AireAr: a New Software for Sizing Aeration Fans

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ABSTRACT

The National Institute of Agricultural Technologies of Argentina (INTA) developed a new software, named AireAr, for sizing and selecting grain aeration fans. AireAr can be used for selecting aeration fans for corn, wheat, soybean, sunflower, canola, barley, oats and sorghum. The user can select two different storage structures, round bin or flat storage, and enter its dimensions as well as the grain depth. The user can also chose between flat bottom or conned bottom, and between leveled grain surface or grain peak. Based on this information the software computes the total grain volume and grain depth. AireAr takes into account the grain moisture content in order to adjust grain density. The user enters the desired specific airflow (0,1 $m^3min^{-1}t^{-1}$ for maintenance aeration, 0,3-0,5 $m^3min^{-1}t^{-1}$ for wet grain aeration and 1-2 $m^3min^{-1}t^{-1}$ for in-bin drying) and the software computes the total airflow (m^3min^{-1}), the air resistance due to the grain using the Shedd´s equation (the resistance of the airflow distribution system is also considered), and the fan power. The user can select from a database a suitable commercial fan that would met the requirements predicted by the software (fan power, total resistance and total airflow). The fans are ordered in the database by power, type (axial or centrifugal) and manufacturer. Once a candidate fan is selected, the user can compare the performance of the selected fan (airflow-static pressure curve provided by the manufacturer) with the requirement of the system estimated by the software for different depths. The software provides charts and tables with the performance of the selected fan if it were installed in the user´s bin, so the user can compare the desired airflow rate with the airflow rate obtained with the selected fan for different grain depths. If the selected fan does not satisfy the desired airflow requirement, the user can select another fan from the database, or add a second fan in parallel or in series configuration. The user can select between Spanish or English language, and International or British unit system. The software is available on-line (http://online.inta.gov.ar:8080/aireAr/login.jsp), and registration and use is for free.

Keywords: Aeration, fan, software, online, selection, Argentina

1. INTRODUCTION

Often, farmers, grain elevator managers and grain industry personnel are in the need of selecting a new aeration fan. This is because a new bin or flat storage structure was installed in their facility, or because an old one is being updated. In any case there is a selection process for a new fan that should be carried out. When selecting a new fan, the main factors to put under consideration are bin dimension, required airflow rate, type of grain to aerate and typical climate conditions in the location. The decision is complex and many times there is no knowledge to calculate the requirements for the new fan. On the other hand, fan manufacturers and dealers often do not have a suitable tool to show to their potential clients the characteristics of their products.

Big corporations have the resources to hire engineers for equipment selection, but that is not the general situation for small elevators or farmers. In that sense, a tool that would help users in selecting a suitable aeration fan allows for a more efficient use of resources for all the grain industry sector, and reducing the risk of grain spoilage due to insufficient aeration, specially for farmers and small elevators.

There was previously available a software developed by the University of Minnesota (Fans) for selecting aeration fans (Wilcke and Vance Morey, 1999). This is an excellent application; however it has some limitations that make its use difficult. The user has to download the software with the associated database, so, after a few years, the database is out of date regarding to fans available in the market. Additionally, if a user has the need of selecting an aeration fan for a new crop, he would have to add the parameters of the new crop by himself. Another limitation of the existing software is that only takes into account round bins with flat bottom and leveled grain surface, situation that is seldom observed in countries such as Argentina, where a big proportion of the grain bins are conned bottom and often they are operated completely full, resulting with a grain peak. Additionally, the Fan software did not allow selecting fans for flat storage structures. These characteristics of the Fan program, along with the fact that the user had not choice but using the British Units System, prevented its use in other countries but the US. The objective of this work was to develop an online software to size and select aeration fans based on state of the art engineering principles.

2. METHODOLOGY

2.1 Location
The AireAr software is available on-line (http://online.inta.gov.ar:8080/aireAr/login.jsp), and registration and use is for free.

2.2 Inputs
The inputs required for the system are:

Type of grain
by selecting the appropriated grain, the system will use the grain specific parameters to compute grain density according to MC (when parameters are available), and airflow resistance.
Moisture content: it is used to adjust grain density (when parameters are available).

Shedd´s Multyplier: Through an advanced option menu, the user can modify the Shedd multiplier to adjust the airflow resistance for a specific storage condition (i.e.: grain more compacted than normal).

Type of storage: the user can select between bin and flat storage structure. By selecting the appropriated storage system the program will change the input menu, requesting the set of parameters required to compute the volume for the bin or the flat storage geometry.

Bin dimensions
When "Bin" option is chosen, the following dimensions are requested (Figure 1):
Bin diameter: the diameter of the bin (D)
Height: the height of the lateral wall of the bin (if loaded full), or the grain depth at which aeration is typically operated (H)
Cone angle: the angle of the cone of the bin, in case of having hopper bottom bin (typically from 25 to 35°). If the bin has flat bottom, the cone angle is "0" (α)
Peak height: the height of the grain peak observed after loading the bin, measured from the position of the grain in the lateral wall to the tip of the grain peak. If grain surface is leveled, thus grain peak height is "0" (P)
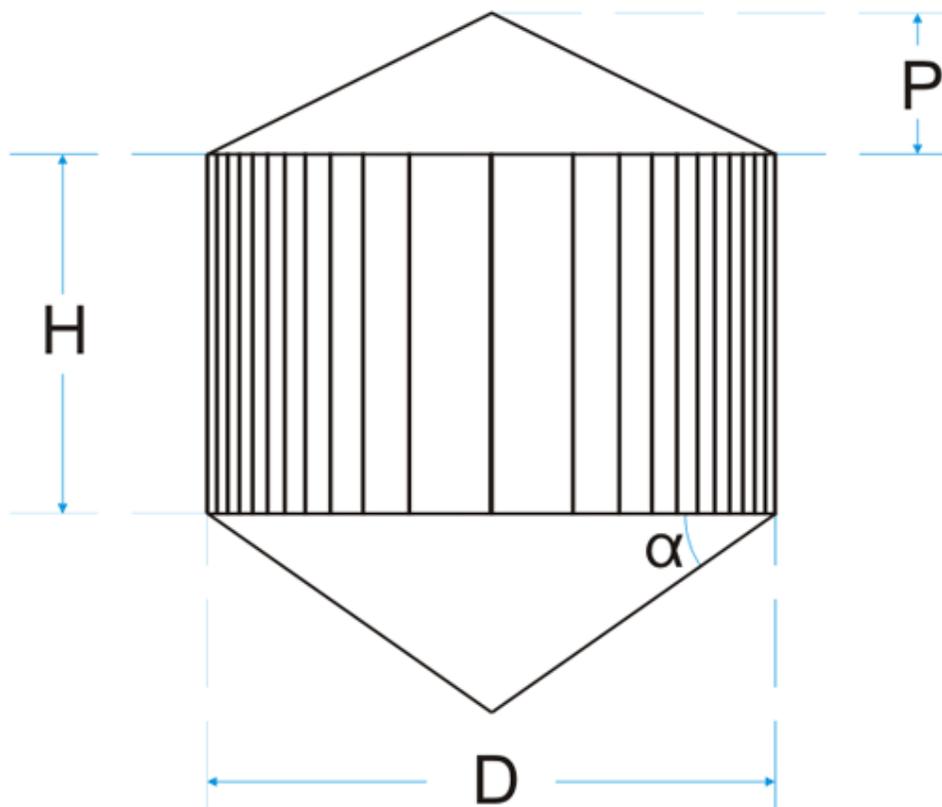
Figure 1. Diagram of a typical bin and the requested dimension for computing storage volume

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Flat storage structure dimension
When "Flat storage" option is chosen, the following dimensions are requested (Figure 2):
Minor side: the length of the shortest side of the storage structure (A)
Major side: the length of the longest side of the storage structure (L)
Height: the height of the lateral wall of the flat storage structure (if loaded full), or the grain depth at which aeration is typically operated (H)
Cone angle: the angle of the cone of the flat storage, in case of having hopper bottom (typically from 25 to 35°). If the flat storage has flat bottom, the cone angle is "0" (α)
Peak height: the height of the grain peak observed after loading the bin, measured from the position of the grain in the lateral wall to the tip of the grain peak. If grain surface is leveled, thus grain peak height is "0" (P)
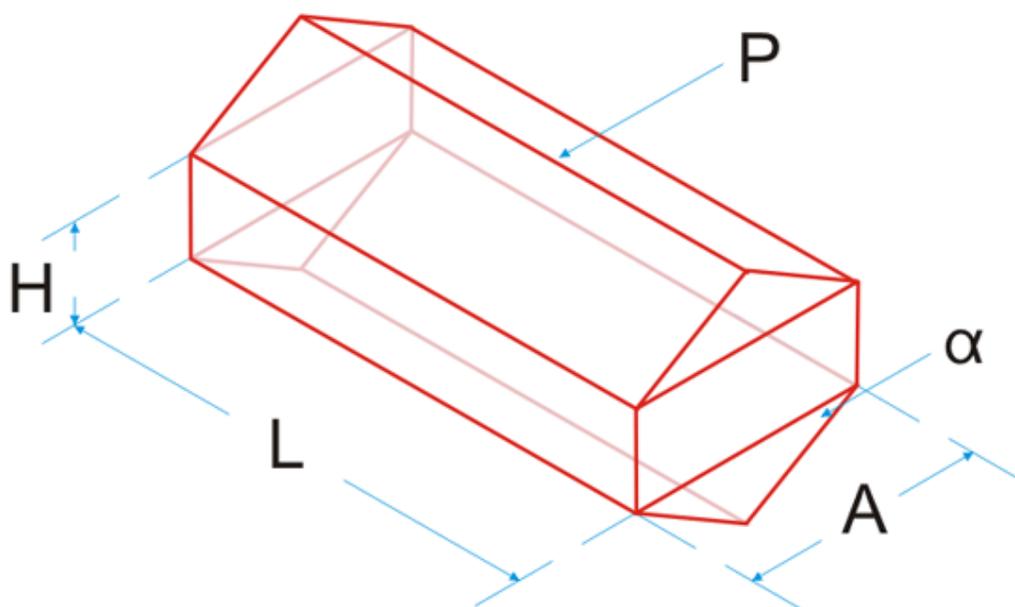

Figure 2. Diagram of a typical flat storage and the requested dimension for computing storage volume

Airflow desired
In this field the user must enter the desired specific airflow rate. An orientation value is provided: maintenance aeration for dry grain (0,1 $m^3min^{-1}t^{-1}$), wet grain storage or dryeration (0,4-0,6 $m^3min^{-1}t^{-1}$) and in-bin drying (1-2 $m^3min^{-1}t^{-1}$).

Aeration distribution system
The aeration duct resistance to the air is taken into account by the software. The user can choose between "Well dimensioned" aeration distribution system and "Bad dimensioned" system. If "Well dimensioned" option is selected, 125 Pa of resistance is added in addition to the grain

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resistance (MWPS-29, 2004). If "Bad dimensioned" option is selected, then the aeration duct resistance is increased by 50% to 187,5 Pa.

2.3 Compute bin and flat storage volume

Bin volume

The bin volume is computed as follows:

$$Cylinder = \pi \frac{d^2}{4} * h$$

$$GrainPeak = \frac{1}{3} \pi \frac{d^2}{4} * p$$

$$BinCone = \frac{1}{3} \pi \frac{d^2}{4} * \tan(\alpha) * \frac{d}{2}$$

Where:
π: pi
d: bin diameter (m)
h: height of the bin cylinder (bin wall) (m)
p: height of the grain peak, from the bin eave (m)
α: bin cone angle (°)

Total volume = Cylinder V. + Grain peak V. + Bin cone V.

Flat storage

$$MainVolume = l * a * h$$

$$GrainPeak = l * \frac{a * h_p}{2}$$

$$Cone = l * \frac{a * d_c}{2}$$

Where:
l: longer side (m)
a: shorter side (m)
h: height of the wall (m)
h_p: height of the grain peak, fro the wall upper end (m)
d_c: depth of the cone (m)

2.4 Compute grain bulk density

The bulk density was computed as function of the grain moisture content according to this general formula. For those grain in which the parameters for computing bulk density at different moisture contents were not available a typical bulk density value was used (ASAE D241.4):

$$BD = x_1 - x_2 M + x_3 M^2$$

Where:
BD: grain bulk density (kg/m^3)
x_1; x_2; and x_3: grain specific parameters
M: grain moisture content (wet basis, decimal)

2.5 Compute bin and flat storage capacity
The bin and flat storage capacity is computed by multiplying the total grain volume times the grain bulk density. Since the bulk density is adjusted with moisture content, the total capacity (tonnes) vary as grain moisture content changes.

$$StorageCapacity = StorageVolume * \frac{BD}{1000}$$

Where:
StorageCapacity: total storage capacity (tonnes)
StorageVolume: total volume of storage structure (m^3)
BD: grain bulk density (kg/m^3)

2.6 Compute total airflow
The total airflow required is computed with the desired specific airflow rate and the total storage capacity, as follows:
$$TotalAirflow = StorageCapacity * DesiredAirflow$$
Where:
TotalAirflow: total amount of air that enters to grain mass per minute (m^{3}min^{-1})
StorageCapacity: total amount of grain stored (tonnes)
DesiredAirflow: desired specific airflow (m^{3}min^{-1}t^{-1})

2.7 Compute air velocity
Air velocity in the grain mass is computed by relating the total airflow to the bin area as follows:
$$AirVelocity = \frac{TotalAirflow}{BinArea}$$
Where:
AirVelocity: velocity of the air moving though the grain mass (m s^{-1})
TotalAirflow: total amount of air that enters to grain mass per minute (m^3 min^{-1})
BinArea: surface of the bin area (m^2)

2.8 Compute resistance per meter of depth
The resistance to the air per meter of depth is computed according to the equation and parameters of the ASABE Standard D272.3 – Resistance to airflow of grains, seeds, other agricultural products, and perforated metal sheets – as follows:
$$\frac{\Delta P}{L} = \frac{aQ^2}{\log_e(1+bQ)}$$
Where:
ΔP : pressure drop (Pa)
L: unit of grain depth (m)

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Q: airflow (m^3 seg^{-1} m^{-2}) or air velocity (m seg^{-1})
A and b: constants for particular grains

2.9 Compute total resistance due to grain

Total air resistance due to the grain is computed by multiplying the pressure drop by the grain depth as follows:

$$\text{AirResistanceGrain} = L * \frac{\Delta P}{L}$$

Where:
AirResistanceGrain: total air resistance due to the grain (Pa)
ΔP : pressure drop (Pa)
L: total grain depth (m)

In case of selecting a bin (or flat storage structure) with conned bottom or peaked grain, the system will add to the grain depth (the height of the bin wall) half of the height of the cone and half of the height of the grain peak. In this way the software acknowledges that there is an increase in the airflow resistance due to the longer path that the air has to follow through the extra grain mass conformed by the grain peak and the conned bottom.

2.10 Compute total air resistance

The duct resistance is assumed to be 125 Pa for well dimensioned aeration duct systems, or 50% higher (187,5 Pa) for poorly dimensioned systems (cita). The user can select the suitable option from the main screen.
The estimated resistance of the air passing through the aeration duct is added to the total air resistance as follows:

$$\text{TotalAirResistance} = \text{AirResistanceGrain} + \text{DuctResistance}$$

Where:
TotalAirResistance: total air resistance in the bin (Pa)
AirResistanceGrain: total air resistance due to the grain (Pa)
DuctResistance: air resistance due to the friction of the air passing through the aeration ducts (Pa)

2.11 Estimate fan power

Based on the predicted total air resistance and desired airflow the fan power is estimated using the following simplified equation:

FP= Total Airflow * Airflow Resistance / (63,43 * Fan Efficiency)

2.12 Fan pressure airflow curve

The AireAr software has incorporated a series of aeration fans pressure-airflow curves, as the one showed in figure 3. The data was obtained directly from the fan manufacturer.

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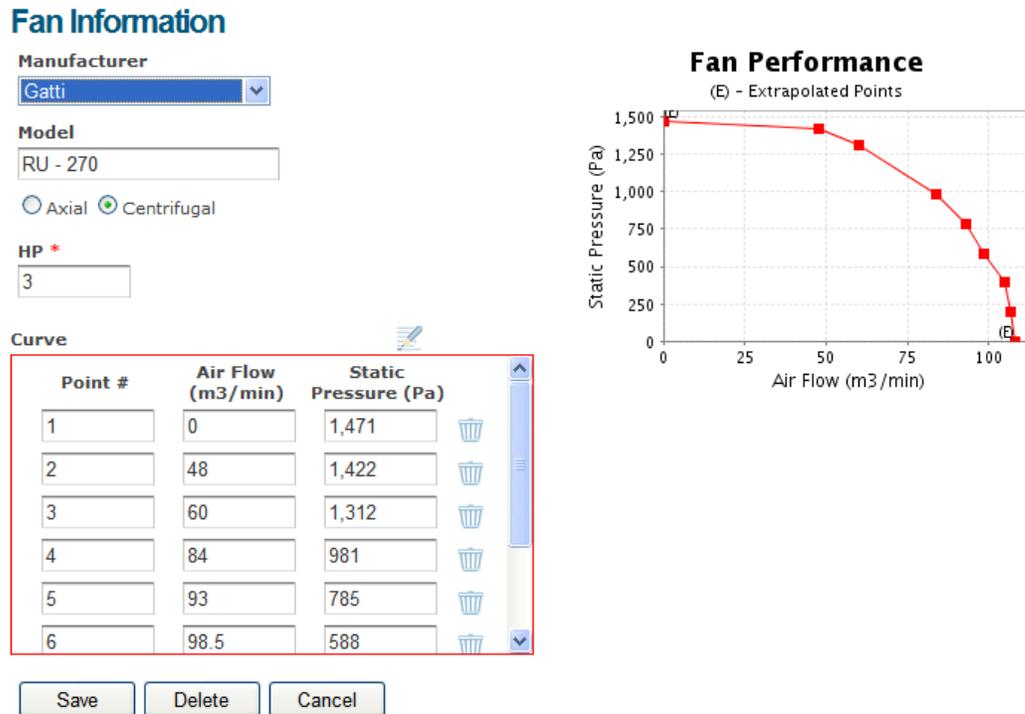
Figure 3. Form for loading aeration fan information showing the fan manufacturer and model, type of fan (axial or centrifugal), fan power, table with the pairs of static pressure and airflow data, and the corresponding static pressure and airflow curve.

2.13 Select a fan from a database

The user can select from the fan database the fans that would possibly meet the predicted requirements for the aeration system (fan power, airflow resistance and total airflow). The fan database is sorted by fan power (from lower to higher). A brief description of the fan features is also available, such as fan type, manufacturer and model.

2.14 Match the fan curve with the resistance curve

After selecting a suitable fan, the program overlaps the air resistance curves for different grain depths and air velocities, and the airflow-pressure fan curve. An algorithm finds the interjection points for the fan curve and the airflow resistance curves, which represents the operating conditions (static pressure and airflow) of the selected fan at different grain depths (figure 4).

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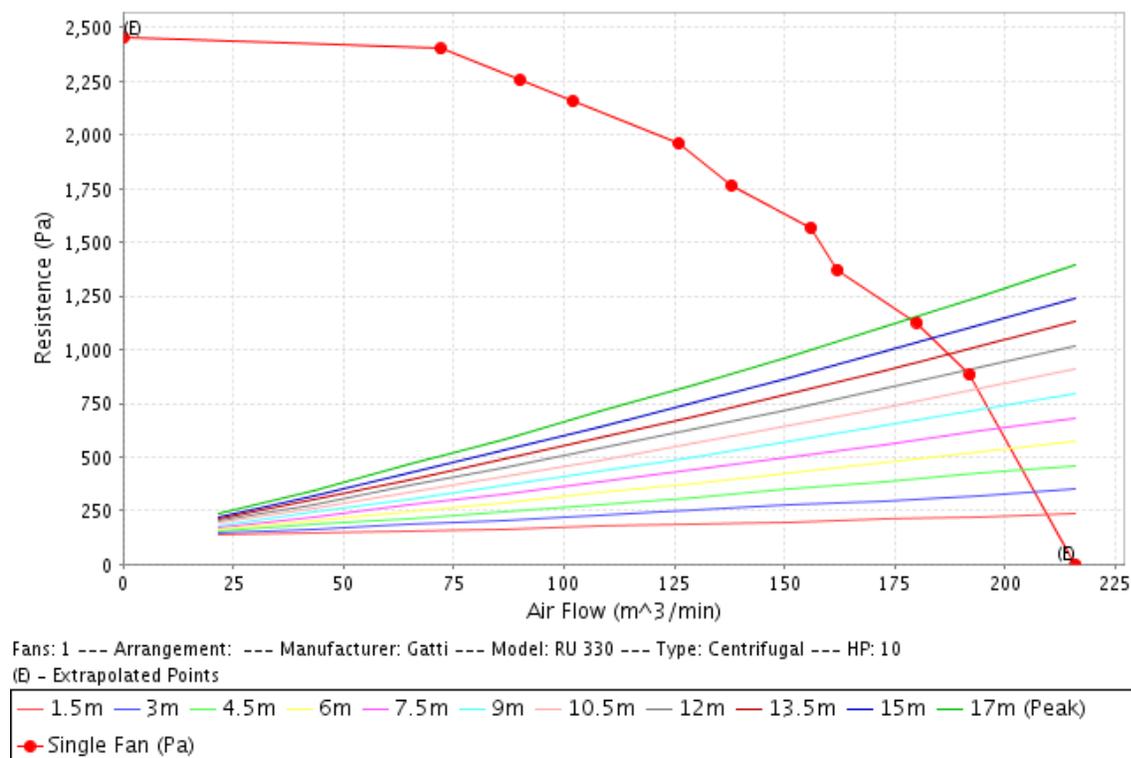
Figure 4. Airflow resistance curves for different grain depths and air velocities, and the airflow-pressure curve of the selected fan.

2.15 Predict the performance of the selected aeration fan
Once the operating conditions of the selected fan is obtained (airflow provided for each grain depth), the software process the information to show the results in specific airflow units (cubic meters of air per minute and tonne of grain). In this way, the user can visualize in a chart or table the specific airflow for each grain depth.

2.16 Other features
AireAr allows for predicting the performance of aeration fans in round bins and also in flat storage structures. Other feature of AireAr is that allows for selecting multiple aeration fans, using parallel or in-series fan configuration.
New grains and fans can be added by the program administrator, so it can be immediately available for all users through the web. Anytime there is an updated version of AireAr the users will benefit of it without having to change anything in their computers. Finally, AireAr is available either in English or Spanish, with the International Unit system or with the British system.

3. RESULTS

The AireAr software will be used to select a suitable fan for maintenance aeration of dry corn in a round bin of the following dimensions:

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Diameter: 10 m
Height (wall): 15 m
Cone angle: 35°
Grain peak height: 4 m

The characteristics of the grain were:
Grain: corn (parameters recommended for aeration, low air velocity (ASABE D272.3))
Moisture content: 14,5%
Desired specific airflow: 0,1 $m^3min^{-1}t^{-1}$

The required inputs were entered in the main frame of the AireAr software (Figure 5).

Figure 5. AireAr main frame for entering grain, required specific airflow and storage structure dimensions data.

After entering the required inputs the user hits the button "Calculate" and the software will provide the following results: the area of the bin (Base Area); the depth of the cone for conned bottom bins (Cone Depth); the height of grain used for computing air resistance, including halve of the cone and halve of the grain peak (Crop Depth); total storage volume (Volume); total grain mass held in the bin (Crop Weight); total airflow required (Air Volume Total); air velocity in the grain mass (Air Velocity); air resistance per meter of grain depth (Load Lost), total air resistance due to grain (Load Lost Total), total resistance, including grain and ducts (Resistance Total); total resistance, including grain and ducts shown in inches of water (Resistance Total Inches), aeration fan power estimated (Fan Power Estimated). The figure 6 shows the results for the bin proposed in the example. It can be appreciated that the fan should provide a total of 103,9 m^3 of air per minute and support a static pressure of 744 Pa for providing an specific airflow rate of 0,1 $m^3min^{-1}t^{-1}$ when the bin is full. Additionally, the estimated fan power was about 3,5 HP.

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Calculate

Output

Base Area	**Cone Depth**
78.54 m^2	3.501 m
Crop Height	**Volume**
18.751 m	1,374.474 m^3
Crop Weight	**Air Volume Total**
1,039.975 T	103.998 m^3/min
Air Velocity	**Load Lost**
0.022 m/s	33.034 Pa/m
Load Lost Total	**Resistence Total**
619.412 Pa	744.412 Pa
Resistence Total Inches	**Fan Power Estimated**
2.99 inAq	3.46 hp
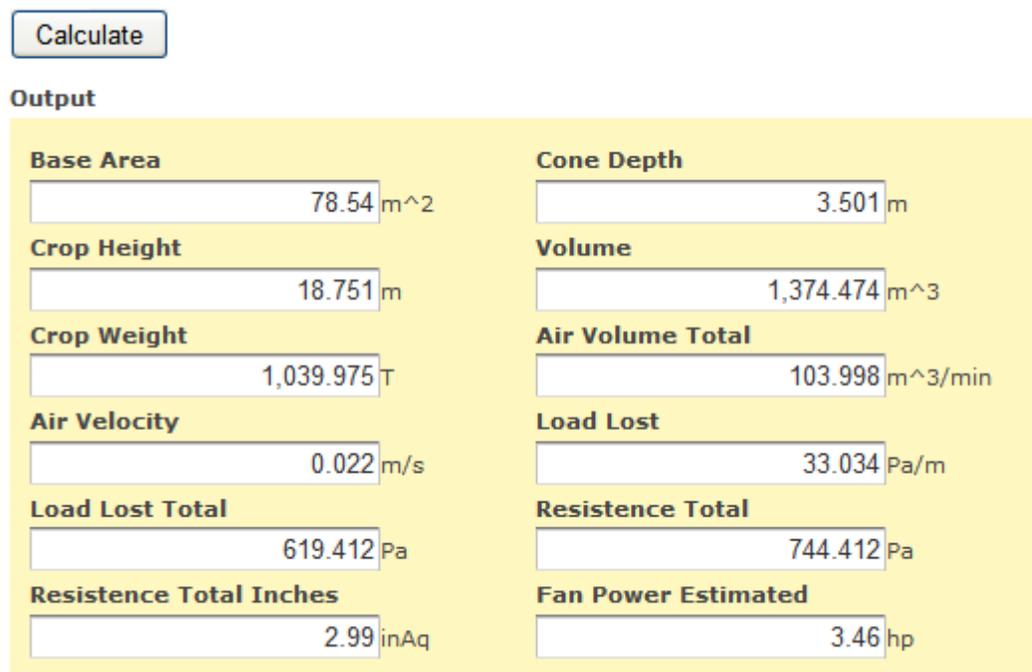
Figure 6. Output results of the AireAr software related to the bin, airflow, static pressure and fan power.

With this information the user can access to the fan database and select the fans that would have similar characteristics in term of total power, static pressure and airflow than the one predicted. In this example, a 5,5 HP centrifugal fan (Gatti RU 300) was selected (Figure 7).

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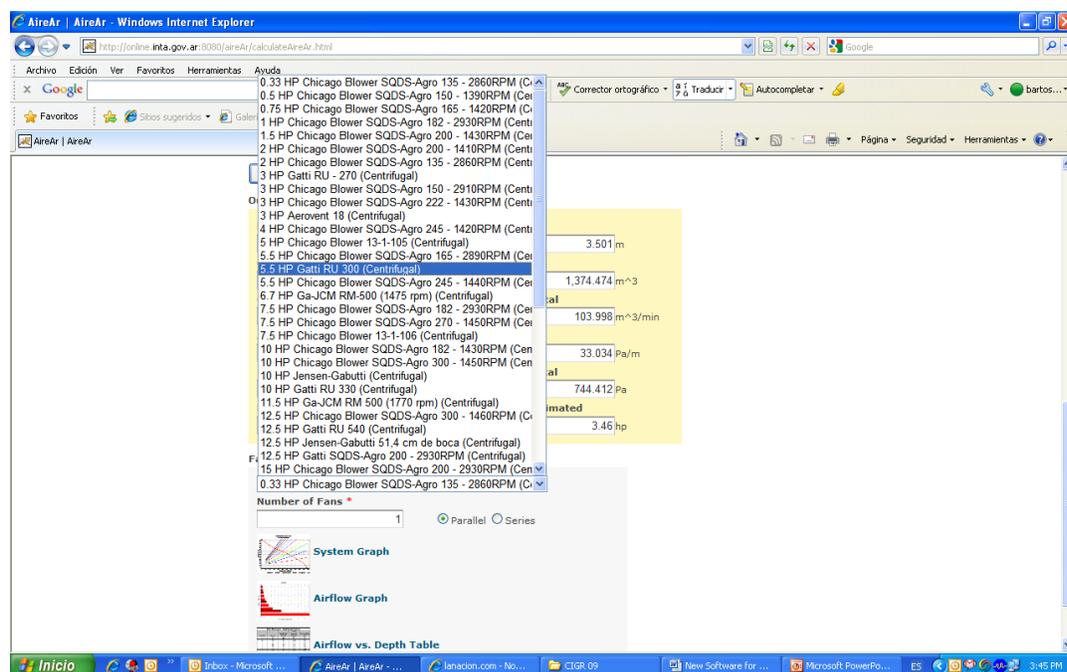
Figure 7. Fan database of the AireAr software, showing the selected fan (5,5 HP Gatti RU 300 (Centrifugal)) in the list.

After the fan was selected, the user can determine if the selected fan can provide the desired specific airflow for the entered bin configuration. To do so, the software provides three tools. The first tool is called the System Graph, in which the software plots the airflow resistance for different grain depths and air velocities, and the airflow-static pressure curve of the selected fan. In the interjection points of each grain depth line with the fan curve it can be found the conditions at which the fan would perform (static pressure and airflow) (figure 8).

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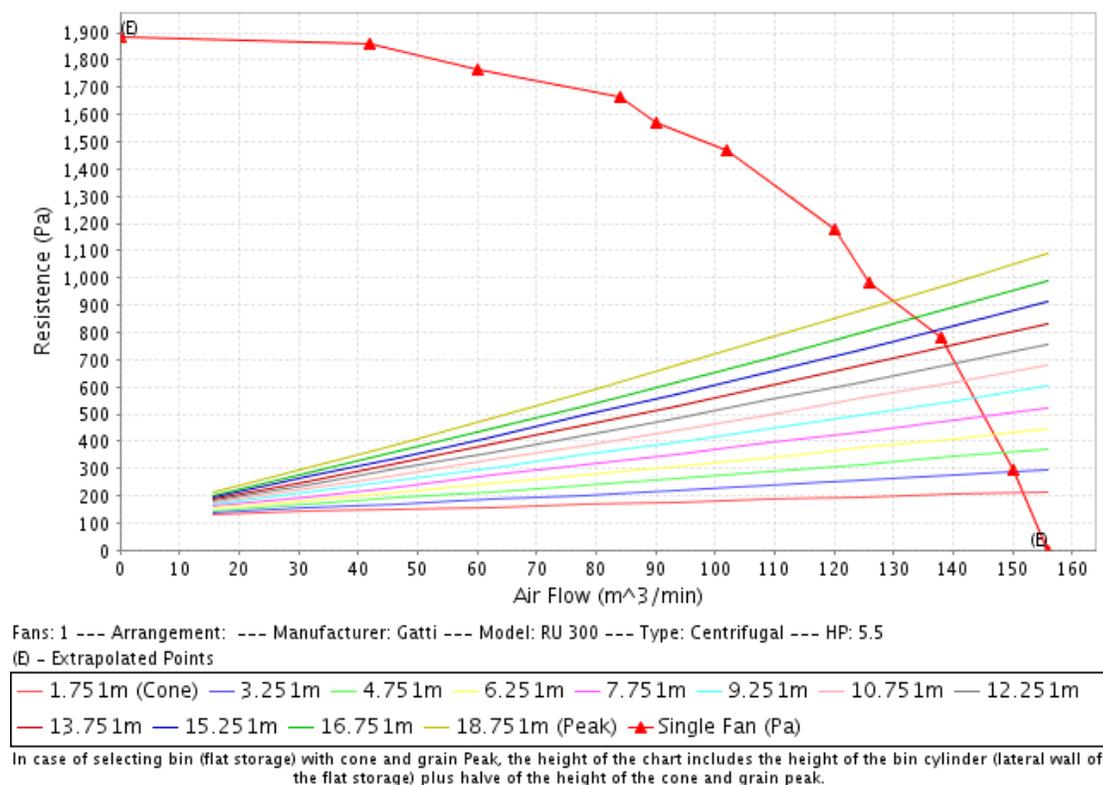
Figure 8. Air resistance for different grain depths and airflow rates and the airflow – pressure curve of the selected fan.

The second tool is a chart which represents the specific airflow rate ($m^3min^{-1}t^{-1}$) for different grain depths. The user can use this chart to predict how would behave the system as different layers of grain are added into the bin. The chart also provides a line that shows the desired airflow rate. By comparing the specific airflow rate of the maximum depth with the line of the desired airflow rate the user can determine if the selected fan is able to satisfy the airflow requirement when the bin is operated full (figure 9). For the selected fan in the example, it can be observed that when the grain covers the conned bottom, the specific airflow rate would be higher than 2,1 $m^3min^{-1}t^{-1}$. On the other hand, when the bin is completely full and a grain peak is left the specific airflow rate was slightly higher than the desired airflow of 0,1 $m^3min^{-1}t^{-1}$. This implies that the selected fan is able to deliver the desired amount of air, even when the bin is full or grain.

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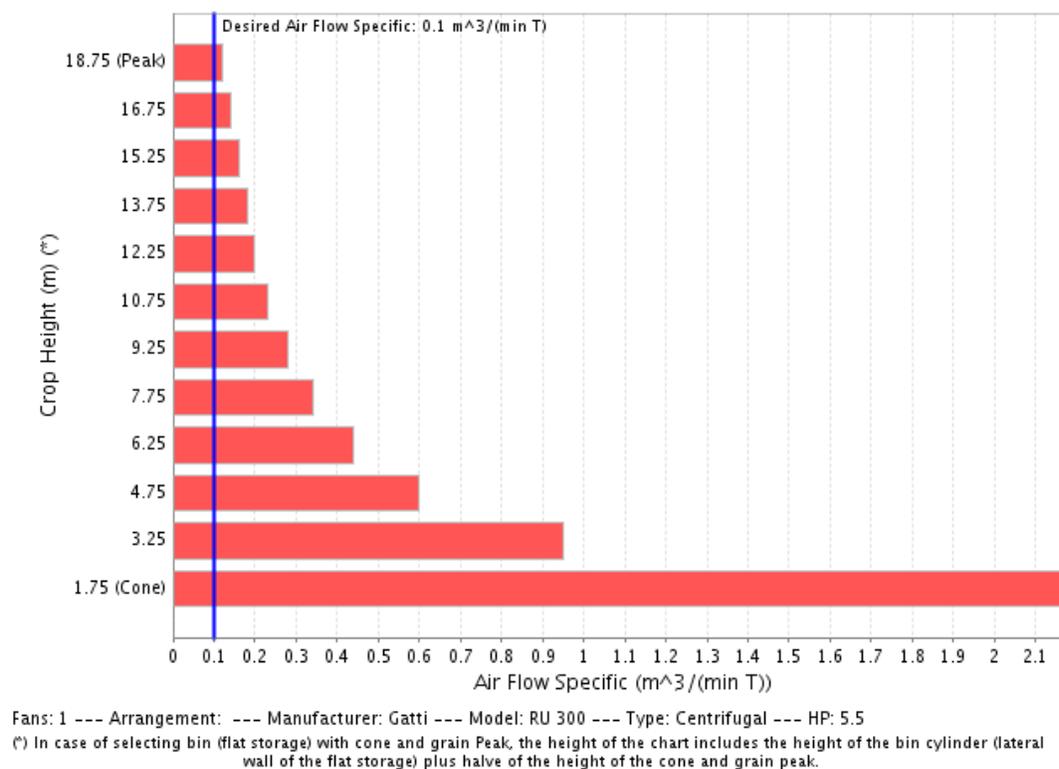
Figure 9. Chart with the estimated specific airflow rate for different grain depths in the horizontal bars, and the vertical blue line showing the desired specific airflow rate.

The third tool is the Airflow vs. Depth Table. This table provides detailed information regarding to the total amount of grain stored in the bin for different grain depth, total airflow resistance, total amount of air and specific airflow rate for each grain depth. For the example, the table shows that when the bin was full (18,751 m) the total amount of grain stored was 1039,9 t, the total airflow provided by the fan was 129,9 m^3min^{-1}, the specific airflow rate was 0,125 $m^3min^{-1}t^{-1}$ and the total static pressure of the system was 915 Pa (figure 10).

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AireAr

Crop: Corn (aeration)
Air Volume Desired: 0.1 m^3/(min T)

Height (m) (*)	Weight (T)	Total Air Flow (m^3/min)	Air Flow Specific (m^3/(min T))	Static Pressure (Pa)
1.751 (Cone)	69.351	151.664	2.187	212.472
3.251	158.49	150.17	0.948	285.656
4.751	247.629	148.461	0.6	356.831
6.251	336.768	146.763	0.436	426.162
7.751	425.907	145.108	0.341	493.756
9.251	515.046	143.494	0.279	559.676
10.751	604.185	141.919	0.235	623.985
12.251	693.324	140.382	0.202	686.741
13.751	782.463	138.878	0.177	748.135
15.251	871.602	136.746	0.157	804.489
16.751	960.741	133.751	0.139	853.398
18.751 (Peak)	1,039.975	129.975	0.125	915.068

Actual airflow differs from desired airflow by more than 5% at this depth. You might be able to increase grain depth or reduce fan power and still get the desired airflow.

Fans: 1 --- Arrangement: --- Manufacturer: Gatti --- Model: RU 300 --- Type: Centrifugal --- HP: 5.5

(*) In case of selecting bin (flat storage) with cone and grain Peak, the height of the table includes the height of the bin cylinder (lateral wall of the flat storage) plus halve of the height of the cone and grain peak.

Export options: Excel | PDF

Figure 10. Picture of the Airflow vs. Depth Table provided by the AireAr software. This table shows the total amount of grain, the total airflow, the specific airflow and total air resistance for different grain depths.

Based on the results of the AireAr software, the user most likely would conclude than the selected fan is a suitable choice for the bin configuration. The user could then proceed with the analysis by selecting different grains (i.e.: canola) and investigate if the fan would be able to deliver enough airflow. Another option is to select other fan from the list and do the same analysis. Then the user could decide to buy the lower cost fan from those that are able to deliver the desired airflow.

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4. ACKNOWLEDGEMENT

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