Combine Harvesters

There are millions of acres of land in the United States devoted to the growth of crops to be harvested in mass quantities. In 2010, 205.6 million acres of the country's three main crops (corn, soybeans, and wheat) were harvested [1]. Since these three crops are produced in such large quantities, mass harvest is required through the use of combine harvesters. Combines are agricultural machines that cut, thresh (separate grain from a plant), and collect grain from cultivated crops. The machines are vehicles that are driven into the crop by an operator and simultaneously convert a field of growing plants into a substance which can be processed as food for livestock or humans. Figure 1 below shows a combine harvesting shelled corn (dry, hardened corn kernels typically used for animal feed).

Figure 1. Combine harvesting shelled corn [2]

Typically, a combine weighs over 15 tons and is approximately 13 feet high, 12 feet wide, and 12 feet long while having the capacity to hold over 2,800 gallons of grain [3]. It is a complex machine with thousands of parts that perform different tasks. With the right parts implemented, a single combine is capable of harvesting corn, oats, soybeans, wheat, rye, barley, sunflowers, and more. For simplicity, our analysis in this report will focus on the harvest of corn. To most effectively explain how this piece of equipment converts a crop to stored grain, we will analyze the main subsystems in the order that they meet the product while ignoring components inherent in self-propelled vehicles such as the engine, suspension, etc.

Subsystem 1: Header

Figure 2. Corn header [4]

The header of a combine is the first component to meet the crop. Its purpose is to extract the useful section of a plant from the rest of the plant and transport it to the next subsystem. The header is an implement that can be attached and removed from the front of the combine. It is designed as an attachment because different headers work best for different crops. For example, when combining corn it is more efficient to simply pluck the ears from its stalk while when harvesting oats it is better to sever the plant near the ground and process it in its entirety. Also, headers come in many different widths, but they all accomplish the same task. The head you see in Figure 2 can process twelve rows of corn and is approximately 30 feet wide, which is rather large. Usually headers this wide have two hinges located at the fourth (counting from the left) and ninth rows so the sides may fold upwards to reduce the width while it is not in operation. The pointed tips you see in Figure 2 are simply to guide stalks into the chain and paddles between each point, which can be seen in Figure 3 where the points have been removed.

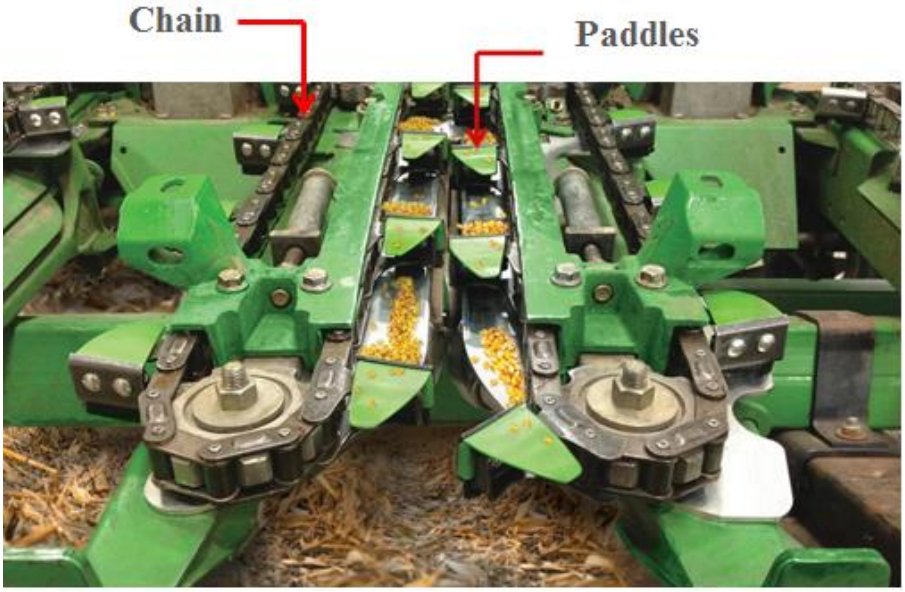

Figure 3. Chain and paddles of a corn header [5]

The two sprockets, or small gears, shown that turn the chains are rotating in opposite directions so the paddles on the inside of either chain are moving toward the combine. These serve to pull the stalks into the header and pinch the ear off from them. Once the paddles remove the ears and pull them to the back of the head, an auger (a helical shaft that rotates, allowing objects to move up its flutes) pulls them to the middle of the header where they will enter the next stage of processing. Figure 4 depicts more clearly the auger of a corn header and the opening through which the ears of corn flow to enter the next stage.

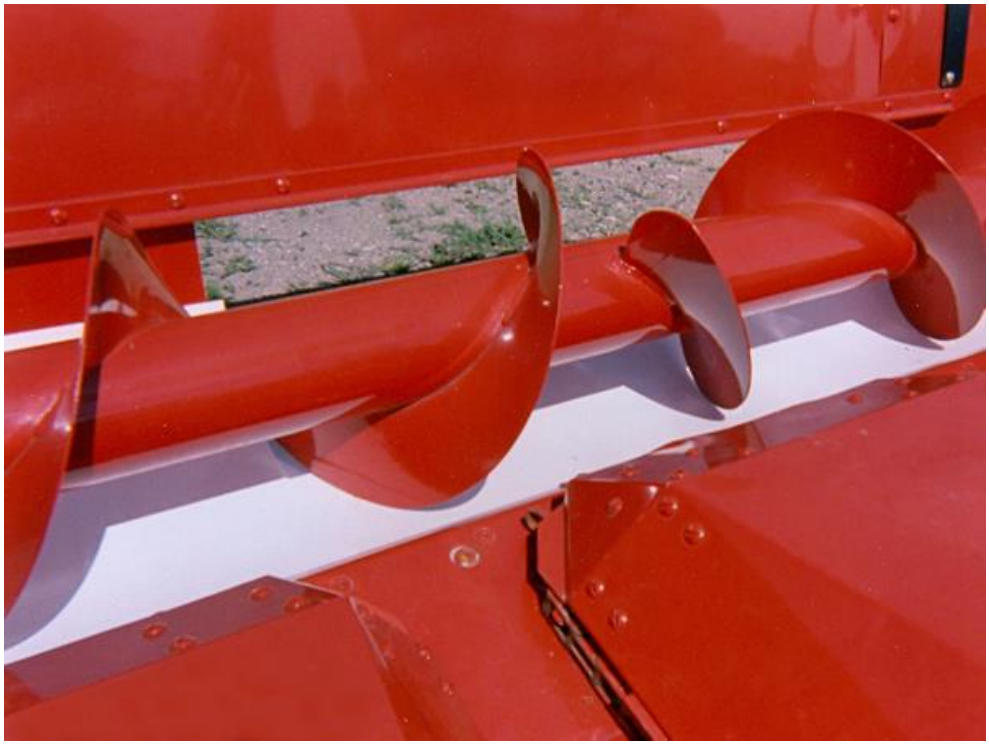

Figure 4. Corn head auger [6]

Subsystem 2: Threshing Section

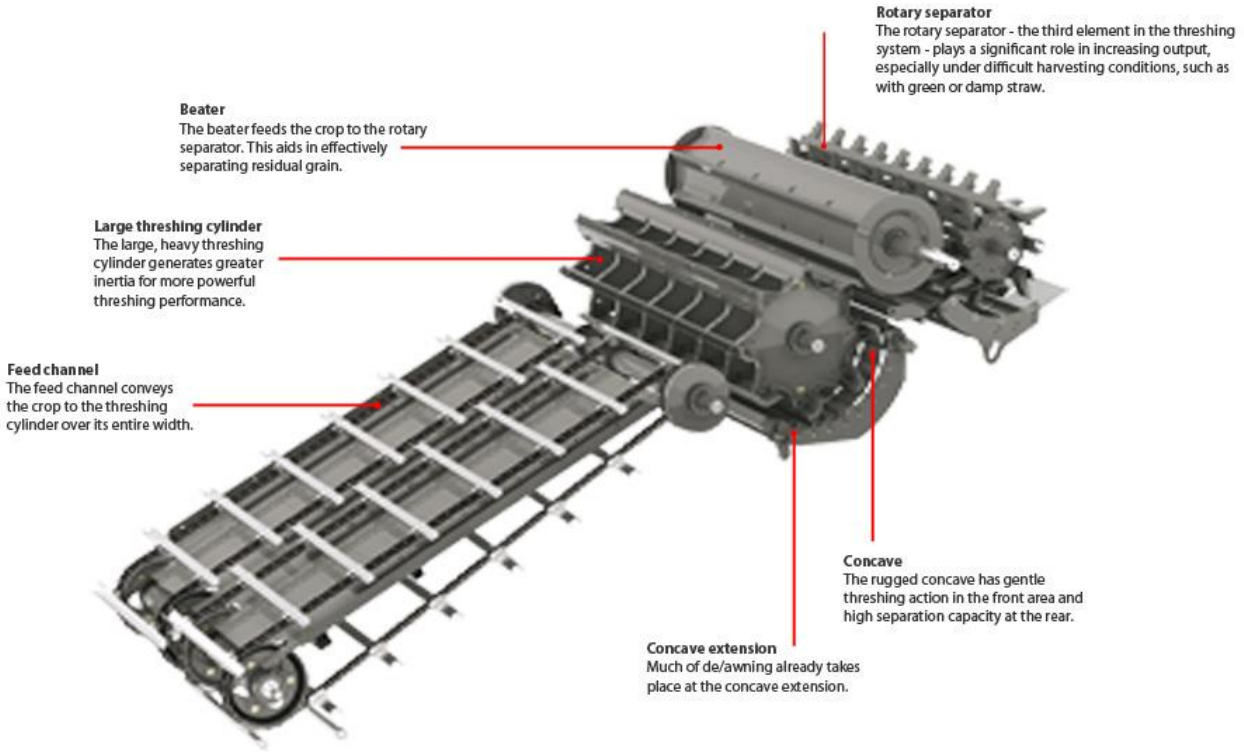

Figure 5. Threshing section [7]

After the ears fall through the opening of the corn head shown in Figure 4, they land on the feed channel shown in Figure 5. This section consists of chains linked with cross bars that serve to carry the ears up to the threshing cylinder and concave. The threshing cylinder is one with pointed fins while the concave is a ridged screen that conforms to the curvature of the cylinder. Figure 6 below depicts a clearer view of the concave. The threshing cylinder rotates (counterclockwise in our orientation) while the concave remains stationary which grinds the ears of corn as they pass through. This grinding action breaks kernels loose and shakes them away from the cob and husks. The cob and husks go through this process again through the beater and rotary separator to ensure that most kernels have been broken loose and separated. The threshing section sends the useful part of the crop, the kernels, on a separate path than the residual waste.

Figure 6: Concave [8]

Subsystem 3: Cleaning Section

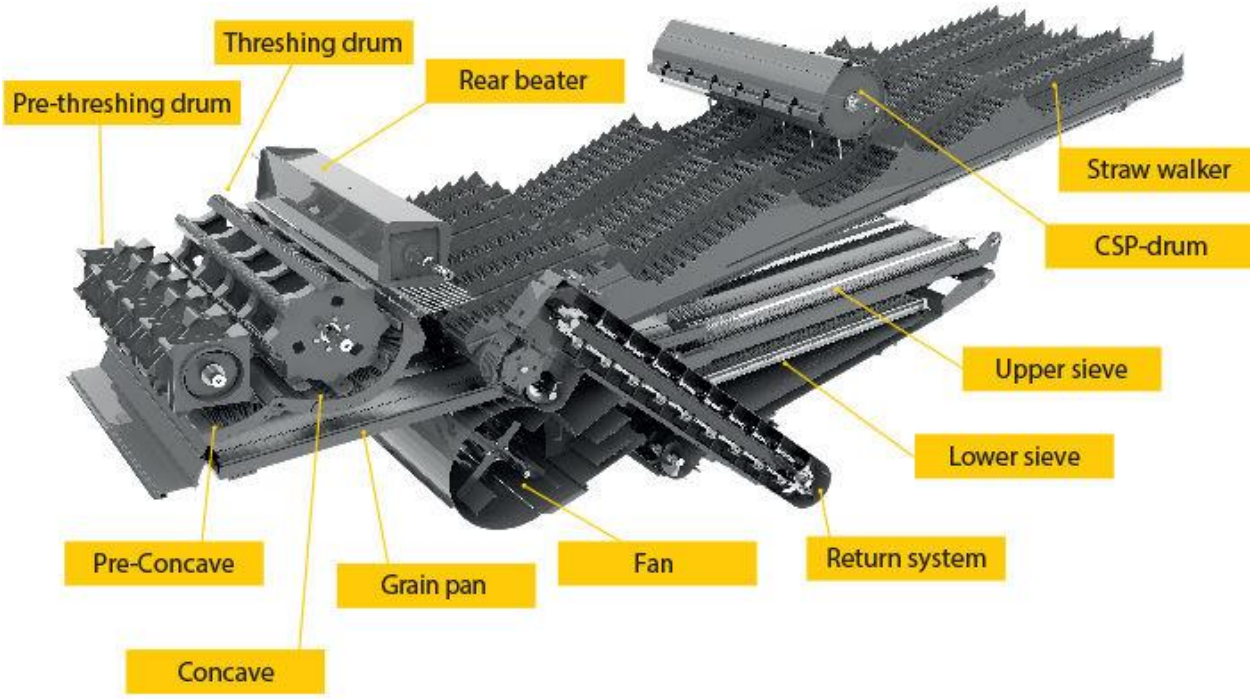

Figure 7. Cleaning system [9]

Following the threshing section, product can take several different paths as it undergoes "cleaning". The larger unusable waste such as the husks and large pieces of stalks gets pushed onto the straw walkers by the rear beater shown in Figure 7. In this graphic there are 5 separate straw walkers shown which serve to push the straw towards the back of the combine and eventually expel it onto the field. They do so by way of a rotating crankshaft like the one shown below in Figure 8 which allows one or more straw walkers to make contact with the straw and continuously drag it toward the back of the combine. These walkers are also vented so they may serve as a sieve to allow any loose grain and smaller pieces of straw to fall through to the upper sieve.

Figure 8. Straw walker crankshaft [10]

The upper sieve is more restrictive than the straw walkers on what particles may fall through. It is vibrating back and forth at high speeds to keep particles flowing. At the end of the upper sieve (not shown in Figure 7) is another slightly less restrictive one whose purpose is to allow larger pieces of straw that made it through the straw walkers and which could potentially still hold grain to fall onto a pan. This extra straw captured slides down the pan and into a return system that takes it back into the threshing section to be re-threshed. Another sieve lies below the upper and is even more restrictive. Ideally, this filter is set to only allow grain to fall through to another pan which directs the product to an auger. While the grain and its chaff transition between sieves and pans, a fan creates a flow of air directed towards the back of the combine. This blast pushes all of the lighter chaff out of the back of the combine, thereby "cleaning" the grain. Going back to the threshing section briefly, as the product gets threshed, grain and smaller straw particles fall through the concave and onto a grain pan shown in Figure 7. The grain pan is also vibrating vigorously and directs this material into the sieves to undergo the same filtering process previously described. Figure 9 below provides a better visualization of what the cleaning section accomplishes. At the end of the cleaning process, clean grain is directed to an auger to be sent to the next subsystem, chaff potentially containing grain is directed back to the threshing section to be re-threshed, and useless straw is thrown out of the rear of the combine.

Figure 9. Cleaning process animation [11]

Subsystem 4: Storage Section

Once the grain is cleaned, it is ready to be collected and stored in the grain tank. The auger previously mentioned that is located below the sieves transports the product to one side of the combine. At the end of that auger is another vertical one that raises the grain to the grain tank located on top of the combine. Figure 10 shows a visual representation of this flow of product where item 16 denotes the grain tank.

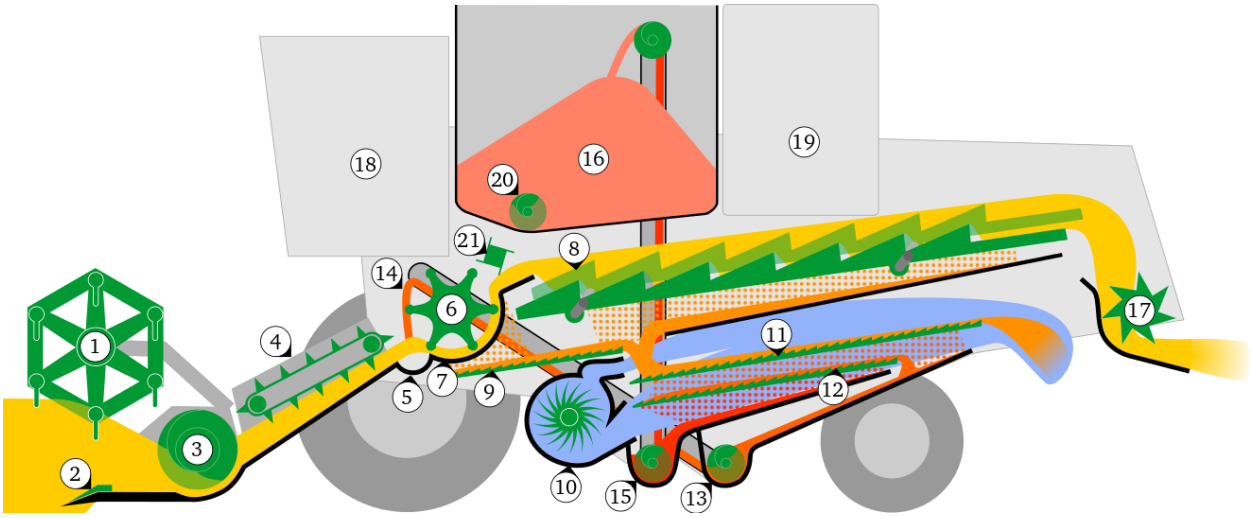

Figure 10. Product flow [12]

The product is stored here until the tank has reached capacity. Once that occurs, the operator must discharge through one last auger usually into a wagon or trailer not attached to the combine. Item number 20 in Figure 10 is an auger that pushes the corn out of the grain tank and into the discharge auger. This discharge auger must be very long to hover above and eject grain into a wagon, so it pivots at its base to be oriented parallel to the combine during operation but perpendicular to it when discharging. Figure 11 shows a combine unloading a tank of grain.

Figure 11. Combine unloading [13]

Summary of System

Combine harvesters consist of thousands of parts working together to take in a growing crop from a field and transform it into clean grain to be used as food for livestock or humans. Different parts belong to different subsystems that play various roles in order to efficiently collect massive amounts of grain. To summarize, the four main subsystems and their purposes are listed below in order of which they meet the product:

1. Header
    - Collects usable product along with its stalk from the field
    - Transports the plant to the threshing subsystem
2. Threshing Section
    - Breaks grain free of plant
    - Transports product to the cleaning subsystem
3. Cleaning Section
    - Cleans grain by filtering out and ejecting chaff
    - Sends incompletely threshed product back to the threshing section
    - Transports clean grain to the storage section
4. Storage Section
    - Moves and collects clean grain in the grain tank
    - Unloads product when the tank is full

Figure 12 depicts all subsystems in relation to each other.

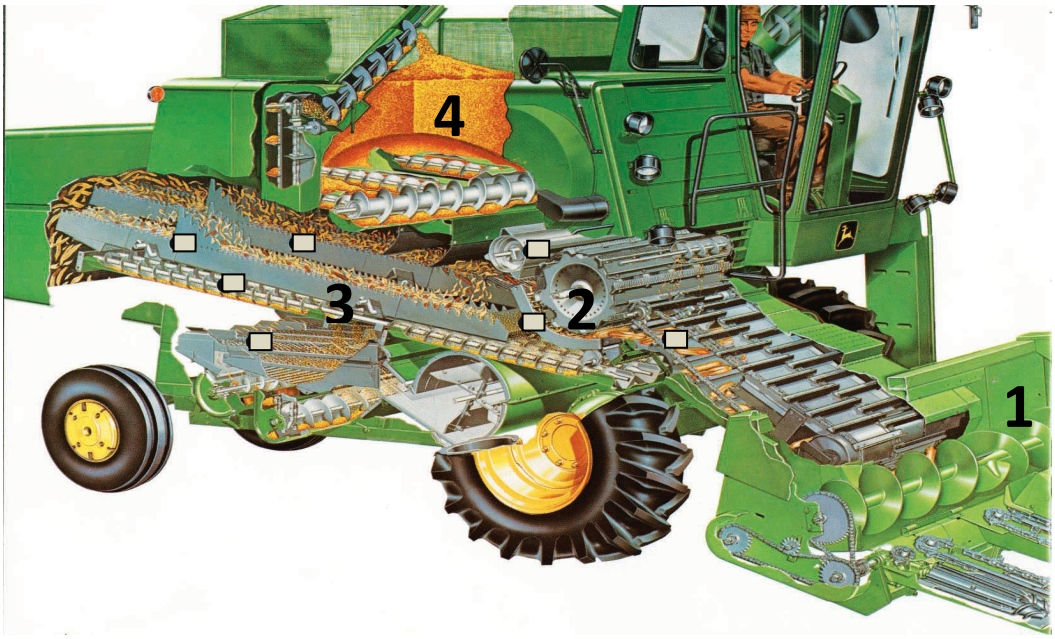

Figure 12. Complete combine harvester [14]

Combine harvesters are large, complex machines that accomplish the relatively simple task of harvesting grain from a plant. However, these pieces of equipment are a true feat of engineering due to their ability to yield such massive amounts of product so efficiently. Combines have become a necessity for grain farmers across the U.S. and their prevalence makes it important and fascinating to know how they contribute to so much success in the agricultural field.

Note about the Audience:

The intended audience for this paper would likely be farmers reading this description out of an agricultural magazine or possibly even from an operator's manual for a combine harvester. With that in mind, I kept the language simple and used common agricultural terms like chaff, husks, auger, thresh, etc. I didn't go into too much depth with individual parts as it would be unnecessary for a magazine article or brief description in a manual.

References (in order of appearance):

[1] Statistical Abstract
[2] https://goo.gl/images/j45yxW
[3] https://www.deere.com/region_ii/media/application/equipment/agriculture/combines/s_series/s_series_specs_en.pdf
[4] https://goo.gl/images/AoJFAz
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[6] https://goo.gl/images/9jpim0
[7] https://goo.gl/images/ssmUSM
[8] https://goo.gl/images/EUsTaf
[9] https://goo.gl/images/ncTts7
[10] https://goo.gl/images/0obr68
[11] https://goo.gl/images/kuzZho
[12] https://goo.gl/images/oBhCRe
[13] https://goo.gl/images/UVkv8D
[14] https://goo.gl/images/0kJGyp