Cub Cadet Zero Radius Lawnmower Redesign

Adapted from a Project Completed in Human Factors in Engineering Design

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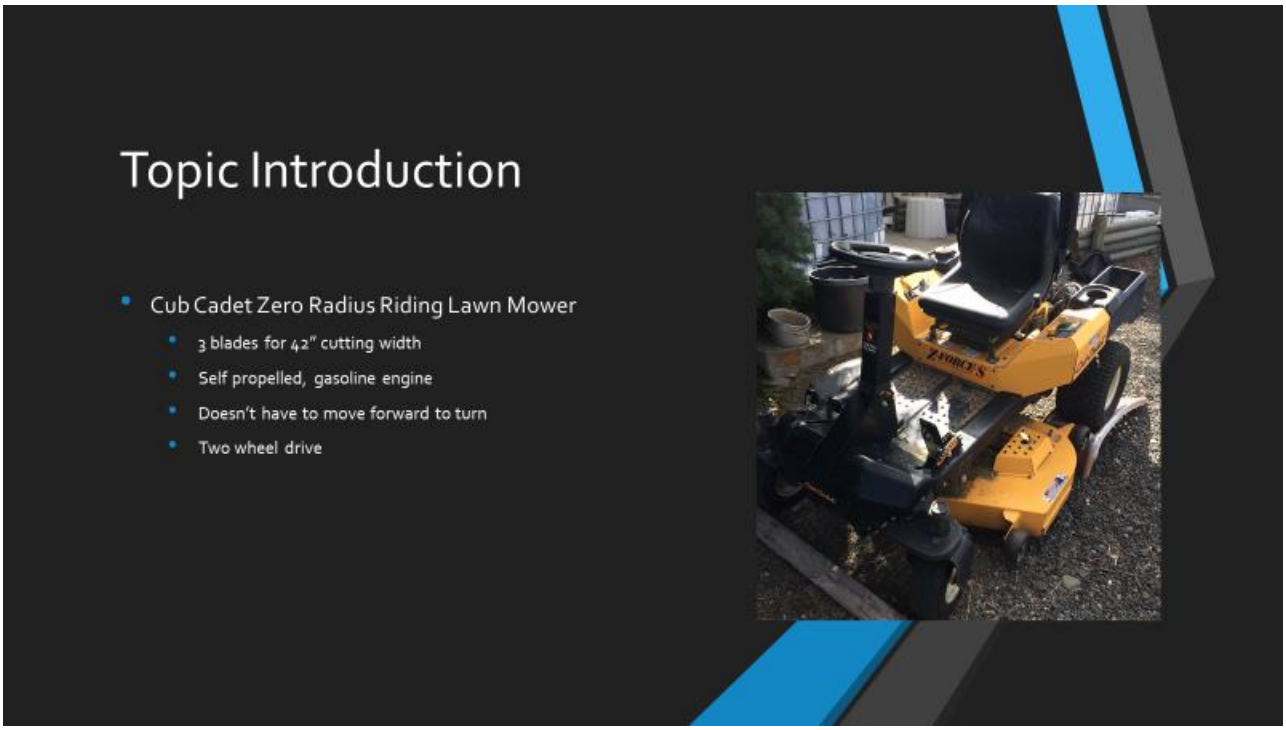
Phase one: Establishing Requirements



The Cub Cadet Zero Radius is a commercially available, gas-powered two-wheel drive riding lawn mower. In this context, the riding lawnmower is used on a family farm.

Relevancy to HF

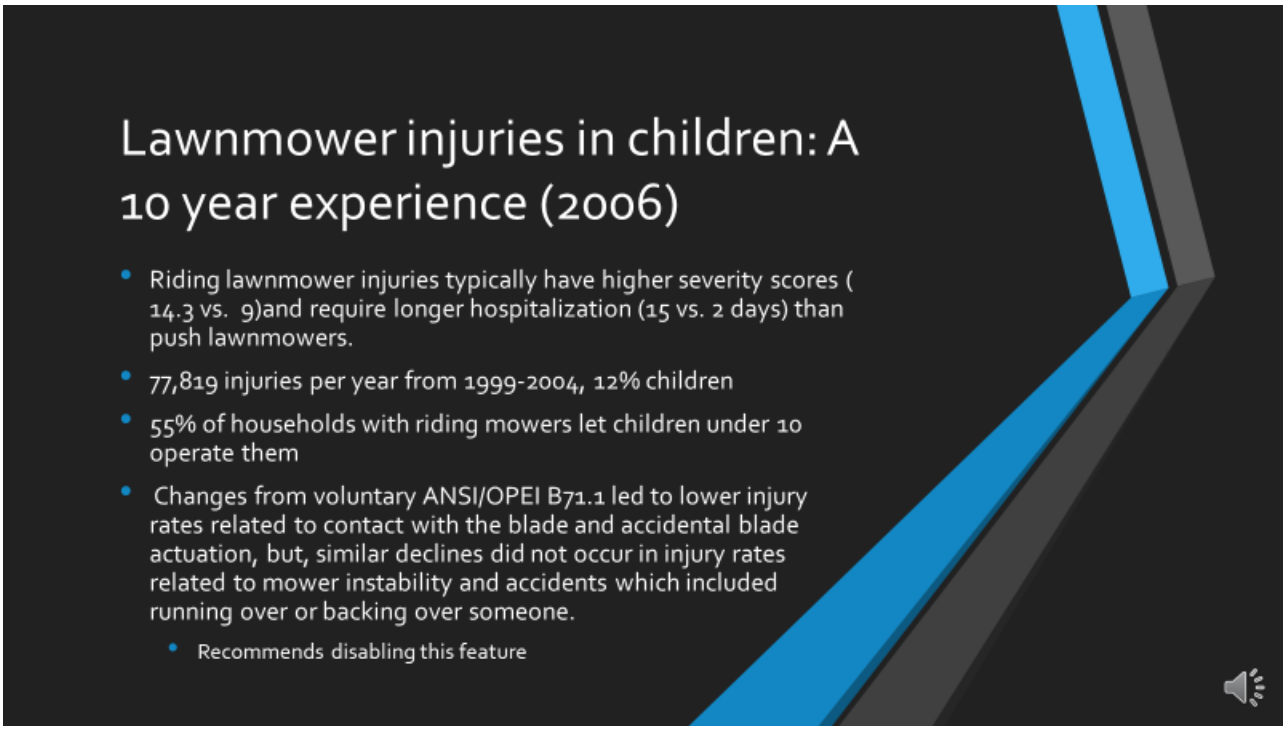
- Displays
  - There aren't any
  - Have vital information that needs to be displayed for monitoring of system
  - Needs to be easily read during operation
- Controls
  - Need to control machine safely
  - Controls need to easily used and identified
  - Adjust settings (blade height and seat)

Relevancy to HF

- Anthropometry
  - User dimensions need to be defines so they can fit in machine
  - Seat needs to be adjusted accordingly
  - Engine needs to reliably carry user
- Ergonomics
  - Steering wheel needs to work for varying hand sizes of primary users
  - Needs to afford all users the power to control direction of mower
  - Controls need to be easily graspable

These slides represent how relevant the application of human factors principles is to this product. Controls and displays, user anthropometry, ergonomics, and work physiology relevant to the lawnmower are discussed.

Literature review:



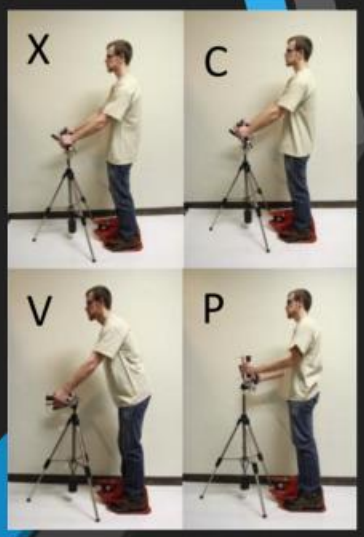
After the relevancy of human factors to the product was established, I completed a small literature review to discover important considerations for the redesign of the lawnmower. First, an article by Lee et al. (2006) stressed the importance of safety, especially during the operation of riding lawnmowers by children (under 18 years of age). While we cannot bar children from interacting with the product, making the product safer for operators of all ages is important to prevent severe injury in the case of operator error. The authors of the articles recommend improving forward and backward operator visibility to attenuate situations involving running over or backing over people. Furthermore, the authors recommend disabling the reverse feature while the blade is activated (but not for normal locomotion).

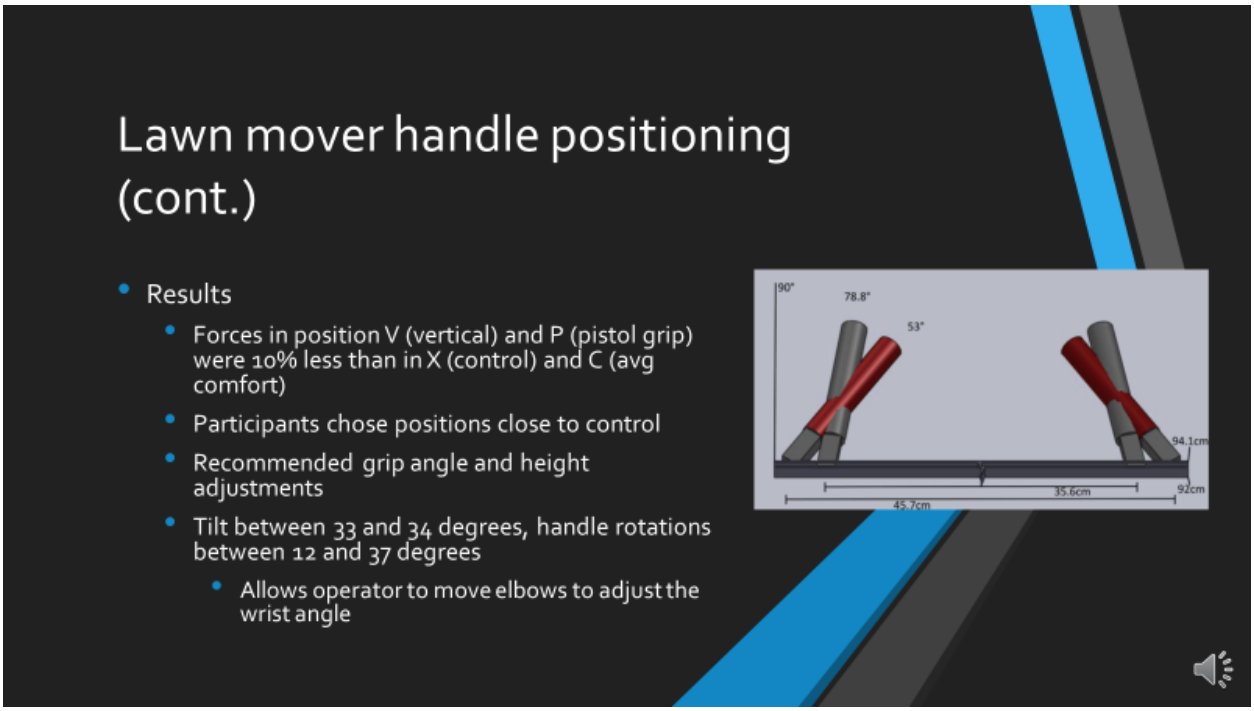
Ergonomics and comfort in lawn mower handle positioning: An evaluation of handle geometry (2015)

- Repetitive high grip force exertions are related to discomfort, fatigue, and musculoskeletal injuries
- There have been many studies about hand tool ergonomics, but none for lawn mower handles
- Designing for neutral wrist position
  - Not just neutral wrist position; many factors influence comfort
    - Modifying the workspace

Lawn mower handle positioning (cont.)

- Methods
  - Three groups (two control, one experimental)
  - Participants moved a mock-up apparatus's handle to a position they deemed comfortable, and data was recorded for group one and two
  - Third group was subjected to randomized positions
  - Forces were measured
  - Subjective comfort evaluated (survey)

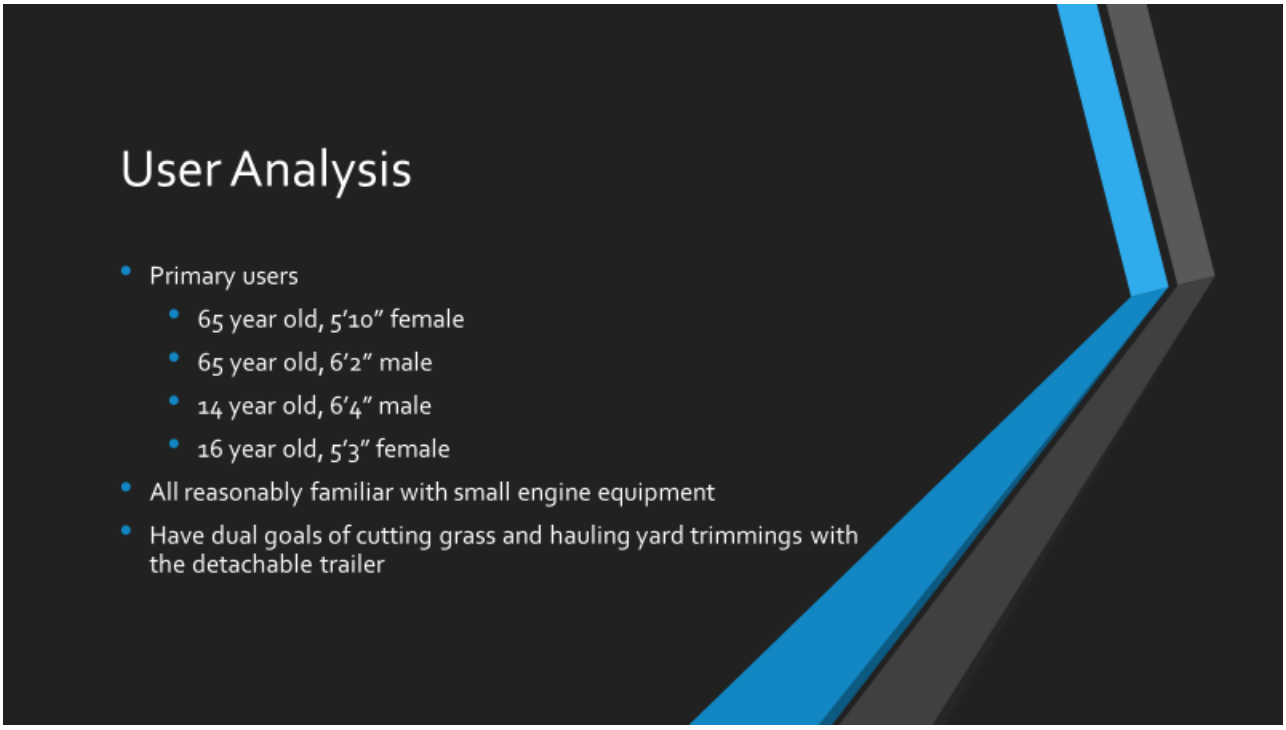




The second piece contained in my miniature literature review is a study conducted by Lowndes, Heald, and Hallbeck (2015) investigating the most ergonomic handle and grip positioning for commercial riding lawnmowers. This article is very relevant to our redesign, which will use handles instead of a steering wheel. An initial subjective comfort study was conducted, creating a model of handle tilt and rotation that was compared against a control condition, and a vertical and pistol grip-style handles. The study found that hand forces were ten percent less in the vertical and pistol grip-style handles, compared to the control and model created from the subjective comfort study.

The study recommended a handle tilt between 33 and 34 degrees, and handle rotations between 12 and 37 degrees. This allows the operator to move their elbows to adjust their wrist for a neutral wrist position.

Front-end Analysis:

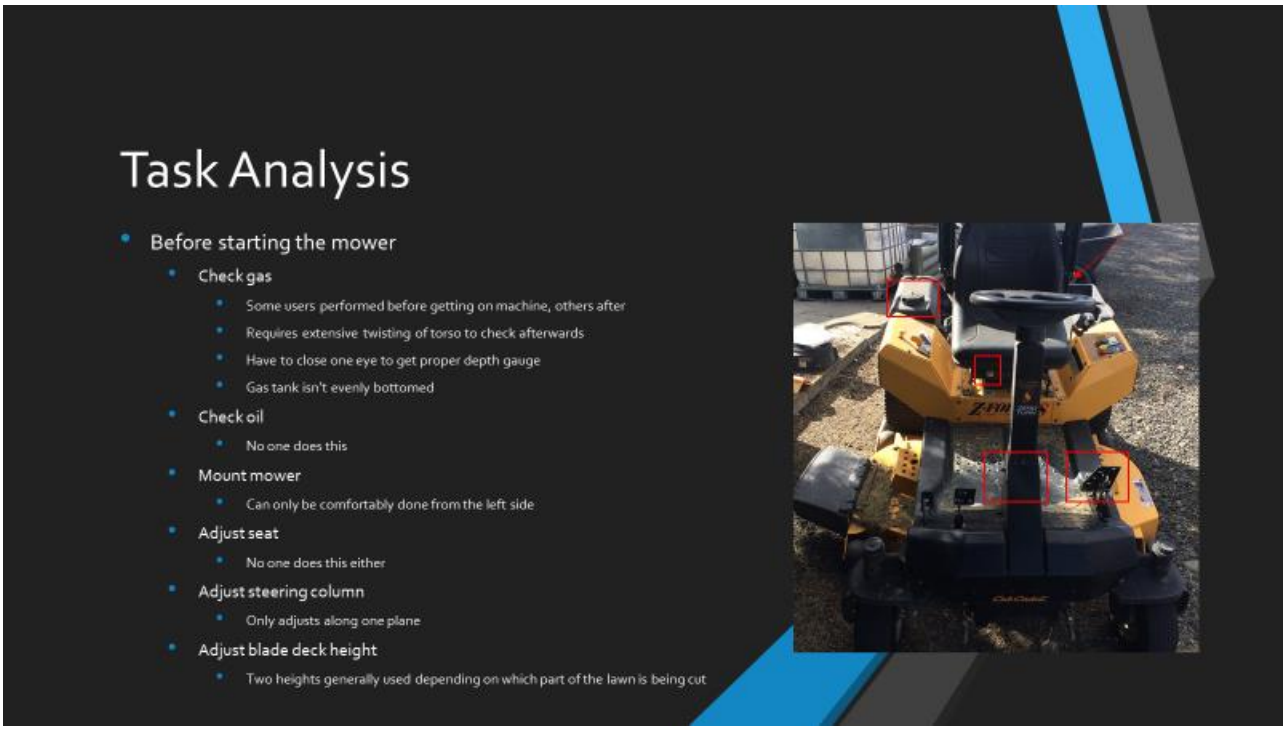


A front-end user analysis was conducted to establish requirements and to inform our future redesign. The focus was placed on primary users, rather than the entire market at once. Note that two of the primary users are under the age of 18.

The operating environment was analyzed, highlighting how different weather conditions throughout the year may impact product performance. Rain may cause a higher incidence of slips due to the decreased co-efficient of friction, as well as rusting of metal parts. High amounts of dust obscures objects in the instrument panels, making system states difficult to see. Because the lawnmower is operated, stored, and maintained outside, the product must be able to withstand high and low temperatures.

Task Analysis:

The primary users walked through how they start, run, shut down, and maintain the lawnmower. These steps are outlined in the functional task analysis. The users were also asked to say out loud why they did what they did ("think-aloud" protocol). The primary users identified the hierarchical structure of functions and the tasks that comprise them. The resulting task analyses generalized all four user's responses.



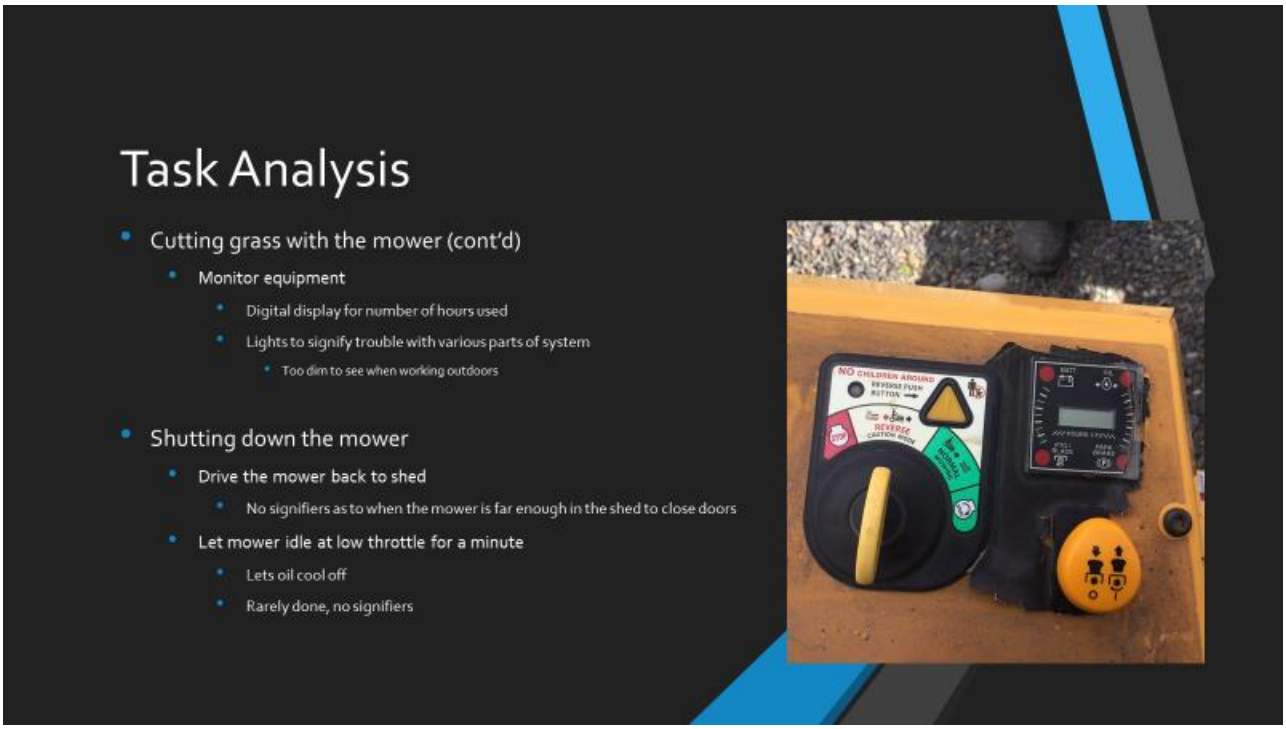
Task Analysis

- Starting the mower
  - Check if brake is engaged
  - Lift choke lever
  - Turn key
  - Push throttle lever forward until engine catches while turning key
  - Depress choke lever
  - Wait for smooth engine run
  - All signifiers for this process have worn off
    - New users have had to go through a brief training despite their familiarity with similar equipment

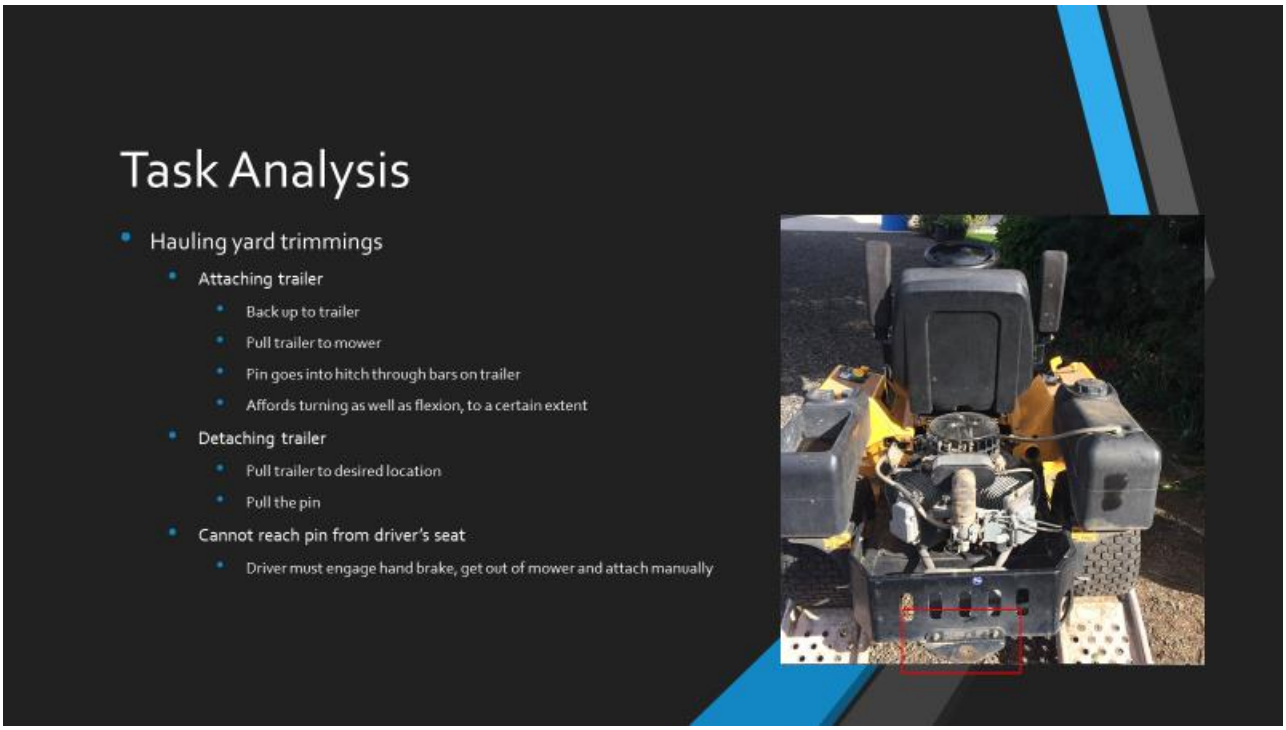
Task Analysis

- Cutting grass with the mower
  - Drive to desired location
    - Has two pedals, one for forward and one for reverse
    - No true brake pedal, have to use reverse as a brake and release that pedal before you start going backwards
    - Adjust speed with throttle lever
  - Engage PTO
    - Pull up on PTO button on the right to engage the belts that drive the blades
    - Supposed to throttle down before engaging PTO to reduce wear on belts and pulleys
      - Not done by most users

This slide contains important issues observed during the task of cutting grass that will assist us in designing alternatives.



An important point is that there is a complete water cleaning system for clearing dirt and clippings, but the users prefer to use a screwdriver to dislodge debris instead.



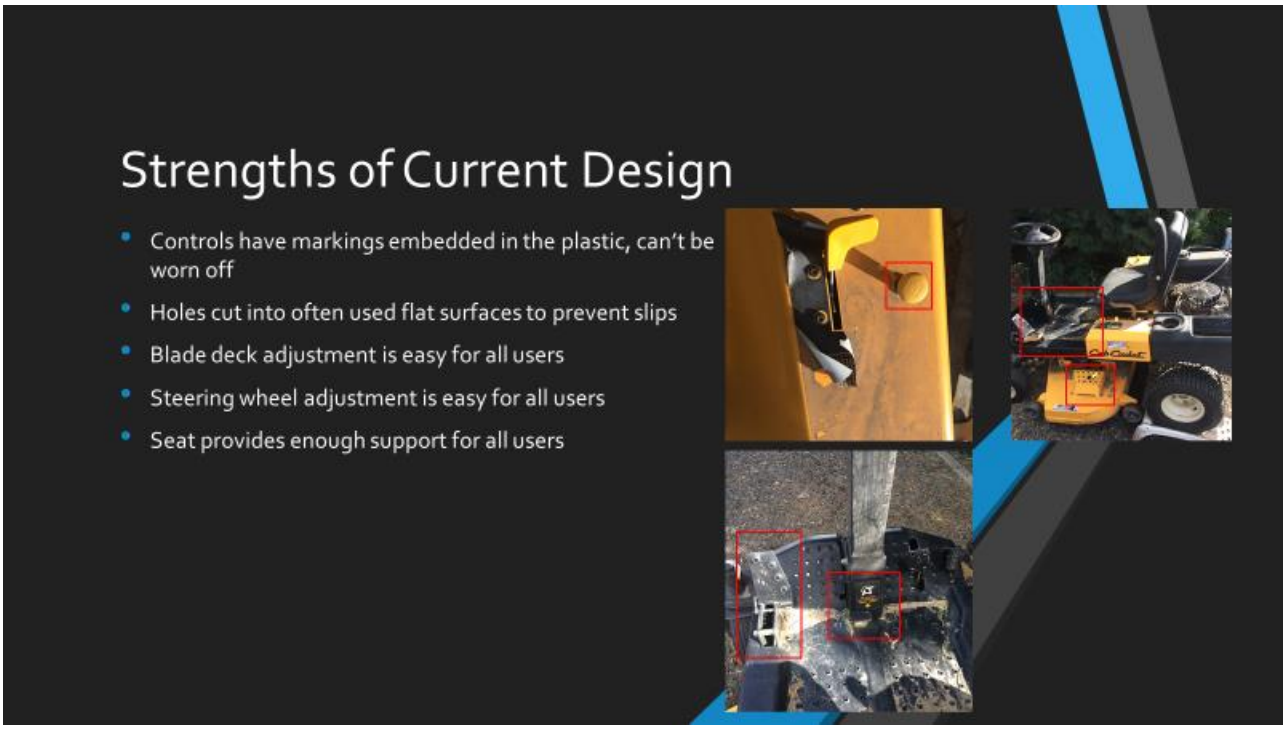
After the functional task analysis was completed, we then conducted an informal focus group, again, to assist us in identifying issues while interacting with the lawnmower and establish requirements that will aid in our eventual redesign.

An important finding from the focus group is that the size of the lawnmower was so wide that the focus group explained that they had to redesign their flower garden around the lawnmower. This is an access issue. Additionally, the throttle placement is sub-optimal, due to foliage hitting the throttle lever, unintentionally slowing down the mower. The focus group also reported soreness one hour into operating the lawnmower for older users, perhaps due to the control configuration, seat design, and vibration from the machinery.

Requirements:

- Cuts grass evenly at varying heights
- Comfortably ridden for 2+ hours
- Adjusts to primary users' dimensions
- Provide easy means of maintenance
- Allow meaningful monitoring of system
- Intuitive use of controls (steering, stop, and go)

- Haul yard trimmings up to 100 lbs
- Safety features that prevent bodily and property harm



What we enjoyed about the original design of the lawnmower was there was evidence of consideration of the operating environment and anthropometry of users. The steering wheel can be adjusted, and the seat was wide enough to accommodate a variety of body sizes. Additionally, there were grips present in high use areas, which would help prevent slips in wet or exceptionally dusty conditions.

Major weaknesses of the original design are focused on the controls of the lawnmower. Some controls, like the PTO button (used for turning on power to the blades) are difficult to reach in an emergency, creating implications for safety. Making the PTO button larger and closer to the operator's seat also reduces operator movement time because in accordance to Fitts' Law, both the amplitude (distance) between the operator's hand and the target button is reduced, as well as the width of the button is increased, decreasing the overall movement time in an emergency.

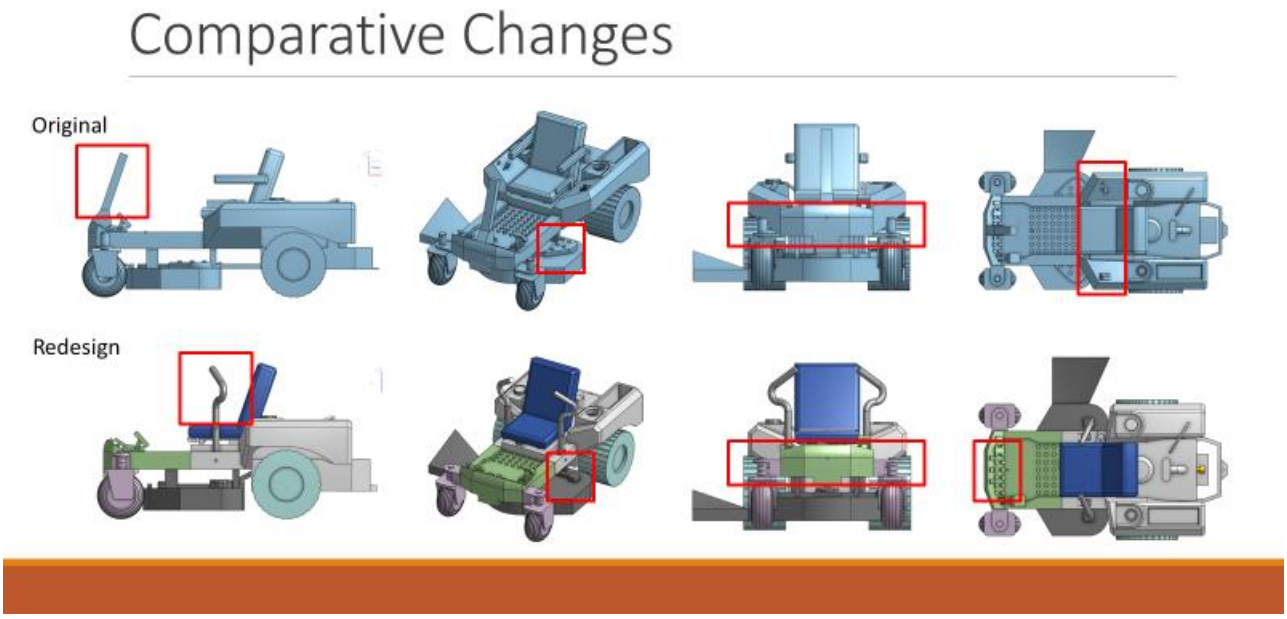
The forward and backward pedals being located too close to each other may cause unintentional operation while the user is wearing large shoes or boots.

A major limitation of the lawnmowers display is that the display is located behind the user, making it impossible for the user to understand system states such as fuel indication without physically dismounting the machine.

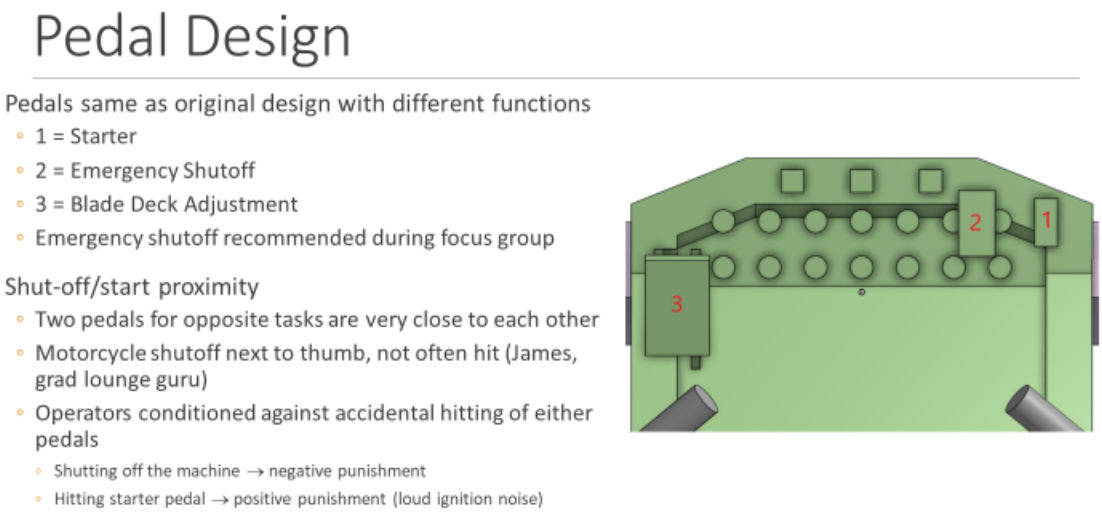
Making the seat adjustable will be able to accommodate a wider range of users' body sizes, increasing the overall comfort and decreasing back and thigh forces if the seat is too high or too low.

The results from the focus group and task analysis showed that the zero-turn radius function heavily advertised in the lawnmower is rarely used due to the steering wheel mechanism, which we feel is less intuitive than using handles to control forward/brake/reverse movements and turning. To activate the zero-turn function, the user must turn the steering wheel multiple times—all the way to the left or right. Handles would allow a faster implementation of this function because the operator would only need to push or pull a handle in one direction. Additionally, the original throttle and shroud design invites foliage to become lodged or hit parts of the machine critical for operation, creating safety and user experience issues (like frustration due to the lawnmower slowing down due to a branch holding down the lever, or confusion as to why the machine is not operating as intended). Another limitation is user comfort. The focus group told our team that older users typically experience fatigue an hour after using the lawnmower, necessitating a better suspension system and adjustable seats to reduces forces and vibration on the operator.

Phase Two: Redesign

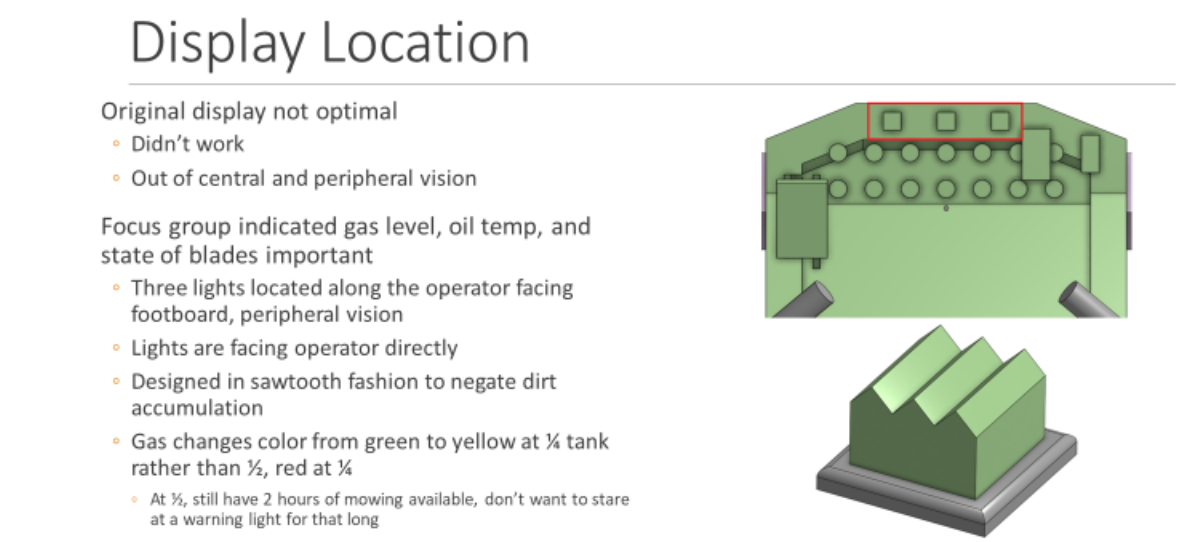


This slide is an overview of the changes we made to the original lawnmower design. Note our lawnmower has a shorter length (but similar width) to the original design, allowing the user to better maneuver through smaller areas (like a garden or small shrubs) than if the entire machine was longer. Our team also replaced the steering wheel and acceleration/brake pedal with a handle system. This is to resolve issues with the discoverability of the zero-radius turn function and to resolve the issue of accidentally pressing the wrong pedal while wearing boots due to the close proximity of the two pedals in the original design. Each change will be described in detail. Special thanks to Luke Sturgeon for creating the 3D computer models in Onshape to help make our changes come to life in higher fidelity!



Instead of having acceleration/brake pedals, we reassigned the pedals to start the machine, have an emergency shut off at the operator's foot, and to have a pedal to adjust the blade deck. Our reasoning for the foot pedals (1 and 2) having disparate operations is so that accidental activation will train users out of making those mistakes. Once the foot controls are learned, there is no issue.

This design is also congruent with the proximity compatibility principle, which states that mentally separated tasks should be located far apart. The controls involving power to the motor are separated from controls regarding adjusting the blade deck.

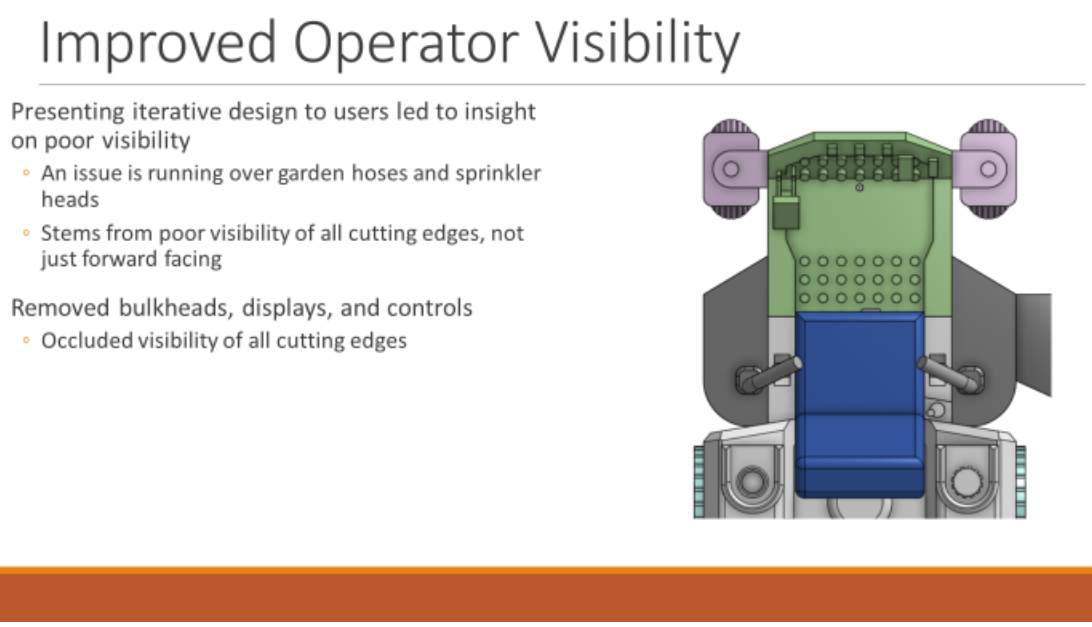


Our redesign of the display moved it from behind the user's seat to at the user's feet. The focus group in our front-end analysis revealed that the gas level, oil temperature, and the state of the blades were the most important to monitor during operation. Instead of an LCD display, which can be affected by the extreme environments the mower is used and stored in, we opted for a simple, three light display: one light indicating gas level, one indicating the oil temperature, and one light indicating the blade status. These lights stay green if the system is operating at optimal condition, and changes from green to yellow if there is a mild warning (but not a critical condition) like if the gas tank is ¼ full, or the oil temperature is beginning to heat up or cool down outside of normal range. The display's location in the periphery allows the operator to sense system changes/ alerts through movement and color changes. A central location for the display may take attention away from the forward view.

The motion produced by the change of color is still ascertained by the operator in their peripheral vision, communicating changes in system status to the operator, again, without them having to look down to watch for a change. The design of the light is not in a square or circle but is instead shaped in a sawtooth fashion to help prevent dirt and dust accumulation on the light.

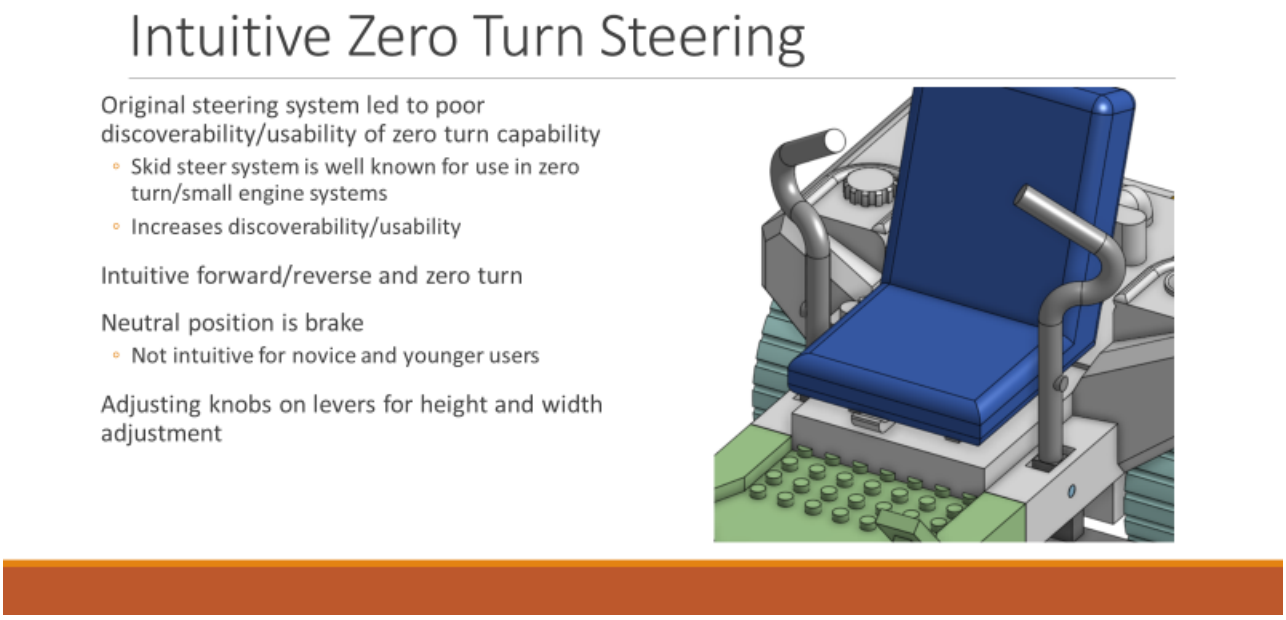
Another reason why we used the light display in our redesign is because this externalizes the information necessary for the operation of the machine. There is less cognitive loading on the operator's memory, so the operator does not assume or keep in memory how much gas remains, but instead sees that information in the light display, offloading that information from memory.

The light display also does not violate absolute judgement limits for color usage, as the display only uses 3 hues. The integrated display maps color codes to the operator's representation of the gas level.



An important safety consideration stressed by the literature review articles is operator visibility. Not only is poor visibility destructive to property that the user did not intend to run over, but there is also a risk of running over an animal or human. Therefore, we removed most of the bulkheads and controls that obscured visibility in front of the machine.

Greater visibility also increases the operator's situational awareness (SA). Operators can view more incoming stimuli from the environment critical for forming level 3 SA (prediction of what will happen next). With an improved view, operators can see that animal moving across their visual field or understand that they will make contact with the wall if they continue in that direction.

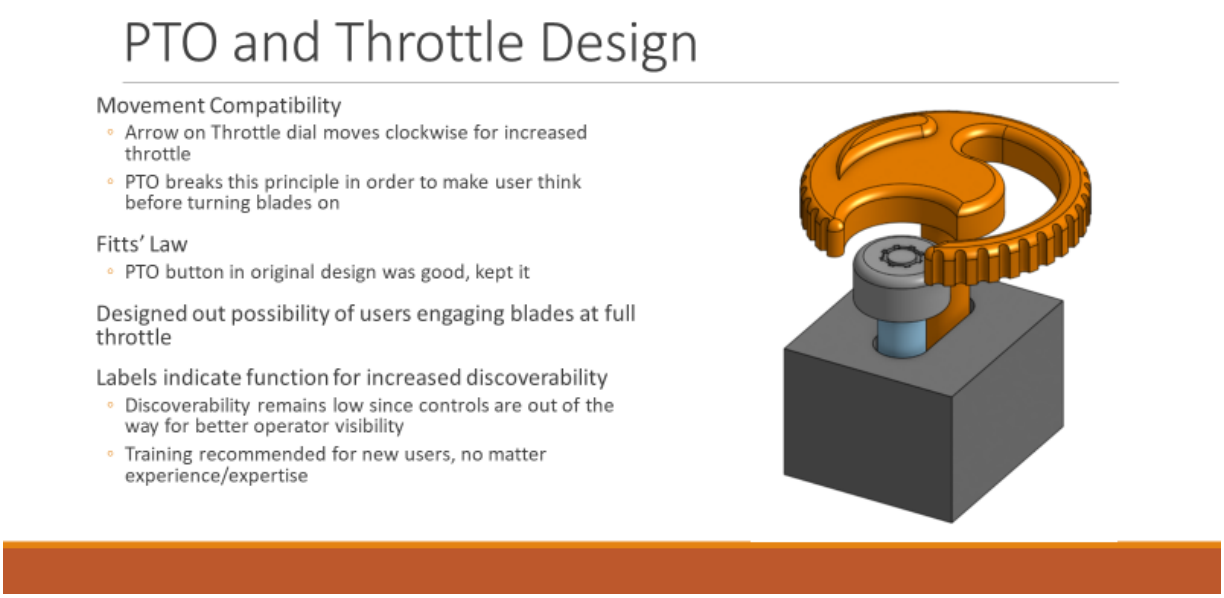


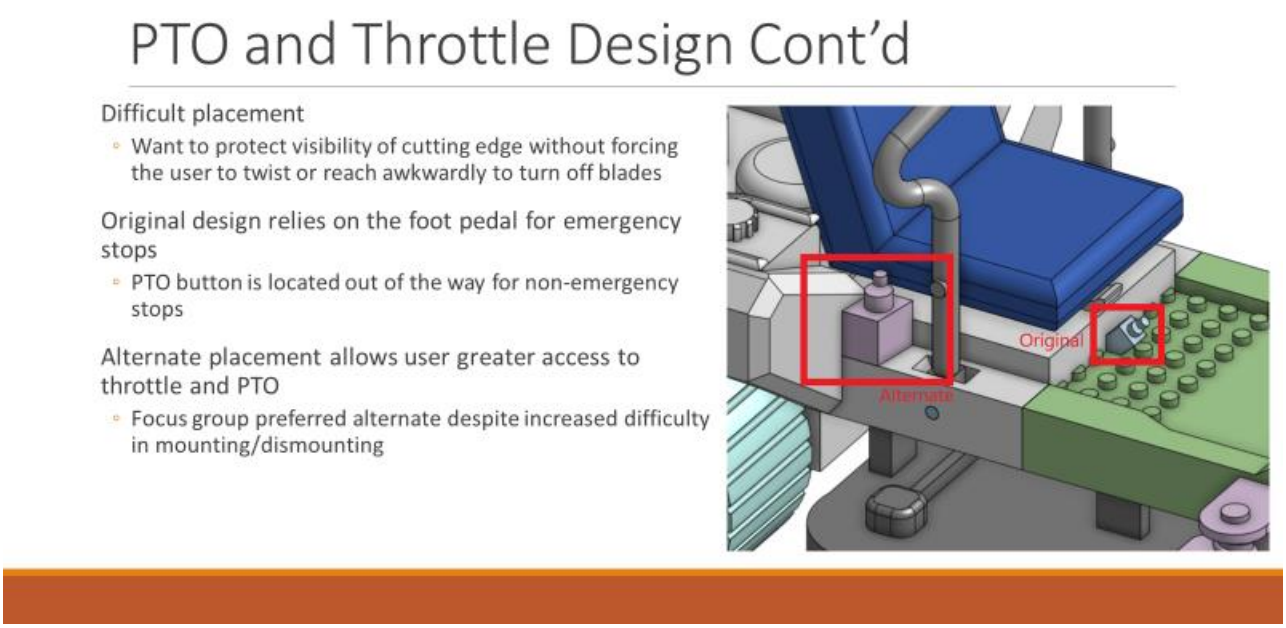
The task analysis revealed a discoverability issue involving the zero-turn radius capability of the lawnmower. Because of the steering wheel design, the operator must turn the wheel all the way to the left or right to activate the function. The large amount of effort to activate the feature left it unused. Inspired by other riding lawnmowers and work-assist personal vehicles used in warehouses to transport product, we redesigned the steering system to use intuitive handles instead.

The handles, in a neutral position serve as a brake, while pulling back on the handles reverses the machine. Depending on which handle is controlled, the machine turns in that direction. For example, moving the right handle forward while keeping the left handle neutral executes a zero-radius left turn. Moving both handles slightly forward accelerates the machine. Moving the right handle forward while also keeping the left handle slightly forward makes a normal left turn. There is tactile feedback when the handles reach the neutral position, the acceleration position, and the reverse position, so operators know they have activated a steering state.

There are also adjustment knobs for handle heights and width for easy boarding and adjustment for a variety of users.

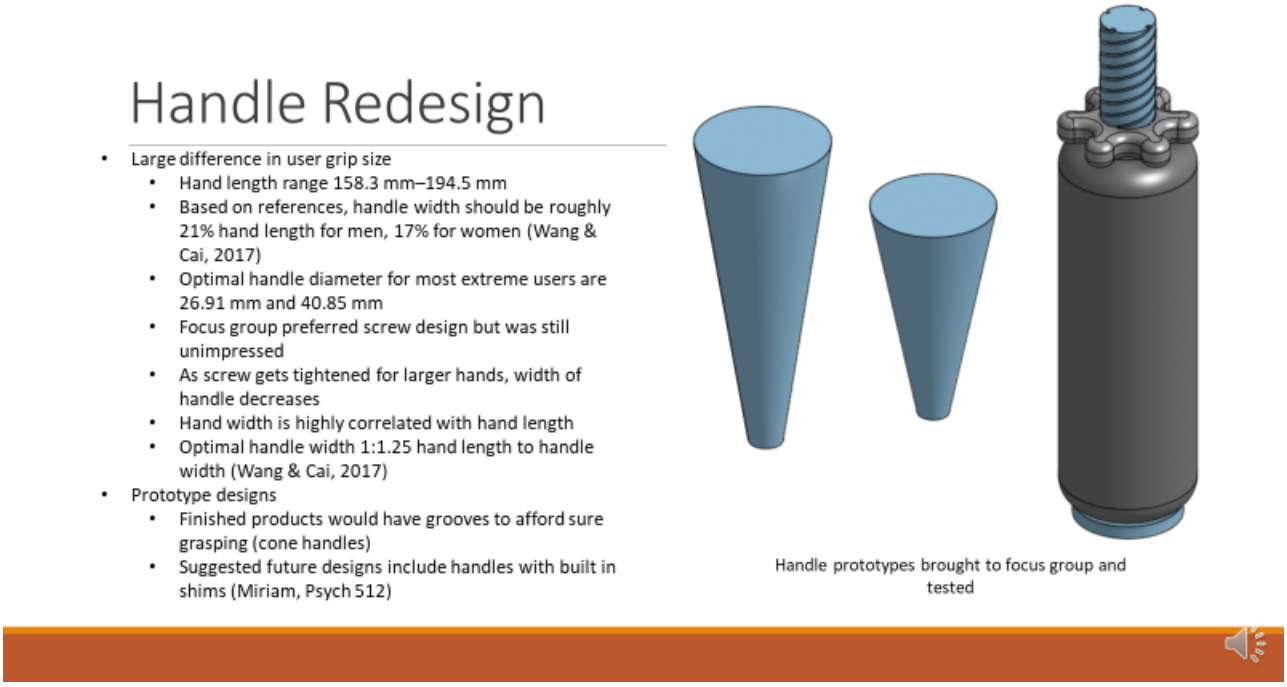
Additionally, the seat and foot pedals can be adjusted to fit 95% of average users comfortably.





The placement of the PTO affects mounting and dismounting the machine at the cost of greater access to the switch in an emergency.

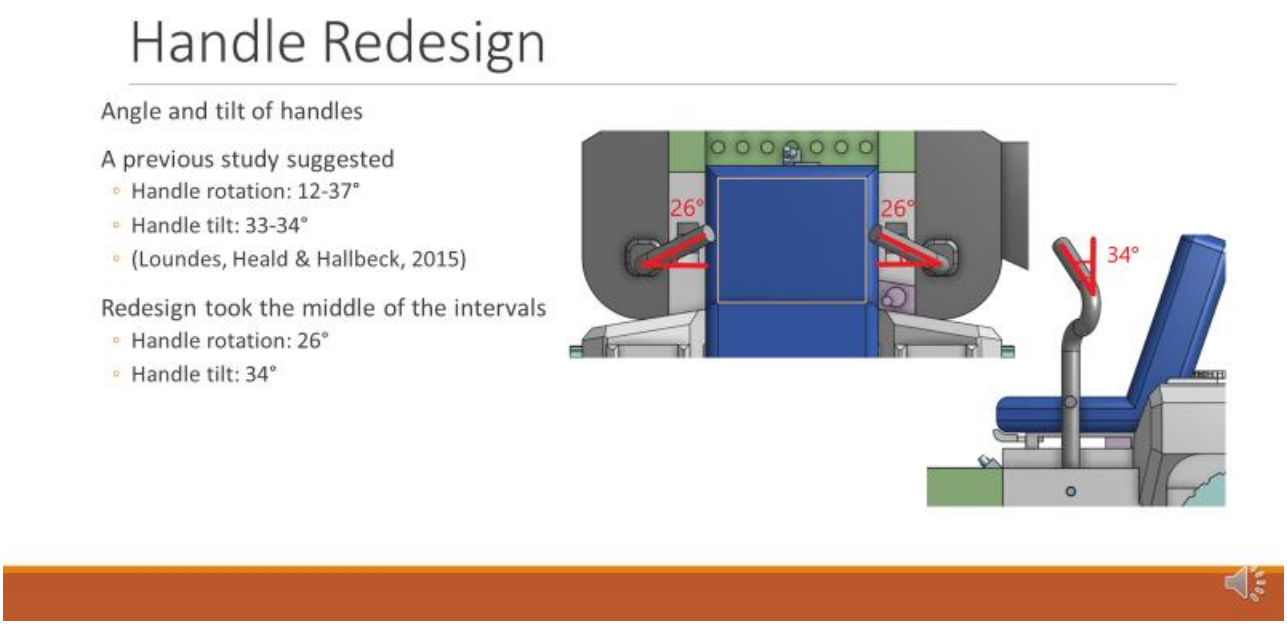
PTO and throttle switch are intentionally redesigned to make it more difficult for the user to operate the lawnmower at full throttle. Because of the importance of the throttle and PTO switch to safety (of both the motor and the blade deck), we redesigned them to violate movement compatibility, requiring training for new users as a safety measure.



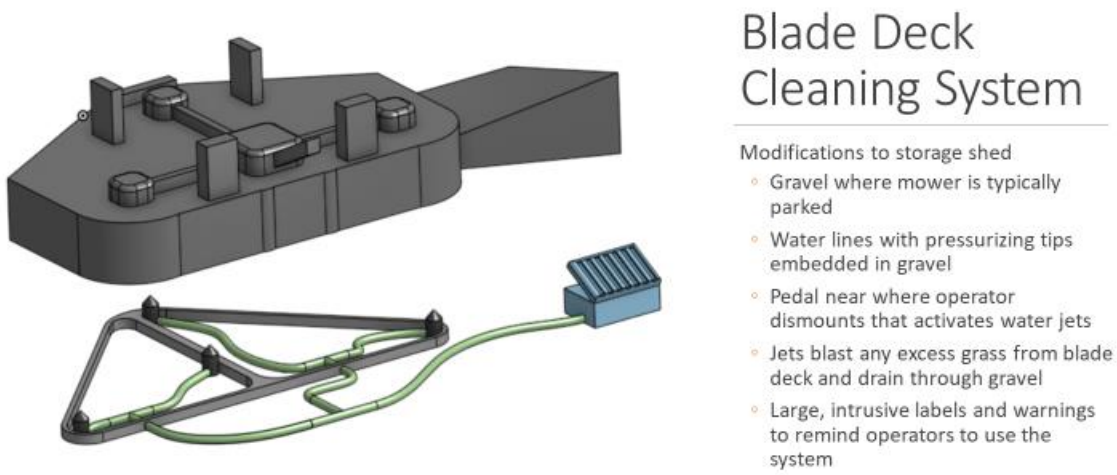
As part of our iterative design process, we drafted and presented a few different handle designs to those in our school's graduate lounge (a focus group).

Understanding the importance of grip span and hand size from our literature review, we concluded that the optimal handle diameter for even the most extreme users is 26.9mm and 40.9mm. The focus group was most interested in the screw-type handle, as opposed to the cone handles, but still rejected the design as too complicated. In the screw-type handles, a screw is tightened or loosened to widen or narrow the grip, providing additional adjustment for different users.

The focus group considered cone handles with grooves for sure grasping the most promising of the handle redesigns we came up with.

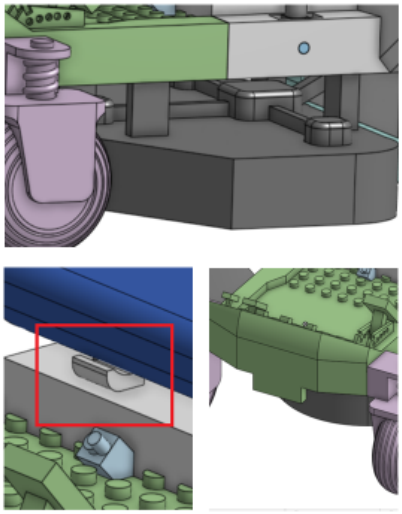


During the requirements gathering stage of our design process, we learned that a previous study (Loundes, Heald, & Hallbeck, 2015) suggested that lawnmower handles should have a rotation of 12-37 degrees and a handle tilt of 33-34 degrees. We incorporated this data into our intuitive zero radius turn design, taking the middle values of those intervals (handle rotation= 26 degrees, handle tilt=34 degrees).



In addition to redesigning the lawnmower, we also redesigned the blade deck cleaning system after learning from the focus group that they forgo using the system in favor of clearing debris with screwdrivers. The involvement of human factors considerations in the system's lifecycle does not end with implementation of the system, therefore, designing for the maintenance of the system is important as well.

The blade deck cleaning system is a modification to the mower's storage shed, which is usually parked on top of gravel for the primary users surveyed during the focus group. The operator simply parks the machine overtop of the cleaning system and steps on a foot pedal to activate the water. Pressurized tips blast any debris trapped under the machine, draining the excess water through the gravel. Because maintaining the machine is an important part of the user's interaction with the machine (poor maintenance=poor user experience and unintended operation), large, salient labels are on the blade deck cleaning system to remind users to clean the lawnmower regularly.



Misc Changes

Blade Drive Method Changed
- Reduce yearly bearing maintenance
- Reduce chance of fire on blade deck
- Cowlings reduce likelihood of things getting caught in drives

Changed Seat Adjustment so it's easier to reach
- For original, non-optimal, seat adjustment

Front and rear axle redesign for operator comfort
- Basic form of suspension prevents chassis from falling into gopher holes with the wheels

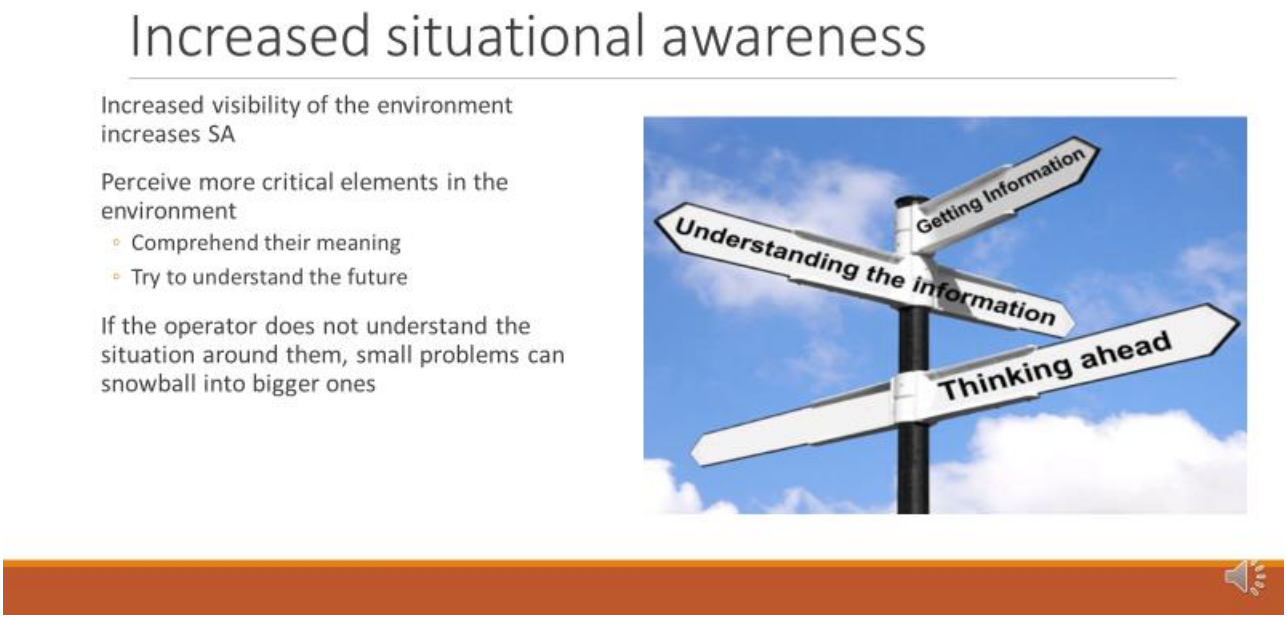
Misc. Changes Cont'd

Tipping Issues
- Ballast underneath seat to lower center of gravity
- Training on angle of hill mower can comfortably be driven across and when appropriate to drive up and down
- Use Boxer engine
  - Side by side pistons lower center of gravity

Issues with caster wheels
- Wheels get stuck when initiating zero turn
- Increase engine size
- Possible to wreck front end unless material used is adjusted accordingly

Hauling Issues
- Increase motor size for towing capacity

Some miscellaneous changes to the lawnmowers design. We added a cowling (covering) to the blade deck to prevent debris from getting caught in the blade drive and becoming a fire hazard. Additionally, we moved the seat adjustment for easier operator access. In the focus group, issues with the mower tipping was uncovered, necessitating a ballast underneath the seat to lower the machine's center of gravity. As the lawnmower is used to transport clippings and other foliage, we increased the motor size to increase towing capacity.



The final point in our redesign is how we increased the operator's situational awareness through our redesign. According to Endsley (1995), situational awareness is, "the perception of elements in the environment spatially and temporally, what those elements mean, and a prediction of how those elements will change in the future. Our redesigned placed emphasis on increasing operator visibility, increasing situational awareness. The users are able to perceive more critical elements in the environment that would otherwise be obscured in the original design, allowing the users to comprehend those element's meaning and predict where those elements will be in the future. The users would be able to see the garden hose stretched out onto the ground and have time to maneuver around it.

End of report.