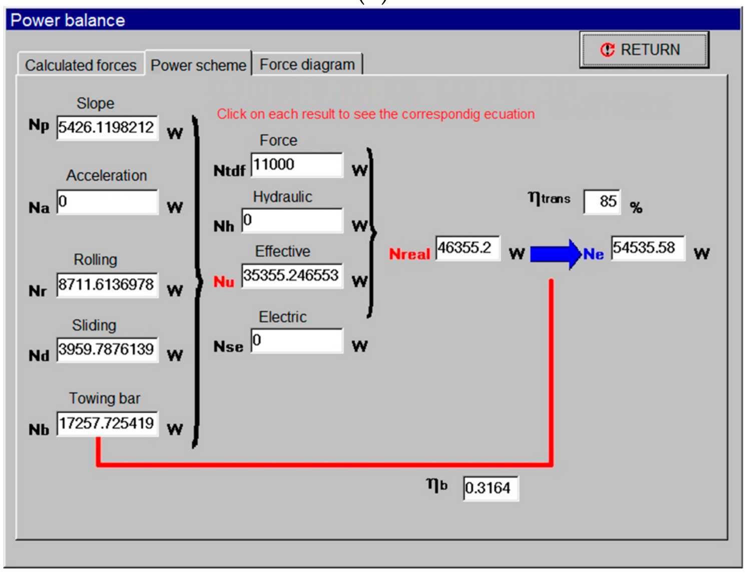


(**a**)

Figure 8. *Cont.*



(**b**)



(**c**)

Figure 8. Results windows; (**a**) Calculated forces; (**b**) Force diagram; (**c**) Power scheme.

2.7. Saving a Problem

Being able to save a problem means the user need not put in all the data every time he or she wishes to return to it. Saving requires the user to:

Push the SAVE option in the main window.

Choose a file name for the problem and press SAVE in the corresponding window.

If a filename is chosen that already exists, a message appears asking the user if the intention is to overwrite that file. The YES button should be chosen if this is the case, the NO button if it is not. The latter choice will allow the user to provide a new name for the problem to be saved.

2.8. Recovering a Saved Problem

If the program has just been opened, a window will appear asking whether the user would like to re-open a saved problem. If this is the case, the user should press ACCEPT, and choose the problem desired.

If the program is already running and the user wants to access a saved problem, the OPEN button in the main window should be clicked. The directory and appropriate file should be sought, and the problem opened by pressing the OPEN button. This will return the user to the main window, where all the data pertaining to that problem will appear in the correct place.

2.9. Printing Results

To print the results, the user should:
Press the PRINT button in the main window.

2.10. Evaluation of the Software

To evaluate the software developed, a survey has been carried out that includes eleven questions to be answered by a group of students (Table 2). Two questions are about the characteristics of the student and the other nine questions about the use of the software. A total of sixteen students of the Grade in Agricultural Engineering of the University of Almería (Spain) have carried out the survey.

Table 2. Qualitative variables collected for each student.

Variable	Category	Abbreviation
Students		
1. Sex	Male Female	Mal Fem
2. Age	$\leq$20 years old $\geq$21 years old	T1 T2
Software		
3. Is the interface easy to use?	Yes No Ever	q3y q3n q3e
4. Would it improve the interface (titles, windows, menus, icons, buttons or figures)?	Yes No Ever	q4y q4n q4e
5. Do you find useful the software to solve problems of power balances in tractors?	Yes No Ever	q5y q5n q5e
6. Is the level of knowledge required to use the software in accordance with the academic level?	Yes No Ever	q6y q6n q6e
7. Is the speed of response of the software correct? (user interaction and program)	Yes No Ever	q7y q7n q7e
8. Do you think necessary previous explanations of the teacher in the classroom for the use of the software?	Yes No Ever	q8y q8n q8e
9. Is it easy to navigate the program?	Yes No Ever	q9y q9n q9e
10. Is the information correct and updated?	Yes No Ever	q10y q10n q10e
11. Rate the software PTractor Plus 1.1. from 1 to 10:	<5 5–7 >7	L M H

The results of the survey have been statistically evaluated using the XLSTAT2018 software (Addinsoft, Paris, France).

3. Results and Discussion

The program developed, known as PTractor 1.1, quickly performs the tedious tasks required in the calculation of power balances in single-traction tractors. It could be used by engineers to rapidly assess the possibility of a tractor being able to perform a desired task, or to simulate small field trials, such as those performed with single-traction tractors by Evans, Clark & Manor [36], Shibusawa & Sasao [37], Sharma & Pandey [38]. and Raheman & Jha [39]. Perhaps more importantly, however, it has the potential to be used as a learning aid.

Generally, students in our department are first exposed to the basic concepts of the equations required to calculate power balances. They then have to use this new knowledge to work out some general problems. These calculations are performed manually with the aid of a calculator. Each question demands considerable time on the part of the student, who has to repeat the majority of the calculations made if any condition of the problem is changed. However, our students are allowed access to the program described, either individually or in groups. They can then check their calculations and easily modify variables to see what effect this has on the final result—something that should reinforce their understanding of the basic concepts they have been taught.

This type of software-supported learning for the verification of results has been tried in other areas of engineering by other authors [6,11].

Regarding the survey carried out for the students (Table 2), the statistical results obtained are showed in Table 3. Most students who have completed the questionnaires are under 21 (56.25%—T1). This means that almost half (43.75%—T2) are students who have repeated the course. Besides, male students are about twice that female students.

Table 3. Frequencies and modes for the qualitative variables by category.

Variable	Categories	Frequencies	%
Age	T1 *	9	56.25
	T2	7	43.75
Sex	Fem	5	31.25
	Mal *	11	68.75
q3	q3e	1	6.25
	q3y *	15	93.75
q4	q4e	5	31.25
	q4n	4	25.00
	q4y *	7	43.75
q5	q5e	1	6.25
	q5y *	15	93.75
q6	q6e	3	18.75
	q6n	3	18.75
	q6y *	10	62.50
q7	q7e	1	6.25
	q7y *	15	93.75
q8	q8e *	7	43.75
	q8n	4	25.00
	q8y	5	31.25
q9	q9e	5	31.25
	q9y *	11	68.75
q10	q10e	3	18.75
	q10y *	13	81.25
q11	H *	7	43.75
	L	2	12.50
	M *	7	43.75

* Mode.

With respect the question about the software, the 93.75% of the users consider that the software is easy to use ("q3") and fast ("q7") but, at the same time, consider that it should be improved ("q4"). This may be due to the fact that the program has been used for more than ten years without having been updated with the new Windows environments; however, almost all students find it useful ("q5").

In question 6, most students think that the software is appropriate to their knowledge; nevertheless, approximately 40% of the students think that it is not appropriate, percentage that coincides with the number of "T2" students. Also, this percentage coincides with the number of students that requires, sometimes, an explanation about the use of the software before using it ("q8").

Near 70% of the students have found the software easy to navigate ("q9") and around 80% think that the information is correct and updated ("q10"). All this is positive, but it should not lead the professors to conformism. Improvements would be necessary in the search for educational excellence. Regarding the overall evaluation of the software, the valuation has been medium-high (close to 90%; "q11").

Finally, as limitations of the software it should be noted that it does not take into account the regenerative auxiliary power of the tractors [40], nor does it solve problems of tractors with double traction. These facts, together with the updating of the interface, advise an update of the PTractor Plus software.

4. Conclusions

The software could be of use to professional engineers when power balances need to be calculated, or for undertaking simulations in the laboratory. However, it may also have great potential as a learning aid for students in real or virtual classrooms.

Also, although the students value, in general, the software positively, a short/medium term update is necessary.

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