The Elebake Oven

Sponsors: Dr. Albert Shih, Dr. Mark Ziadeh, and Doug Rakoski, Clinical Specialist

University of Michigan Hospital

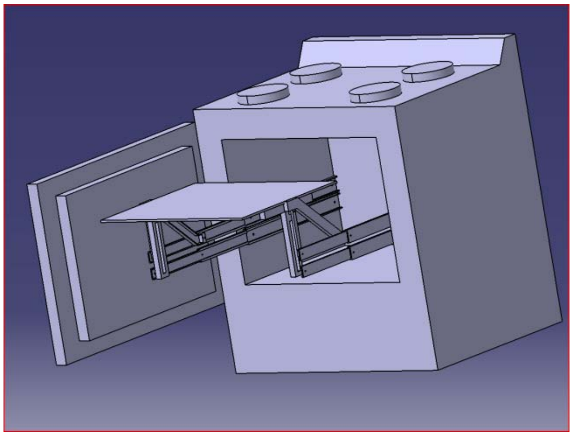

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Table of Contents

Executive Summary

We are designing an elderly/impaired friendly oven. Currently, commercially available oven designs present a possible safety hazard to the elderly and impaired in that when the oven door is opened, they require the user to bend over and insert their arms into the oven, while clearing their legs of the hot oven door at calve height. For some fractions of the elderly, not limited to those with Parkinson's disease, motor control of bodily extremities like their arms may have deteriorated to the point that to perform the simple task of extracting an item from the stove presents the possibility of severe burns. Bending over to even perform that action can be an issue for those with back problems, regardless of age. Additionally, for wheelchair users, clearing the oven door when it's opened poses a significant hazard. The opened door presents an obstacle to clear when accessing the contents of the stove and presents a hazard of the individual leaning into the oven and falling out of the wheelchair.

Customer requirements were rated by occupational therapists of University of Michigan Health System. The most important requirements are ease of opening the oven door, accessibility of the oven racks, safety from heat, and height adjustability of oven racks. Based on these customer requirements, the most important engineering specifications are the height and lateral distance of rack travel, the projected floor area occupied by the door, the door seal's thermal efficiency, the volume swept by the door's opening, and the force needed to open and close the door.

The oven door and rack system concept generation accounted for different door openings: hinged at the bottom (standard), hinged at the side, sliding vertically, and sliding horizontally. Of these, concepts utilizing a side hinged door were more feasible, require less force in use, and minimize the projected floor area occupied. Different rack systems involving linkages, springs, and/or pulleys were considered. To keep our design simple and not dependent on tolerance for thermal expansion of materials, we gave more consideration to those using linkages. Of our linkage designs, a derivation of concept 1 and concept 12 were combined to give us our alpha design. This alpha design eliminates many of the possible hazards mentioned above by using a door that swings to the side of the user and using a hook to extend the racks out and up to significantly reduce the user's bending and reaching into the oven.

We have finalized our design, and finished prototyping. Through validation we found that our concept works the way we planned, however there are minor adjustments that can be made to improve the design. Most importantly, we suggest that the left and right side sliders be connected by rigid bars, promoting uniform movement of the entire oven rack assembly.

Problem Description

The global society is aging. From 2000 to 2030, the worldwide population of people aged over 65 years is approximately expected to increase by 550 million to 970 million, increasing from 6.9% to 12.0% worldwide, 15.5% to 24.3% in Europe, 12.6% to 20.3% in North America, 6.0% to 12.0% in Asia, and 5.5% to 11.6% in Latin America and the Caribbean [1]. The smallest increase amongst this age group will be seen in Africa, increasing from an estimated 2.9% in 2000 to 3.7% in 2030 [1].

The growing elderly population in the United States raises healthcare concerns for their physical and medical safety. With aging, people are more prone to debilitating diseases such as arthritis, the leading cause of disability in the United States, Alzheimer's, cancer, and other cardiovascular and muscle degenerating diseases [1]. For example, in the United States, arthritis affects approximately 59% of people older than 65 years old and is the leading cause of disability [1], and diabetes, which causes excess morbidity and increased health-care costs, affects approximately one in five (18.7%) [1]. People age 75 and older report an average of three chronic health problems at any time and use more than 4.5 prescription drugs [2]. Without at least some assistance, many aging persons are unable to bathe, transfer, sit, stand, feed, climb stairs, medicate themselves, and use the toilet [2].

Compounding the problem of increased medical costs, most people over the age of 65 are on a fixed income: only 13% of Americans in this age group are employed [3]. In 2003, households with householders greater than 65 years old had a median income of $23,787 [3]. The statistics show that elderly people demonstrate a large need for assistance in overcoming their illnesses; however they do not have much money to go towards assistance. Aging persons receive care from their often busy relatives and visiting nurses. Less than 1 percent, 21,500, of the nation's 2.2 million practicing registered nurses are certified in geriatrics. With inadequate assistance, more aging persons are injuring themselves in their homes attempting to do normal daily tasks. As a society, we must develop inexpensive solutions to their problems.

One problem that elderly people face daily is getting around the kitchen; specifically, operating an oven. By nature, ovens are very dangerous as they can reach temperatures of higher than 500°F. It is very common for elderly people, and others who have limited stability for any reason, to have a fear of reaching into an oven. The worry of falling in/ onto the hot oven surfaces may be enough to deter them from using an oven altogether. This can be hard for some people, as being able to cook on their own is key to living an independent life, and being able to live independently is very important to many elderly people.

Our goal is to design a user-friendly oven which would be accommodating to the elderly, who, generally speaking, have a hard time bending at the knees and waist, and with reaching objects far away. Ideally, our oven design would also accommodate people who use a wheelchair for mobility. According to the U.S. Census Bureau, 2.7 million people over the age of 15 use a wheelchair [4], and approximately one-third of all wheelchair users are elderly [5]. This shows that our oven would not only benefit the elderly, but also a large portion of the population with similar disabilities.

Project Idea Development

Initially, we had three assistive geriatric project topics to pursue. They were an advanced medication dispenser, an inflatable cushion to help older persons sit and stand, and a ramp and track system to allow wheelchairs users transportation up and down a staircase while still seated in their wheelchair. Shortly after expressing these three project topics, we participated in an information session with Dr. Mark Ziadeh and his occupational therapists to get a first-hand look at geriatric and disabled persons' needs. With this visit, we devised two other project ideas. One of them was assistive cookware that would make it easier for people with tremors and poor gripping strength to more easily cook. The other idea was an assistive stove and/or oven which would assist geriatric patients' cooking ability. Of our many project ideas, our supervising graduate student instructor, Dan Johnson, and professor, Albert Shih, assigned us to our narrowed project topic of an assistive stove and/or oven.

Our team met with Dr. Ziadeh on September 19, 2008 to discuss the outcome he'd like to achieve through our design of an assistive stove and/or oven. We proposed a few ideas of how to narrow the project to a specific system. Our first proposal was to make a dynamic oven/stove combo where the oven and stove could physically shift to allow better access to wheelchair users. Dr. Ziadeh recognized this was an innovative idea but not the outcome he'd like to see from this semester's design team. We proposed removing the common drawer found at the bottom of the oven and designing a system that would lower the oven by that drawer's height to allow a wheelchair user better view of the stovetop. Dr. Ziadeh acknowledged this as enabling the user to better use the stovetop but as disabling the user from accessing the oven at such a low position. Overall, Dr. Ziadeh wanted us to focus on a certain aspect of either the stove or oven rather than physically moving either or both.

We discussed moving the stove burners from the back to the front. Dr. Ziadeh agreed that this would help. Further discussion led to perhaps lining four burners up front. Even further discussion led to limiting the number of burners to simplify things for geriatric patients to only two in the front and even possibly limiting oven size as well. The idea of limiting burners and oven size and bringing burners to the front wasn't a critical design requirement though for Dr. Ziadeh.

With narrowed focus, we discussed three different projects that were each feasible to accomplish within our Gantt chart timeframe, all quite pertinent to assisting geriatric patients' cooking ability, and all acceptable outcomes for Dr. Ziadeh. The first of these was modifying stove and oven knobs to be better accessible to people with arthritis and adding big stickers to the knobs of the interface to see settings more clearly. The second of these was adding pressure sensors to stove burners to automatically turn off the burner when pressure was released (pot taken off burner). This would prevent the user from accidentally starting a fire by leaving an unattended flame. The third project was modifying an oven door to be easier to open and connecting the opening of the door to having a rack automatically slide out. This would help prevent physical burns caused by careless placement or removal of items from the oven rack. Out of these three narrowed projects, Dan Johnson and Albert Shih suggested we design the modified oven door and rack system.

We met with Doug Rakoski on Oct. 7th to discuss the problems that geriatric patients face, as well as go over some of our design concepts. Doug Rakoski works in the Occupational Therapy Division of the Department of Physical Medicine & Rehabilitation at University Hospital, and formerly worked at the Center for Applied Rehabilitation Technology at the Rancho Los Amigos National Rehabilitation Center near Los Angeles, CA. Doug told us that a major obstacle for wheelchair users operating an oven is that they have to lean over a hot surface to reach inside to grab the food. He suggested that it would be beneficial if they were able to reach the food without leaning into/over the oven. In this case, it is more important for the food to be outside of the oven. The food moving out of the oven is beneficial to both wheelchair users and geriatrics, and because our motivation for this project is the increasing geriatric population, we added in the idea that the rack move vertically, as well as laterally.

Doug also told us that a typical wheelchair user opens a refrigerator by positioning themselves next to the door opening at an angle, opening the door, and reaching in to get the food. After talking to Doug, we realized that this would be the ideal way for a wheelchair user to open the oven, while also catering to the needs of geriatrics.

Customer Requirements

We met with 3 occupational therapists (OTs) at the University Hospital to discuss our customer's requirements. After our initial meeting with Dr. Ziadeh, we came up with a list of 10 items that we wanted the OTs to rank on an importance scale of 1-5 with 1 being not as important, and 5 being extremely important. The items were: low cost, appearance/ aesthetics, safety (heat), ease of cleaning, ease of opening door, durability, accessibility of oven racks, oven rack height adjustment, having more than 1 oven rack, and low noise level. The items that were unanimously ranked extremely important (5) by the 3 OTs were: ease of opening door, accessibility of oven racks, and safety (heat). Oven rack height adjustment was the only other item with an average ranking above 4. Copies of the completed surveys are located in Appendix D.

Engineering Requirements/ Specifications

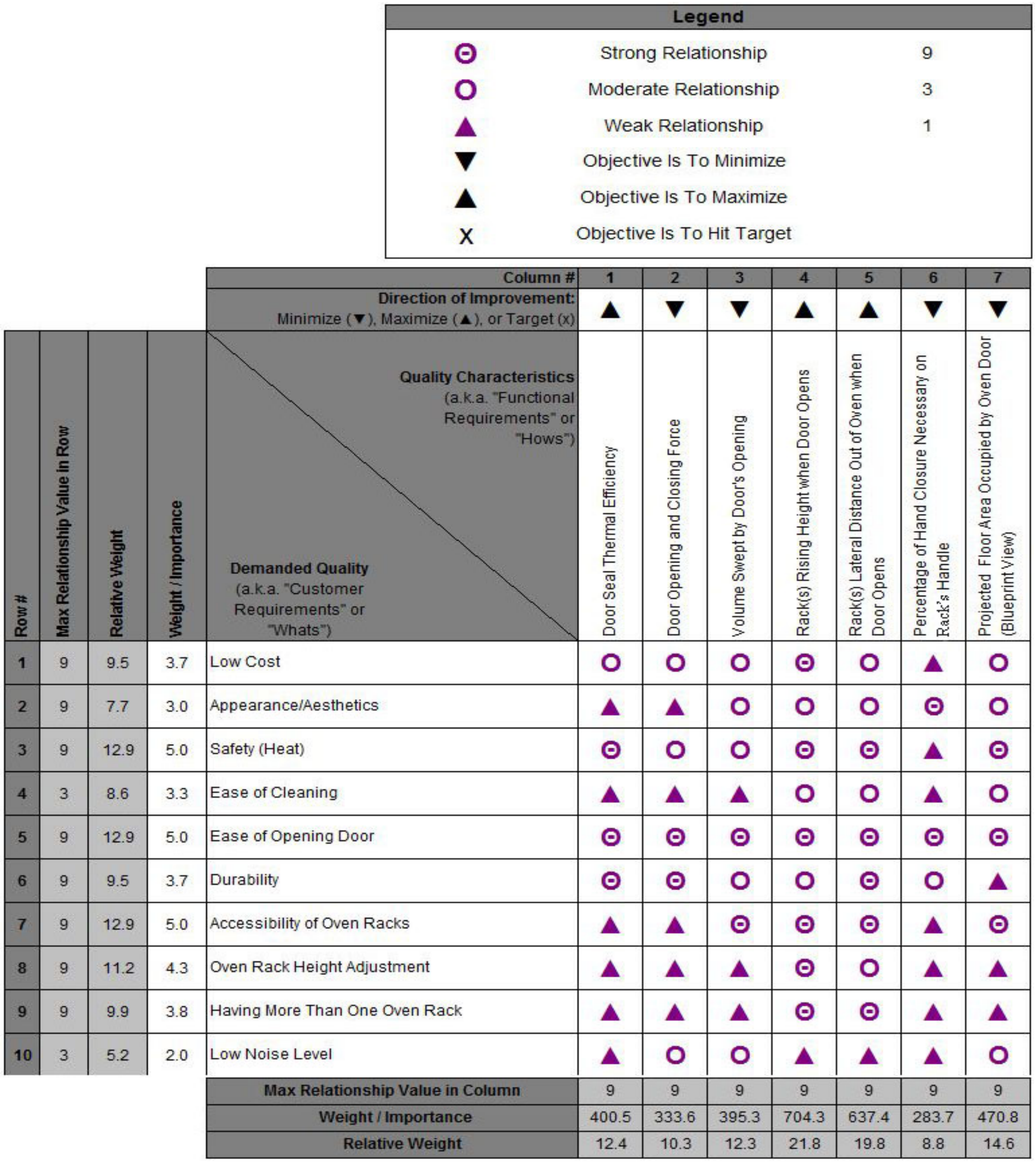
To judge our concepts against each other, and against the goal of our project, certain engineering specifications need to be measured: force required to open and close the door, thermal efficiency of the door seal, height of the rack travel, lateral distance of the rack travel, volume the door opens into, projected floor area taken by fully opened door, and percentage of hand closure necessary on the rack's handle. Our project is targeted towards geriatric patients, who statistically have strength and grip limitations. This means it is best to have the door open with the least amount of force required, and similarly the least amount of force required to close the door. Geriatric patients also have limited mobility, especially with bending at the knees and waist. This makes it important to raise the oven rack to limit the amount of bending required by the customer. In addition to geriatric patients, our secondary customers are wheelchair users. Conventional ovens open outward, blocking the ideal standing place to reach inside. With the front of the oven blocked, it is hard for wheelchair users and geriatric patients to reach to the food inside. It is important to minimize the volume that the door opens into, in order to allow the most access to the contents of the oven.

The correlation between our engineering specifications and customer requirements is shown through the QFD diagram below in Fig. 1. The main result of this diagram established a hierarchy of engineering specifications for our project. The most important specifications to focus on are the height and lateral distances the rack travels when opening the oven followed by minimizing the projected floor area occupied by the door, the door seal's thermal efficiency, the volume swept by the door, the force needed to open and close the door, and finally the percentage of hand closure necessary on the rack's handle. These specifications are quantified below in Table 1.

Table 1: Target values based on engineering specifications. These values will guide the dimensioning and material selection for our alpha concept.

Engineering Specs	Target Values
Volume Swept	$< 5.5\ \text{ft}^3$
Projected Floor Area	$< 4.2\ \text{ft}^2$
Force Needed to Open Door	< 13.3 lb
Force Needed to Close Door	< 4.3 lb
Force Required to Pull Rack	< 5 lb
Vertical Rise of Rack	6 in.
Maximum Temperature Inside Oven	800 °F

Figure 1: QFD Diagram: The engineering specifications we need to focus on involve rack travel distance and making the oven more accessible by reducing the floor area occupied by the door.



Legend		
⊙	Strong Relationship	9
○	Moderate Relationship	3
▲	Weak Relationship	1
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

				Column #	1	2	3	4	5	6	7
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▼	▼	▲	▲	▼	▼
Row #	**Max Relationship Value in Row**	**Relative Weight**	**Weight / Importance**	**Quality Characteristics** (a.k.a. "Functional Requirements" or "Hows") / **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	Door Seal Thermal Efficiency	Door Opening and Closing Force	Volume Swept by Door's Opening	Rack(s) Rising Height when Door Opens	Rack(s) Lateral Distance Out of Oven when Door Opens	Percentage of Hand Closure Necessary on Rack's Handle	Projected Floor Area Occupied by Oven Door (Blueprint View)
1	9	9.5	3.7	Low Cost	○	○	○	⊙	○	▲	○
2	9	7.7	3.0	Appearance/Aesthetics	▲	▲	○	○	○	⊙	○
3	9	12.9	5.0	Safety (Heat)	⊙	○	○	⊙	⊙	▲	⊙
4	3	8.6	3.3	Ease of Cleaning	▲	▲	▲	○	○	▲	○
5	9	12.9	5.0	Ease of Opening Door	⊙	⊙	⊙	⊙	⊙	⊙	⊙
6	9	9.5	3.7	Durability	⊙	⊙	○	○	⊙	○	▲
7	9	12.9	5.0	Accessibility of Oven Racks	▲	▲	⊙	⊙	⊙	▲	⊙
8	9	11.2	4.3	Oven Rack Height Adjustment	▲	▲	▲	⊙	○	▲	▲
9	9	9.9	3.8	Having More Than One Oven Rack	▲	▲	▲	⊙	⊙	▲	▲
10	3	5.2	2.0	Low Noise Level	▲	○	○	▲	▲	▲	○
				Max Relationship Value in Column	9	9	9	9	9	9	9
				Weight / Importance	400.5	333.6	395.3	704.3	637.4	283.7	470.8
				Relative Weight	12.4	10.3	12.3	21.8	19.8	8.8	14.6

Benchmarks and Regulations

One benchmark that corresponds to our oven door design is a toaster oven; when the door of some toaster ovens is opened, the racks inside automatically slide outside of the toaster oven. That is achieved by putting hooks on the door and attaching them to the rack so it pulls the rack out when the door opens. The racks are on a track system so when the door closes, the racks will go back into the toaster oven instead of flipping over.

Our second benchmark is a tackle box and it also opens with racks coming out. The racks within the tackle box are connected by linkages and are guided by the opening of the lid. This allows for staggering of equal size racks so each rack can be accessed easily. Though the tackle box does not translate the motion that our oven door requires, the idea of using linkages can be incorporated in our design.

For the design of the oven rack assembly, we found a telescoping track system in an oven at Home Depot. The oven was an Electrolux 30” Wall Oven, model #EW30EW65GB, and while inspecting the rack, we notice that the telescoping track was made by a company called Accuride, as shown in Figure 2. Electrolux only refers to their track system as a “luxury-glide” system on their website [6].

Figure 2: Accuride Track

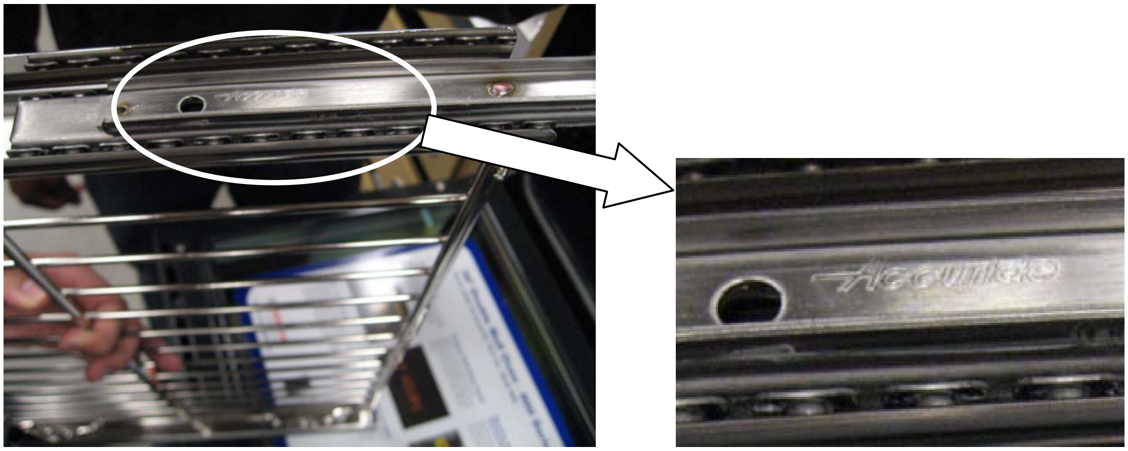


Figure 3: Electrolux Oven – Track Extended

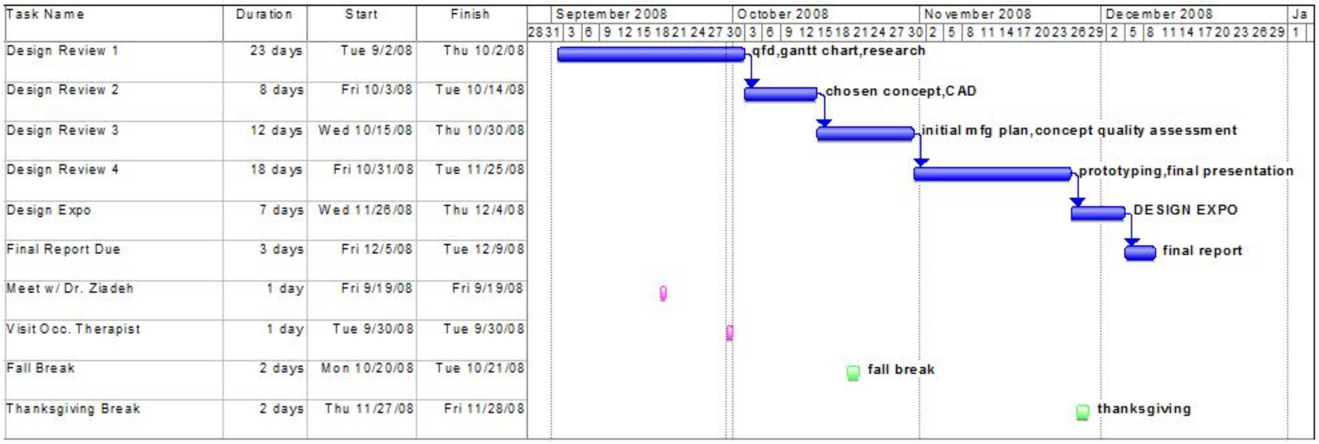
The Accuride oven rack system is capable of holding a maximum load of 40 lb when fully extended, is lubricated with high heat FDA thermal grease, and can withstand temperatures of up to 800°F with occasional relubrication [7]. The tracks sit on separate wire stands on either side of the oven. It may be possible to utilize this system when designing our oven rack system.

The two standards for baking ovens are for energy efficiency [8] and gas intakes [9]. The only standard that might affect our design is the energy efficiency. It states minimum standards of energy efficiency for many major appliances were established by the U.S. Congress in Part B of Title III of the Energy Policy and Conservation Act (EPCA), Public Law 94-163, Public Law 95-619, Public Law 100-12, Public Law 100-357, Public Law 102-486, Public Law 109-58 [8]. We must keep these standards in mind when selecting material and designing the door.

Project Plan

We have implemented the Gantt chart found in Fig. 2. This chart set a general schedule for our project that includes the design reviews, meetings, and breaks. By mid-October, we generated many concept sketches, chose one, and started CAD design. By the end of October, we worked on an initial manufacturing plan and gave our concept a quality assessment. We finished in November with a prototype build and worked through the design expo to document our work in this final report and presentation. Our budget for completing this project was $800, and we used less than $300.

Figure 4: Gantt chart showing the timeline of our project plan.



Task Name	Duration	Start	Finish
Design Review 1	23 days	Tue 9/2/08	Thu 10/2/08
Design Review 2	8 days	Fri 10/3/08	Tue 10/14/08
Design Review 3	12 days	Wed 10/15/08	Thu 10/30/08
Design Review 4	18 days	Fri 10/31/08	Tue 11/25/08
Design Expo	7 days	Wed 11/26/08	Thu 12/4/08
Final Report Due	3 days	Fri 12/5/08	Tue 12/9/08
Meet w/ Dr. Ziadeh	1 day	Fri 9/19/08	Fri 9/19/08
Visit Occ. Therapist	1 day	Tue 9/30/08	Tue 9/30/08
Fall Break	2 days	Mon 10/20/08	Tue 10/21/08
Thanksgiving Break	2 days	Thu 11/27/08	Fri 11/28/08

Concepts Generation, Rating, and Selection

As shown through the QFD in Fig. 1, our main focus will set on the oven rack dynamics in an effort to maximize the height and outward lateral distance of the rack. Whatever components we use to achieve this motion must also withstand a considerable amount of heat being their location in the oven. Here we discuss the rating system used in selecting the best concepts to meet our engineering specifications, the concepts themselves, and the alpha design derived from the highest rated concepts.

Concept Selection Process

Each concept was scored according to three criteria (safety, functionality, feasibility), each set on a scale of 1 to 5, 1 corresponding to poor, 5 corresponding to optimal. Each member of the group scored each design and these scores were averaged in the scoring matrix for ranking.

Safety and functionality incorporated a number of engineering specifications. The safety criterion primarily considered the exposure of the user to the heat emerging from the oven. Will the user have to stick their hands into a hot oven? Will the design have heat rising into the users face? Among safety considerations was also limiting the force necessary from the user to open and close the door as to limit any injury through use as well as considering the volume swept by the door as to limit the motion required by the user. Functionality took into account the objective of the project itself, being to minimize the amount of movement required from the user to access food from the oven. Engineering specifications drawn from this rating were the lateral and vertical distances traveled by the racks, volume swept by the door, and projected floor area occupied by the door in an open position. For rack motion, on the 1 to 5 scale, if the design just extended racks, instead of extending and rising, then it was scored lower than a design that lifted the racks. It was also scored lower if the design required anything but a side swing door (which was determined to be most accessible for our target demographic after discussions with Dr. Mark Ziadeh and Doug Rakoski). Higher ratings were also given if the door minimized the projected floor area occupied when fully opened while taking into account trying to minimize the volume swept by the door based on target values.

The feasibility criteria considered ease of creating the prototype and hence the amount of time necessary to implement the design. For example, one of the concepts used a cross bar 4 bar linkage attached to a spring that slid in a guided track. This was for obvious reasons scored lower than the design that used a bar that slid in a curved track, as the latter design was much simpler and thus much easier to manufacture. This criterion was important to highlight due to the disadvantage that time presents us given the late start on the project that the group had.

Highest Rated Concepts

The ranking of concepts was established by the system described above. The result of this ranking is shown in Tables 2 and 3. The top four concepts are discussed below these tables followed by a section dedicated to the alpha design, a concept derived from the top concepts. The other system and rack concepts not discussed below can be found in Appendix A.

Table 2: Combination door and rack system design rating and ranking based on summed ratings.

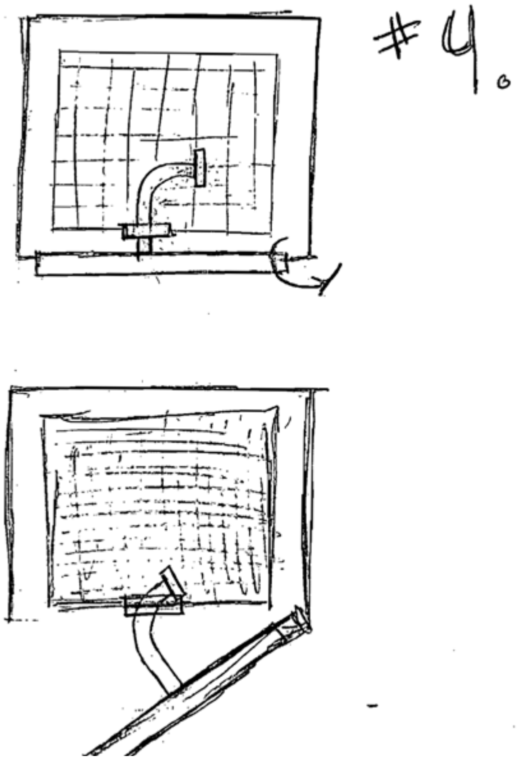
Concept No.	Door Style	Safety	Functionality	Feasibility	Total
4	Side Hinged	4	3	4	11
2	Side Hinged	4	4	3	11
6	Bottom Hinged	2.5	4	4	10.5
3	Side Hinged	3	3	4	10
9	Side Hinged	4	3	2.5	9.5
7	Side Hinged	2	3	3.5	8.5
11	Bottom Hinged	3	4	1.5	8.5
8	Drawer	3	3	2	8
10	Vertical Sliding	1	3	2	6

Table 3: Rack system design rating and ranking based on summed ratings.

Concept No.	Safety	Functionality	Feasibility	Total
1	4	5	4	13
12	4	3	5	12
5	5	4	1	10

Concept 4 is a similar design to that of Concept 3 (see Appendix A), but aims to simplify the design by utilizing an arced, single piece linkage, instead of the two-bar linkage of Concept 3. The arced linkage with the broad end allows for a delay between the opening of the door and the extension of the rack. This decreases the amount by which the racks have to be cut down as to not extend into the door. This concept scored an 11. With regard to safety, the concept is similar to concept 3 and was scored a 4 due to the user not having to reach into the oven, but having to apply considerable force when the door is near fully opened. Functionality was similar as well, scoring a 3 due to the need for the user to still bend more to access the food. For feasibility, the design scored a 4 due to the arced design of the link, and the greater need for precision that would come along with it.

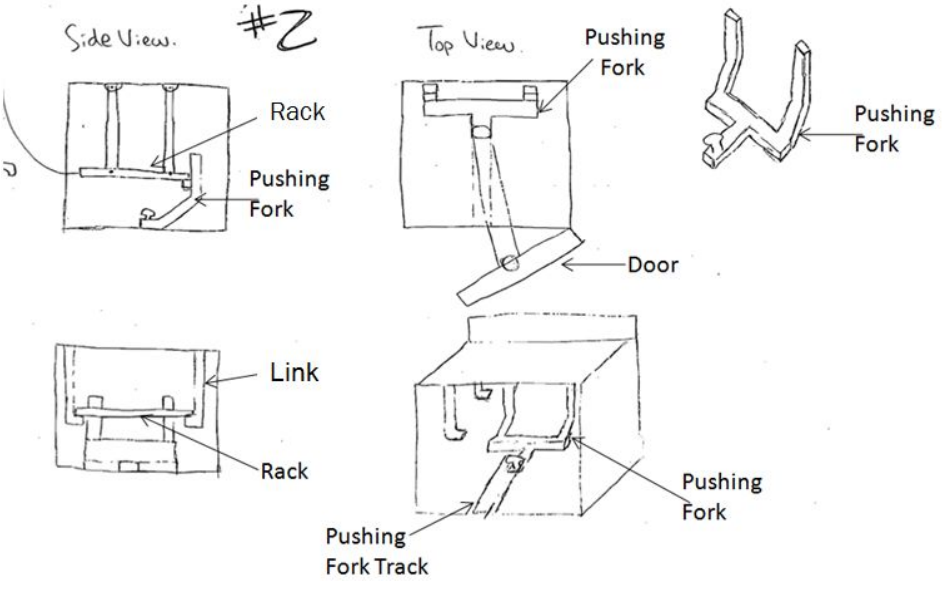
Figure 5: Rack Concept #4



Concept 2 is an oven door and rack system design. It incorporates a side-hinged door linked to a pusher fork's ball joint. The pusher fork is on a track perpendicular to the oven face to keep the fork parallel to the back edge of the oven rack. The oven rack design has one rack attached near each corner by links to the oven ceiling. As the fork pushes the rack, the rack moves on a circular path while remaining horizontal. The fork's linkage to the door allows the user to have the rack/food come out by opening the oven door and have the rack and food go back into the oven via gravity when the door is closed, completely eliminating the need for someone to place their arms into the oven.

The simplistic hinged rack would not be affected by frictional forces like many conventional ovens have. The downfall for safety rating in terms of force comes with the reactionary horizontal gravitational force applied to the fork by the rack *at all times* while the door is opened. Force required will be large as the applied force to the door becomes almost perpendicular to that needed to pull the rack out. Closing the door would be assisted by the horizontal reactionary force, but may result in the door slamming if not properly controlled. We gave this a safety rating of 4 due to these factors. Because of the circular nature of this rack system allowing for lateral and vertical travel simultaneously and the fact that this motion is accomplished by one motion of opening the door, we gave concept 2 a functionality rating of 4. Manufacturing this design would be difficult as we are mainly concerned with designing large linkages intricately related in a limited heated oven space, giving the feasibility rating of 3. This concept has a total rating of 11.

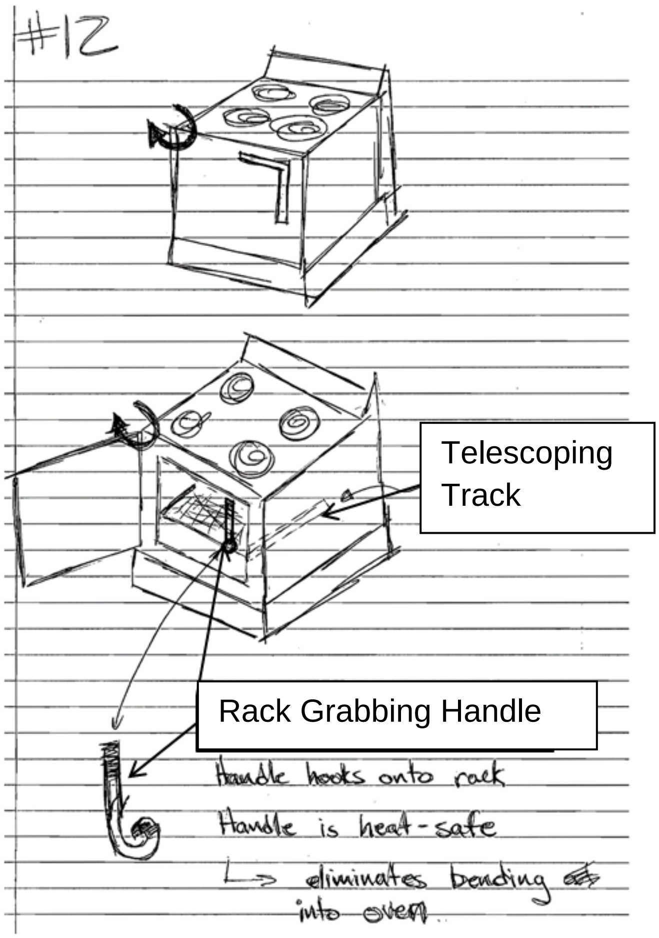
Figure 6: Rack Concept #2



Concept 12 is one of our simpler concepts. It utilizes a side-swinging door, mimicking a microwave oven or refrigerator, and the door is separate from the rack movement. There would be a handle kept outside of the oven, which would attach to the rack and allow the user to pull the rack out without bending, or leaning into the oven. We felt that we needed a basic concept that would fulfill the ideals of limiting the bending at the waist, eliminating leaning into the oven, and reducing the occupied floor area.

This design scored very well, receiving second highest total rating of 12 because it is safe (4), it provides good functionality (3), and it is very feasible (5). The safety issue is the fact that the user must hook the handle onto the rack inside the oven. Functionality took a hit due to the rack not rising. Making an accessory handle is much more feasible than trying to link the oven door to the rack. We have decided to pursue this concept because the rack movement is separated from the door, which will significantly decrease the force necessary to lift the racks as discussed as one of the major problems with concept 2.

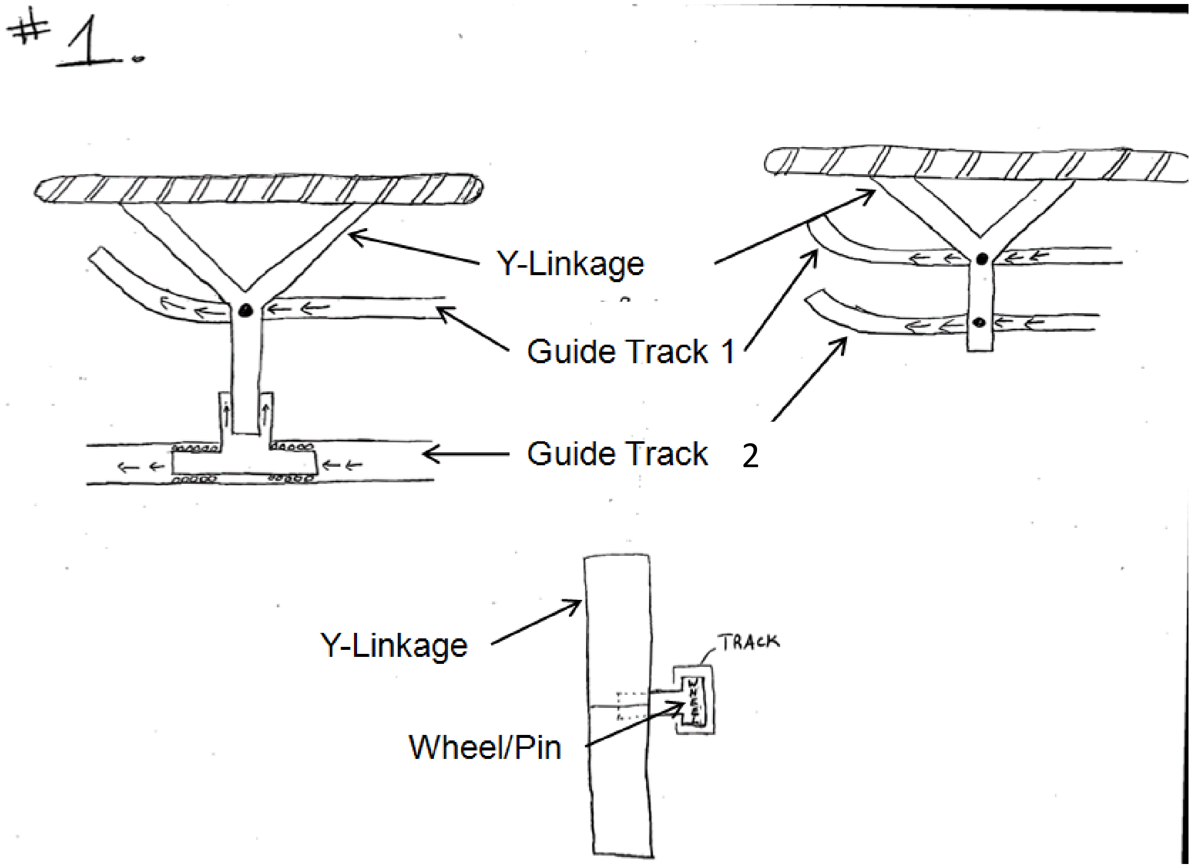
Figure 7: Rack Concept #12



Concept 1 is an oven rack design that would allow for lateral and vertical motion. The left drawing shows a rack supported by a solid Y-bar. A pinned wheel would be attached to the Y junction and would follow a curved track as depicted. To keep the rack horizontal, an adjusting support would restrict any Y-bar rotation. The right drawing has similar motion, but a more simplified support. A second pinned wheel replaces the ball bearing slider of the left drawing, but another identical curved track is needed.

Due to the wheeled tracks, force necessary to move the rack would be less than that of conventional ovens that slide rack metal to oven metal. We characterized this force with a higher safety rating of 4. Since the rack would slide out and up, we gave it a functionality rating of 5. Despite the more difficult track manufacturing, we thought that the overall time feasibility was quite high compared to some of our other designs using pulleys, springs, and large linkages, giving it a time feasibility rating of 4. The concept has the highest rating of 13.

Figure 8: Rack Concept #1

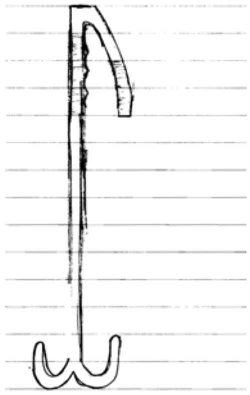


Handle Concepts

To get the rack out of the oven, we have incorporated a handle that can be used to lift the rack without requiring any bending by the user. One of the main fears that elderly have about current oven designs is that they may fall into the hot oven while bending at the waist. All of our handle designs have a crook at the grip end, which is meant to assist users who have limited grip strength. This crook will allow them to slide their hand underneath, and lift using their arm strength in addition to their grip.

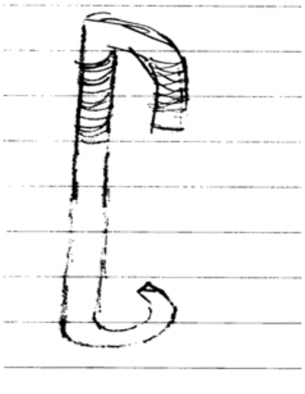
We came up with 5 handle designs, and rated then on a scale of 1-5 on each safety, functionality, and feasibility:

Figure 9: Handle Concept #1



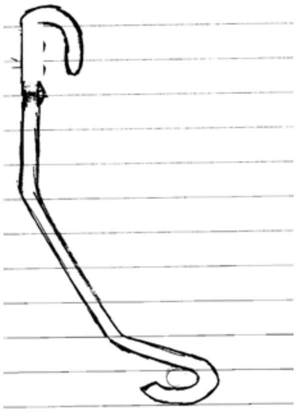
This handle design received a score of 3 for safety, because we felt that the two hooks would be less safe than having a single hook. For functionality, it received a 3 because of the straight bar, which would not be as easy to use as a bent bar. Finally, for feasibility, it scored a 2, because we feel like manufacturing the double hook would be very difficult. Overall this design scored an 8.

Figure 10: Handle Concept #2



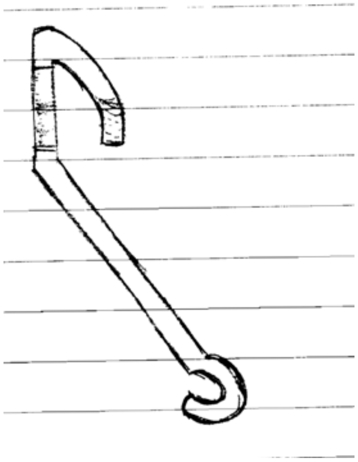
Handle concept 2 scored well on safety, receiving a 4, because it only has a single hook. It scored a 3 on functionality, because we feel like the straight bar design is limited. Lastly, it scored a 4 for functionality, because it is a very simple design. The total score is 11.

Figure 11: Handle Concept #3



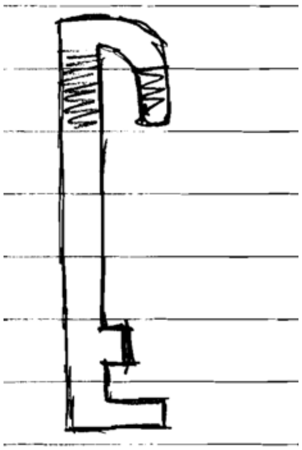
Handle 3 is similar to handle #2, but has a bent bar. The bent bar is designed to allow the user to stand away from the oven, but still be able to reach inside. This design scored a 4 on safety, because of the distance from the heat. For functionality, it also scored a 4, because of the bend. However, we gave it a 3 for feasibility, because we think the double bend, and design of the hook would be hard to manufacture. This is a total score of 11.

Figure 12: Handle #4:



Concept 4 follows a similar design as #3, however only has a single bend in the bar. This concept received a 4 on safety, because it keeps the user away from the heat. For functionality we gave it a 5, because we feel that the single bend is much more efficient than the double bend of concept #3, and also better than a straight bar. For feasibility, it scored a 4, because the bend might still be a little hard to manufacture. The total score is 13.

Figure 13: Handle Concept #5



This concept follows the same idea as #2, utilizing a straight bar, however the hook design is different. This new design has both a hook that will allow the user to pull the rack out, and a second piece that will allow the user to more easily push the rack back into the oven. This design scored a 4 on safety because of the safe hook design. It scored a 4 on functionality, because we like the pusher, but it still has a straight bar. Finally, it scored a 5 on feasibility, because we feel the square hook design would be easier to manufacture than a curved one. The total score is a 13.

Through these rankings, we have chosen to combine handles #4 and #5. We like the single bend of handle #4, and the square hook and pusher design of handle #5.

Alpha Concept

When narrowing down our concepts, we chose to eliminate all of the concepts with doors that didn't swing to the side. We eliminated the traditional pull-down oven door because it takes up too much floor space, blocking wheelchairs, and it is too low, making it hard for geriatrics to bend over and lift it. We eliminated doors that slide to the side because we were worried about the affect the hot door would have on the cabinetry, and we eliminated a vertically sliding door because we didn't want to force anybody to reach above their shoulders to close the door. Our ratings reflect this reasoning in the ranking established in Table 4. Finally, other concepts such as a cylindrical door, or a drawer-style door were eliminated because we found them infeasible. By eliminating these concepts, as well as our conversation with Doug Rakoski, we chose to pursue an oven door that swings to the side like a refrigerator or microwave.

Table 4: Door style rating and ranking based on summed ratings.

Door Type	Safety	Functionality	Feasibility	Total
Side Hinged	4	5	5	14
Bottom Hinged	3	2	5	10
Vertical Sliding	3	2	3	8
Drawer	3	3	2	8
Side Sliding	1	3	3	7

We started with the rack design of concept number 1. We modified the rack design slightly, in an effort to create fewer manufacturing hours. Instead of having 4 curved telescoping tracks (2 per side), we adjusted to have a curved track with a separate straight track underneath it. The rack will sit on a rigid bar shaped like a 'T', which will be attached to a roller sitting inside a track. This track will be welded onto a slide, similar to a slide used to pull a drawer out, and a second slide will be positioned below it, to allow for vertical stability.

To move the rack out of the oven, we have decided to implement the idea proposed in concept #12. The handle approach is the most feasible given our timeframe and the other designs we have looked at. We couldn't come up with an effective and efficient way to link the movement of the door to the rack assembly, and decided that it will ultimately be easier for a consumer to open the door, and then pull the rack out when they are ready. The handle also allows us to address part of our motivation, which is to eliminate the danger of losing balance while bending to grab the rack. The consumer will be able to stand next to the oven, and pull the rack assembly out without any bending. The handle will have a grip on top, with a crook allowing for people with limited grip strength to lift with their arm strength. There will be a bend below the handle, which allows for the user to reach into the oven, while keeping the handle vertical and away from the heat. The hook on the bottom of the handle will have a straight bar for pulling, and a second bar, half the length, which will allow for pushing the rack back into the oven.

Alpha Concept Images: (All engineering drawings can be found in Appendix C)

Figure 14: Alpha Concept Isometric; Door Hinge; Handle

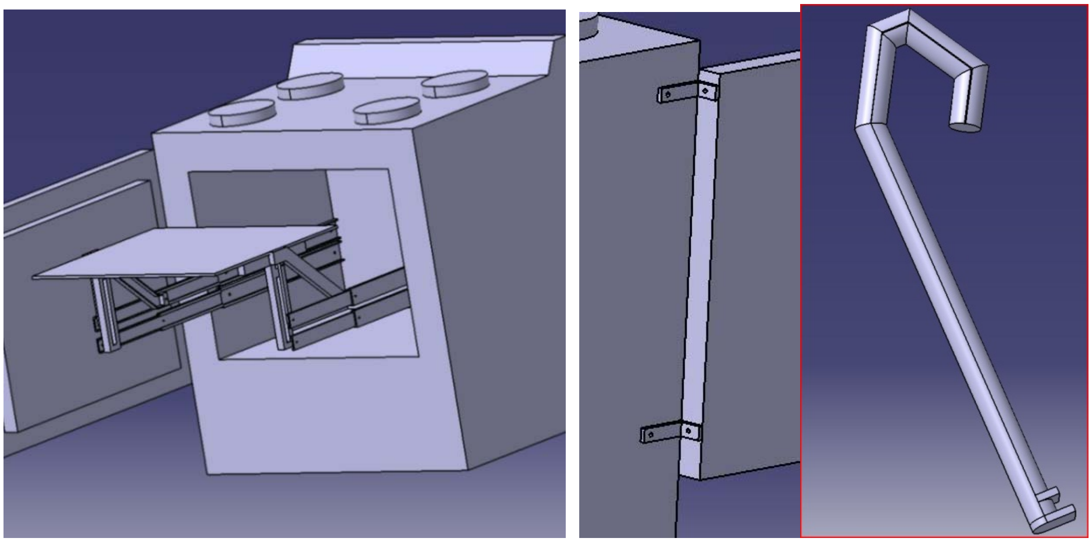
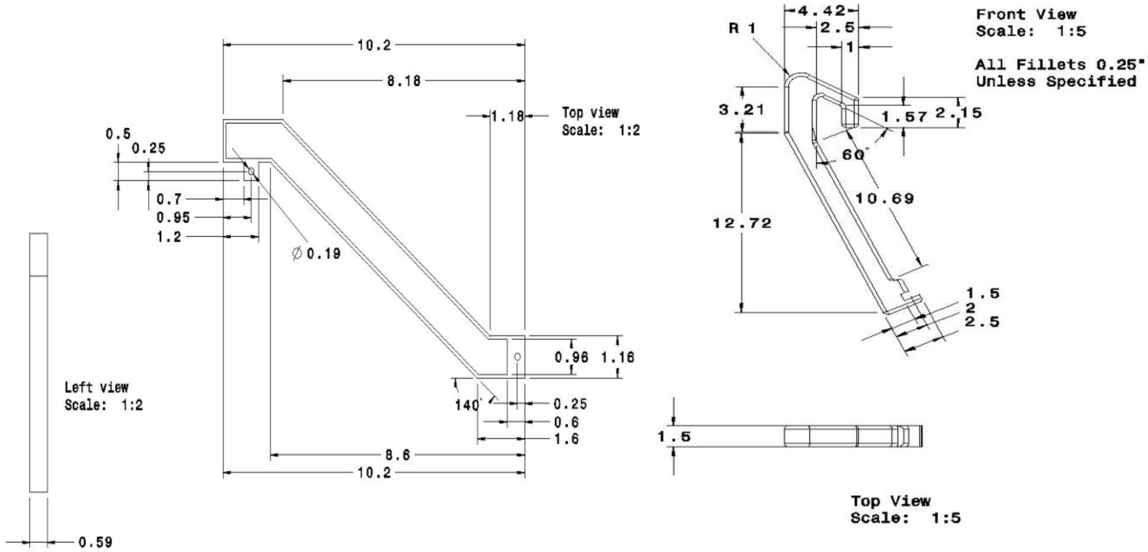


Figure 15: Shown left to right, alpha concept assembly drawings of the "Track" and "Handle"



Problem Analysis

Our design is mainly going to be a study of dynamics, linkages, and solid mechanics. Specifically, we are concerned with breakage of the bolts, the slides, or the tracks attached to the slides when a 40 lb load is applied to the middle of the rack. Recall that the Accuride rack system is designed to take a maximum load of 40lb, and this is what we've designed for. Breakage of the side hinges supporting the door is another concern of ours. Our analysis section that follows encompasses the force calculations necessary to determine stresses on the critical members of our design. The critical members we'll be analyzing are the bolts attaching the slide to the oven, the bolts attaching the track to the slide, the track itself, and the side hinges holding the door on the oven. Though the slide and rollers attaching the T-bar to the slide are important as well, the interaction of the ball bearings is difficult to model and we will trust the load specifications given to us by the manufacturer. The results of the following analysis section drive our material selection and manufacturing as to develop a sturdy and reliable prototype. It is important to note that we are also considering the application of our design in a hot environment. Though our prototype oven will not be heated, we will use materials capable of withstanding temperatures up to a cleaning temperature of 800°F to the best of our ability.

The design driver is feasibility. The least amount of parts and the least complication are desired. One of the bigger complications will be the wedge ridges of the prototype oven walls that were used to hold the oven racks. We will work around those using spacers on the bolts into the oven to offset our system from the oven wall so the slide can still move freely. Bolting into the oven sides will be a challenge as we must take the outer sidewall off the oven and discover what is in between the outer and inner walls. We must also consider having to cut the oven rack down and weld it back together to decrease its length in order to fit between our added hardware on either side. Slight oven rack rotation must be avoided to keep whatever's on the track level. Keeping the rack from rotation is accomplished by the slotted joint of the T-bar to the bottom slider. That square pin must be carefully fabricated under tolerance to maintain a snug fit in the slot to keep the T-bar vertical at all times.

Design Analysis

As a supplement to what is found in this section, we have also compiled our hand calculations in Appendix B. Engineering drawings could be found in Appendix C.

Dimensioning:

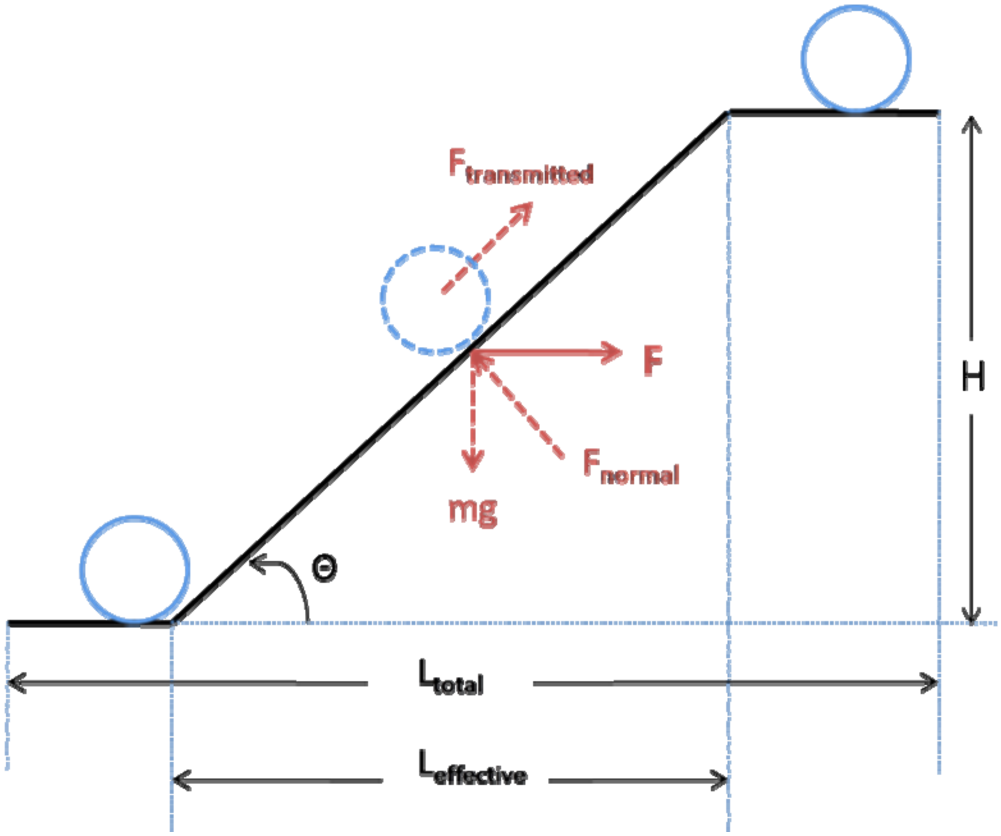
Dimension-wise, the alpha prototype is limited by the space available inside of the oven, which was measured by us to be 19”x24”x17.25” (*L*x*W*x*H*). The length of the gooseneck track was confined by the oven length of 19”, so the length was set to be 18” to ensure non-interference with the door. The telescoping portion of the track was dimensioned at 9”, half the length of the entire track linkage, which loads the T-bar linkage right down its center. The rise of the racks was set to 6”, primarily based on engineering judgment, to best serve the user in maximal height rise while ensuring the item(s) on the rack will clear the roof of the oven. These track length and height specifications set the angle within the telescoping track to be at ~40° [Appendix B]. The T-linkage was initially a Y-shaped linkage, as was our demonstrated design intent with the initial alpha concept. Eventually, a possible area for concern arose, where the bottom of the Y-linkage would travel too far downward and interfere with the bottom of the oven. To keep the same rise specification while avoiding that problem of interference, the top of the Y was eventually flattened into a T shaped linkage.

Force to Pull Rack Out of Oven:

Our design of the rack assembly dictates that the rack is rests on two wheels, each in the center of the rack, one on each side. We also decided that our goal was to raise the oven rack 6”, in order to make it more accessible to the user. These factors meant that our angle, and therefore the force to lift the rack, would be determined by geometry.

First, we had to find the length that would be used for the 6” vertical rise. The geometry of our oven led us to choose a rack length of 18”, which meant that the supports would be 9” from the front. On the base of the track, we subtracted 0.5” for the radius of a 1” wheel as seen in McMaster Carr. This leaves 8.5”, however we had to also subtract some length from the top resting area. We plugged the numbers into a Microsoft Excel worksheet to determine the difference in force for each a 1”, 1.5”, and 2” resting length on the top. We also varied the angle, to find the max height per minimum force, in case we found 6” to be infeasible. The figure we used is shown below, and a more detailed version is shown in Appendix B along with our Microsoft Excel data.

Figure 16: Force to Lift Rack



To determine the best angle to reach our desired height, we used the following equation:

$$\theta = \tan^{-1}\frac{H}{L_{effective}} \qquad \text{[Eq. \#1]}$$

where; θ is the angle in degrees, H is the height rise in inches, and $L_{effective}$ is the length across the height rise.

To determine the force, F, as shown in Figure 16, we used the following equation:

$$F_{transmitted} = mg * \sin\theta \qquad \text{[Eq. \#2]}$$

where mg is the load in pounds, and θ is the angle in degrees.

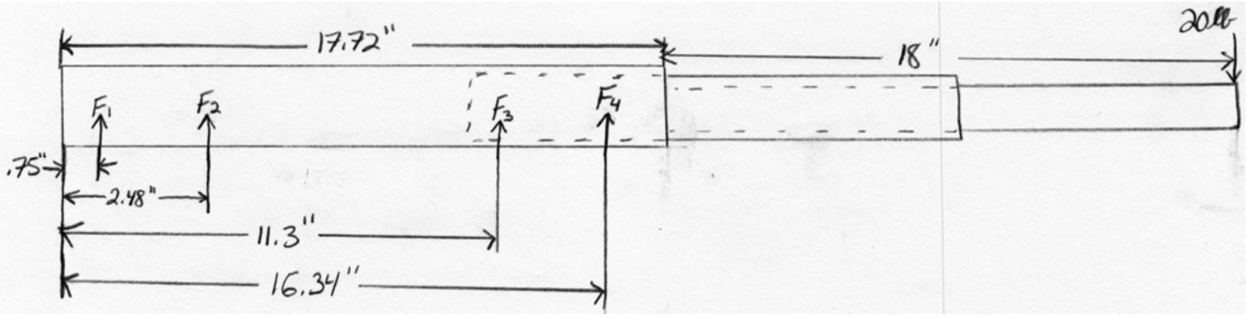
Our calculations led us to choose an angle of 40°, which delivers our goal of a 6”, but only transmits 64% of the force F along the track. To pull the rack to its top resting position, the force required, F, is equal to 136% of the weight of the food item. While this force may seem too great, our oven rack assembly only weighs 3lbs and most items placed inside the oven will be less then 10lbs. We are assuming that the user is operating the oven independently, and they are strong enough to lift the food (load) that they place inside the oven. This means that using the handle will not require much more strength than they need to lift the food with their hands.

Yield Strength and Placement of Bolts Connecting a Slide to the Oven Wall:

Stress on the bolts attaching the slides to the oven centers around the shear force applied to the bolts by the weight of the slide. The possible mounting holes of the slide are shown in Figure 17 as F_1, F_2, F_3, and F_4. We're assuming the weight of the slide and attached track are negligible compared to the 40 lb max load possible to apply to the Accuride rack system. Making the force calculation on one of the oven slides, a max load of 20 lb is applied since we assume the 40 lb load to be applied equidistant from each track. Based on engineering judgment and the force distribution described along the channeled track for the needed user-input force, the maximum force applied to the oven bolts will occur when the 20 lb force is applied at the end of the track's full extension of 18". We are assuming the force interaction between the three slide components to translate the moment force of the 20 lb as if the three slide components were one solid bar; this simplifies our model.

Figure 17: Free body diagram for resultant forces of the bolts connecting the slide assembly to the oven. The dimensions shown come from Fig. 23 in the manufacturing section. We chose the force locations based on the holes given in that engineering drawing.

F =



Different combinations of bolts can be used to secure the entire track assembly to the oven wall. Of these combinations, we've chosen to use either two or all four bolts. To solve the resultant forces on the bolts, we've used basic statics equations of the sum of forces and moments are equal to zero respectively. The resultant forces are organized in Table 5 for each possible combination of two bolts.

Table 5: Resultant forces of different combinations of bolt positioning of two bolts securing the slide assembly to the oven wall based on force and moment balances. Resultant forces' magnitude makes logical sense as all pairings compliment a moment created by the 20 lb force at least 18" away.

Applied Forces	$\sum F_y = 0$	$\sum M$ about	$\sum M \circlearrowright = 0$	Force Solution (lb)
1 & 3	F_1+F_3-20	1	$10.55*F_3-34.97*20$	$F_1 = -46.2938$, $F_3 = 66.2938$
1 & 4	F_1+F_4-20	1	$15.59*F_4-34.97*20$	$F_1 = -24.8621$, $F_4 = 44.8621$
2 & 3	F_2+F_3-20	2	$8.82*F_3-33.24*20$	$F_2 = -55.3741$, $F_3 = 75.3741$
2 & 4	F_2+F_4-20	2	$13.86*F_4-33.24*20$	$F_2 = -27.9654$, $F_4 = 47.9654$

Solving for the resultant forces on all four bolts, we use Equations 3-6 which are combined into matrix form as Equation 7. The solution of this linear system of equations was solved using a Matlab code written to perform Gaussian elimination with scaling and partial pivoting. The code may be found in Appendix B. The resultant forces of the four bolts are shown as Equation 8. Although the first two bolts don't have reactionary forces, all four equations are satisfied as we've checked this solution by hand. The left-most matrix of Equation 7 is singular, meaning that there exists only one solution to the force and moment balance equations below. We did not expect this result, but tried the same force and moment balance strategy on 3 bolt combinations and obtained the same result of the right-most bolts complimenting and offsetting each other to balance the static system. Because only the third and fourth bolts take all of the load and the fact that they are so close to each other, much higher resultant force magnitudes exist.

$$F_1 + F_2 + F_3 + F_4 - 20 = 0 \qquad \text{[Eq. \#3]}$$

$$\sum M \circlearrowright = 0 \text{ about 1: } 1.73 * F_2 + 10.55 * F_3 + 15.59 * F_4 - 34.97 * 20 = 0 \qquad \text{[Eq. \#4]}$$

$$\sum M \circlearrowright = 0 \text{ about 2: } -1.73 * F_1 + 8.82 * F_3 + 13.36 * F_4 - 33.24 * 20 = 0 \qquad \text{[Eq. \#5]}$$

$$\sum M \circlearrowright = 0 \text{ about 3: } -10.55 * F_2 - 8.82 * F_3 + 5.04 * F_4 - 24.42 * 20 = 0 \qquad \text{[Eq. \#6]}$$

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 1.73 & 10.55 & 15.59 \\ -1.73 & 0 & 8.82 & 13.86 \\ -10.55 & -8.82 & 0 & 5.04 \end{bmatrix} * \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix} = \begin{bmatrix} 20 \\ 699.4 \\ 664.8 \\ 488.4 \end{bmatrix} \qquad \text{[Eq. \#7]}$$

$$\begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ -76.9048 \\ 96.9048 \end{bmatrix} (lb) \qquad \text{[Eq. \#8]}$$

Based on the resultant forces for all aforementioned bolt combinations, the combination yielding the smallest forces is the one that uses only two bolts spread furthest apart. We've found through our overall slide statics analysis that when the active bolts are spaced furthest apart, those bolts will take the smallest magnitude reactionary forces. Based on this discovery, we will use two bolts to secure the slide assembly to the oven wall and they will be in the positions of F_1 and F_4 shown in Figure 17.

The yield strength of the bolt is calculated using Equation 9.

$$\sigma = \frac{M*y}{I} \qquad \text{[Eq. \#9] [10]}$$

Where M is the moment applied to the bolt, y is the distance from the centerline through the center of the bolt cross-section, and I is the moment of inertia of the bolt.

Calculating the moment if inertia we use Equation 10 and obtain 0.000192 in^4.

$$I = \pi * \frac{r^4}{4} \qquad \text{[Eq. \#10] [10]}$$

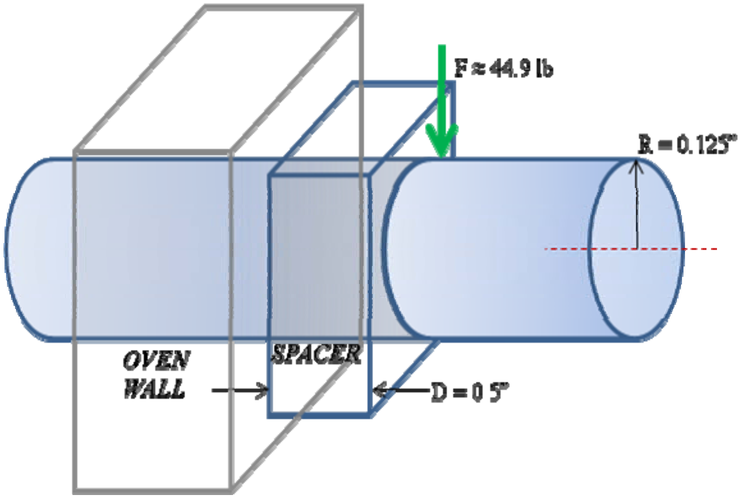
Where r = 0.125", the radius of the intended bolts to be used.

A 0.5" in spacer will be used to space the slide from the oven wall. This must be done to avoid the prototype oven's rack-holding wedges cast in the sidewalls. This spacer will create a moment of 22.4311 lb-in,

$$M = F * d \qquad \text{[Eq. \#11]}$$

Where F is 44.8621 lb and d is 0.5". See Figure 18 for an associated free body diagram.

Figure 18: Free body diagram for the force on a bolt holding the slide to the oven wall.



The radius is the value of y. With all values necessary to calculate yield strength known, yield strength of the bolt is approximately 14.6 kpsi. Upon viewing the bolt strength chart mapping bolt grade against minimum yield strength applied, 14.6 kpsi relates to a grade 1 low or medium carbon steel bolt [11].

Yield Strength of Bolts Connecting a Track to a Slide:

Stress on the bolts attaching each track to each slide centers around the shear force applied to the bolts by the weight of the slide. We're assuming the weight of track is negligible compared to the 40 lb max load possible to apply to the Accuride rack system. We again assume a maximum 20 lb load applied to each side since the maximum 40 lb load should be equidistant from each side of the oven. Figure 19 shows the positioning of the two bolts we will use to secure the track to the slide. F_1 locates the connection of the track directly to the slide as F_2 locates the connection of the track's connection bar to the slide. The 20 lb force is applied 0.5" from the right end as the roller will have a radius of approximately 0.5". The basic force and moment balance equations as well as resultant forces are shown below in Table 6. We will calculate the shear force of the bolt based on the maximum force applied of 21.33 lb.

Figure 19: Free body diagram for resultant forces of the bolts connecting the track to the slide

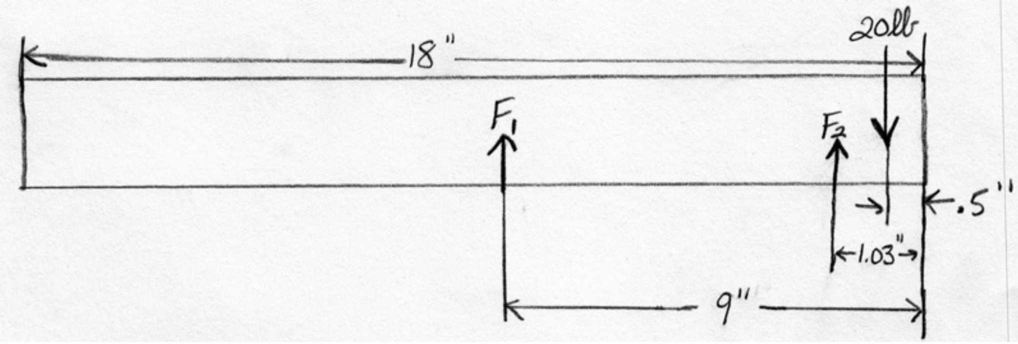


Table 6: Resultant forces of two bolts securing the track to the slide based on force and moment balances.

$\sum F_y = 0$	$\sum M$ about	$\sum M$↺ $= 0$	Force Solution (lb)
F_1+F_2-20	1	7.97*F_3-8.5*20	F_1 = -1.33, F_3 = 21.33

The yield strength of the bolt is calculated using Equation 12.

$$\sigma = \frac{M*y}{I} \quad \text{[Eq. \#12] [10]}$$

Where M is the moment applied to the bolt, y is the distance from the centerline through the center of the bolt cross-section, and I is the moment of inertia of the bolt.

Calculating the moment if inertia we use Equation 13and obtain 0.000061 in^4.

$$I = \pi * \frac{r^4}{4} \quad \text{[Eq. \#13] [10]}$$

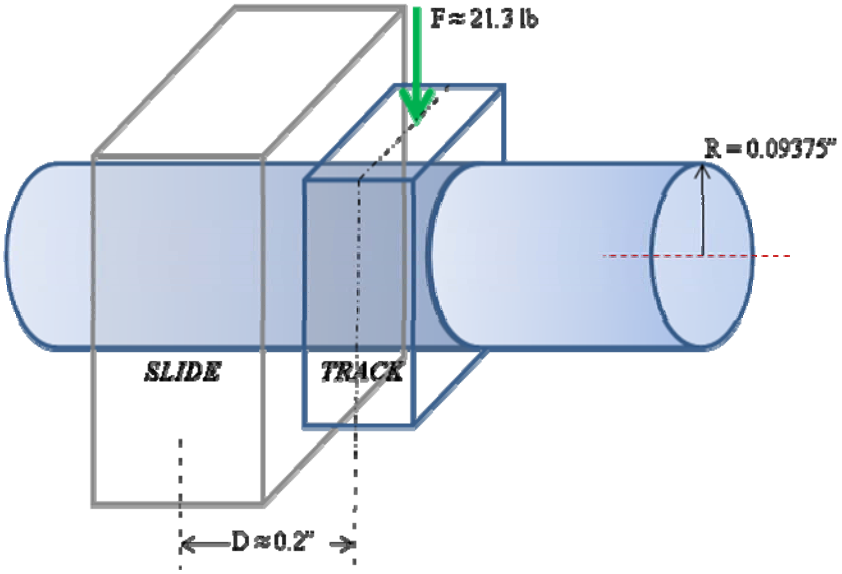
Where r = 0.09375”

Approximately 0.2” of space separates the opposing forces of the track to the slide. This will create a moment of 4.266 lb-in,

$$M = F * d \quad \text{[Eq. \#14]}$$

Where F is 21.33 lb and d is 0.2”. See Figure 20 for an associated free body diagram.

Figure 20: Free body diagram for the force on a bolt holding the track to the slide.



The radius is the value of *y*. With all values necessary to calculate yield strength known, yield strength of the bolt is approximately 6.6 kpsi. Upon viewing the bolt strength chart mapping bolt grade against minimum yield strength applied, 6.6 kpsi relates to a grade 1 low or medium carbon steel bolt [11].

Yield Strength of Simplified Track from our CAD Design

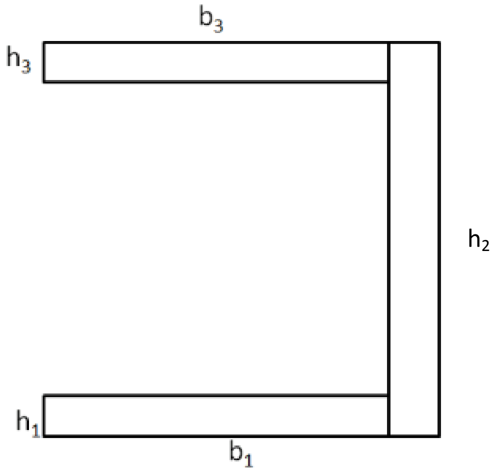
The yield strength of the track is calculated using Equation 15.

$$\sigma = \frac{M * y}{I} \qquad \text{[Eq. \#15] [10]}$$

Where *M* is the moment applied to the track, *y* is the height of the track (h_1), and *I* is the moment of inertia of the track.

The simplified model of the track from our CAD design with thickness of what we will purchase for our prototype is given below in Figure 19. The cross section of the track was simplified to the C-section seen in Figure 19 for ease of analysis. However, the cross section, as seen in Figure 24, is much more circular in nature and thus does not present any concerns for stress concentrations where respective faces of the track meet.

Figure 21: Cross-section view of the track



Calculating the moment if inertia we use Equation 16 and obtain 0.0433 in^4.

$$I_y = \sum_{i=1}^{i=3}\left[\frac{1}{12}b_i h_i^{3} + (z_i - z_0)^2 A_i\right]$$ [Eq. #16] [10]

Where, $z_0 = \frac{\sum_{i=1}^{3} b_i h_i z_i}{\sum_{i=1}^{3} b_i h_i}$, $h_2 = 1.16$”, $h_1 = h_3 = 0.1$”, and $b_1 = b_3 = 0.49$”.

0.53” of space separates the opposing forces of the track’s right-most bolt, 21.33 lb, and the applied 20 lb force. This will create a moment of 11.305 lb-in,

$$M = F * d$$ [Eq. #17]

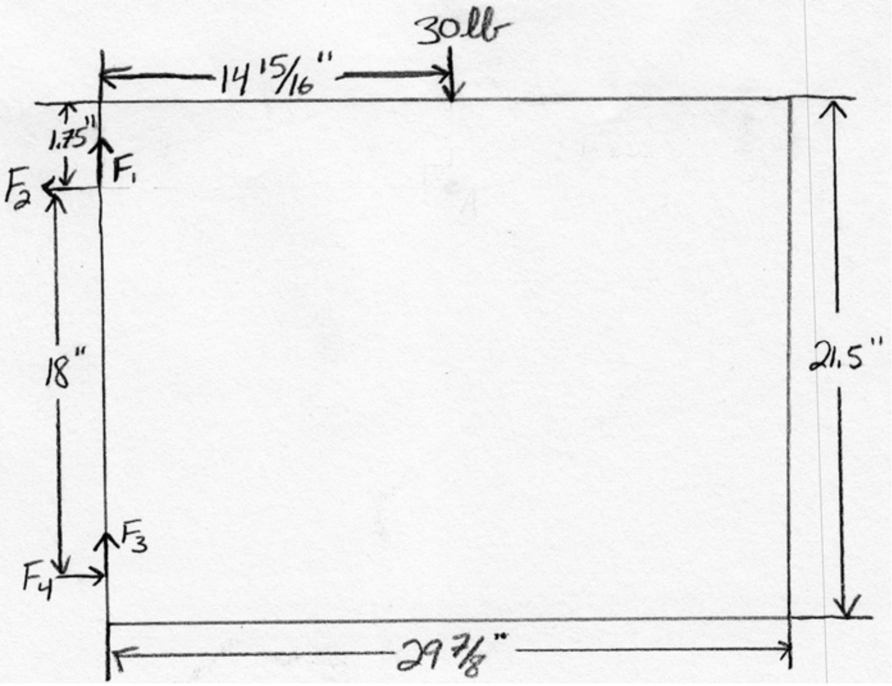
Where *F* is 21.33 lb and *d* is 0.53”.

The height, h_2, is the value of y since we’re taking the moment of inertia about the bottom of the track. With all values necessary to calculate yield strength known, yield strength of the track is approximately 0.303 kpsi.

Door Hinge Resultant Force Analysis:

Equivalent force applied on each hinge attaching the oven door to the oven was calculated based on dimensions as shown in Figure 20 and certain assumptions. We’ve assumed that the weight of the door is uniform and can be applied to the horizontal center point. We’ve also assumed that we’re installing the hinges properly, meaning they should each bear an equivalent portion of the door weight. The oven we are using for the prototype has not yet had its door detached for us to weigh it. We’ve used our judgment and confirmed with Dr. Shih that the door weight can be approximated as 30 lb.

Figure 22: Free body diagram for resultant forces of the hinges connecting the oven door to the oven.



Summing the forces in the horizontal direction we obtain,

$$\sum F_x = 0 = -F_2 + F_4 \quad \text{[Eq. \#18]}$$

$$F_2 = F_4 \quad \text{[Eq. \#19]}$$

Summing the forces in the vertical direction we obtain,

$$\sum F_y = 0 = F_1 + F_3 - 30 \quad \text{[Eq. \#20]}$$

$$F_1 + F_3 = 30 \quad \text{[Eq. \#21]}$$

Assuming we install the hinges properly, they should each bear an equivalent portion of the door weight. Knowing this and Equation 21,

$$F_1 = F_3 = 15\ lb \quad \text{[Eq. \#22]}$$

The hinges are in the same horizontal position. The moment force balance to prevent the door from rotating is accomplished by the horizontal forces, F_2 and F_4.

$$\sum M \circlearrowleft = 0 \text{ about } F_1\text{:} \quad -14\frac{15}{16} * 30 + 18 * F_4 = 0 \quad \text{[Eq. \#23]}$$

$$F_4 = F_2 = 21.875\ lb \quad \text{[Eq. \#24]}$$

Total force applied to a hinge is then,

$$F_{total} = \sqrt{15^2 + 21.875^2} = 26.524\ lb \qquad \text{[Eq. \#25]}$$

Thermal Expansion

We also determined the maximum thermal expansion coefficient of 78.125 µstrain/°F based on the cross section of the track to ensure the metal's expansion at a peak temperature of 800°F (oven-self cleaning function) wouldn't result in the track jamming. (Additionally, the material can not be flammable) To determine the needed thermal expansion coefficient we assumed the roller and the rail of the track to be made of the same material (thus having the same coefficient). Taking the difference between dimensions M and A to give the total gap between the roller and the track, and using Eq. #26 below, the needed thermal expansion coefficient was to be no larger than 78.125 µstrain/°F.

$$gap = M - A = M\left[\frac{\sigma_{rail}}{E_{rail}} + \alpha_{rail}\Delta T\right] + A\left[\frac{\sigma_{roller}}{E_{roller}} + \alpha_{roller}\Delta T\right] \qquad \text{[Eq. \#26]}$$

We simultaneously found a track/roller system from McMaster-Carr that seemed to fit our dimension constraints. It's part number 601535K52

When the above stated coefficient of thermal expansion was input to CES, one of the materials returned was type 420 steel, which is what the roller material is. The rail material is type 316, so to ensure that thermal expansion would not be an issue, another calculation was run [Appendix], and found that the max expansion under 800°F operating conditions would be less than 5% of the available gap.

Materials Selection

Table [7] lists the inputs to CES Edupack 2008. Of the almost 3000 materials in the database, the material of the track we've selected from McMaster Carr, type 420 steel, was among the 919 materials that satisfied those material properties. Additionally, there are 13 different types of type 420 steel in the database as seen in Figure 22. Assuming that there are several types listed for several grades of steel, the 919 materials returned by CES could easily be reduced significantly (to just the different grades of steel, not all the variations on each grade like wrought ferritic, hot rolled, etc.)

Table 7: Material parameters entered into CES

Property	Value
Yield Strength	1.82 ksi
Maximum Service Temperature	800°F
Thermal Expansion Coefficient	78.125 µstrain/°F
Flammability	Non-flammable

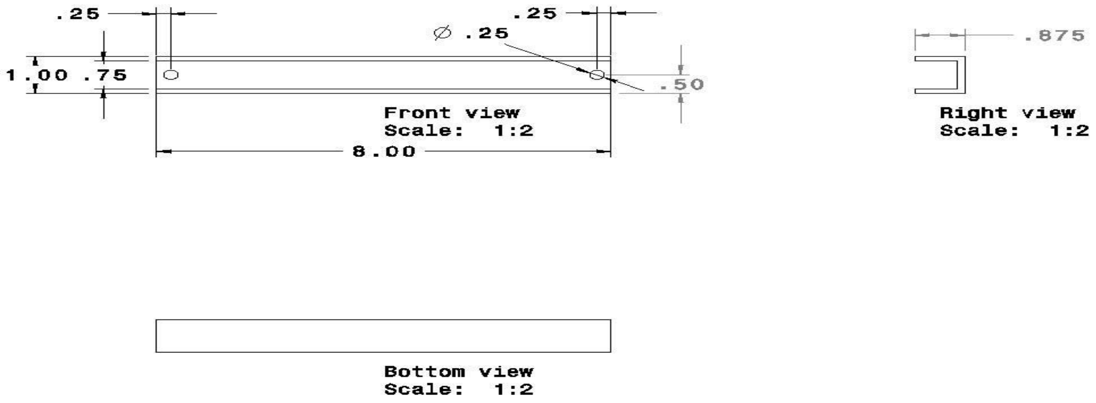
For the handle, the body will be a low density aluminum (eliminating mass from the handle), and the end to be gripped by the user will be coated by Plasti-Dip, a rubber composite, with the aim of insulating the user's hands from heat in the aluminum shaft, while having a high coefficient of friction for grip [12]. This product was chosen among researching similar products, namely, CPT-305-20 Corrosion Proof Coating [13], HumiSeal 1B51 Synthetic Rubber Coating [14], and EPDM Rubber Kit [15]. Of these, Plasti-Dip was significantly less expensive, approximately $10. Unfortunately we couldn't find the material properties of Plasti-Dip, but it is known for being highly thermally insulative.

Engineering Changes

After the initial alpha design, we were forced to make some engineering changes due to the limitations of the oven and a mistake in our initial concept. We found our design to be limited by the built in original rack heights inside the oven, making the distance between our sliding tracks greater. Therefore, the original height of the T-bar had to be increased and this was achieved by welding material with a similar slot on the top of the vertical part and then welding the horizontal part onto the add on. We welded 7/8" of material.

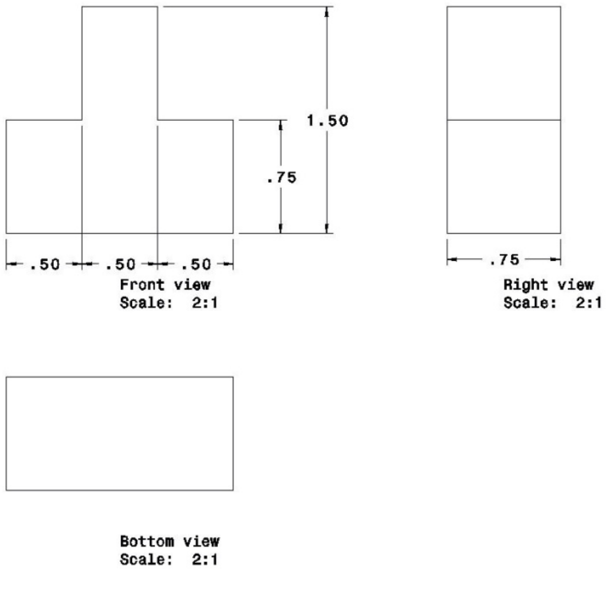
The second problem that caused an engineering change was a mistake in logic. We originally thought that the square pin could be connected directly to the bottom sliding track. We then discovered that if we indeed attached it to the bottom track, the bottom track would have to be shorter than the top sliding track by 7", the horizontal distance of the gooseneck. To remedy this problem, we fabricated an aluminum track with the length of 7" and with a width of the thickness of the square pin, ¾". This track is installed to the end of the bottom slider, where the original square pin was to be attached, and 7" behind the end. The drawing for the aluminum track is seen below in Figure 23.

Figure 23: Aluminum track



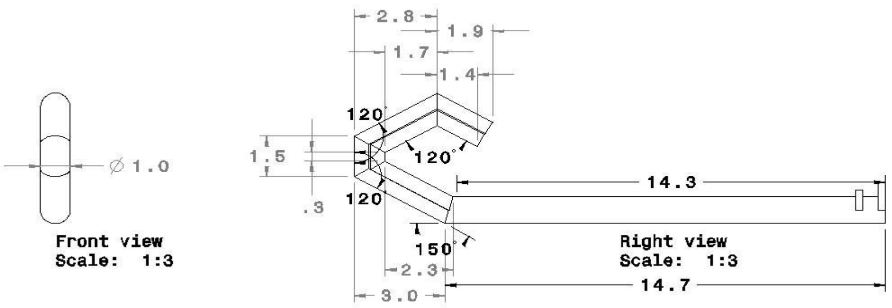
With the fabrication of the aluminum track, it also changed our design for the square pin. The square pin is now a spacer to slide along the aluminum track and along the T-bar to provide stability. The new design for square pin is seen in Figure 24 below. See Appendix C for the ECNs.

Figure 24: New design of square pin



Another modification made was in the design of the handle. We found the original design too hard to fabricate, especially the round corners. So the new design calls for angled cuts along with welding to give the handle its prescribed shape. We also decided to make the handle out of tube stock instead of bar stock to improve ergonomics. The new drawing for the handle could be seen below in Figure 25. See Appendix C for the ECNs.

Figure 25: Redesigned handle



Manufacturing Plan

It is important to first introduce some of the components we are purchasing in lieu of fabricating or to assist us in fabricating components of the prototype. Upon establishing this background information, fabrication and/or modification of components were necessary to create subassemblies. Subassemblies were brought together to make a finished prototype. Based on our bill of materials found in Appendix D, the total cost of building this prototype was $265.

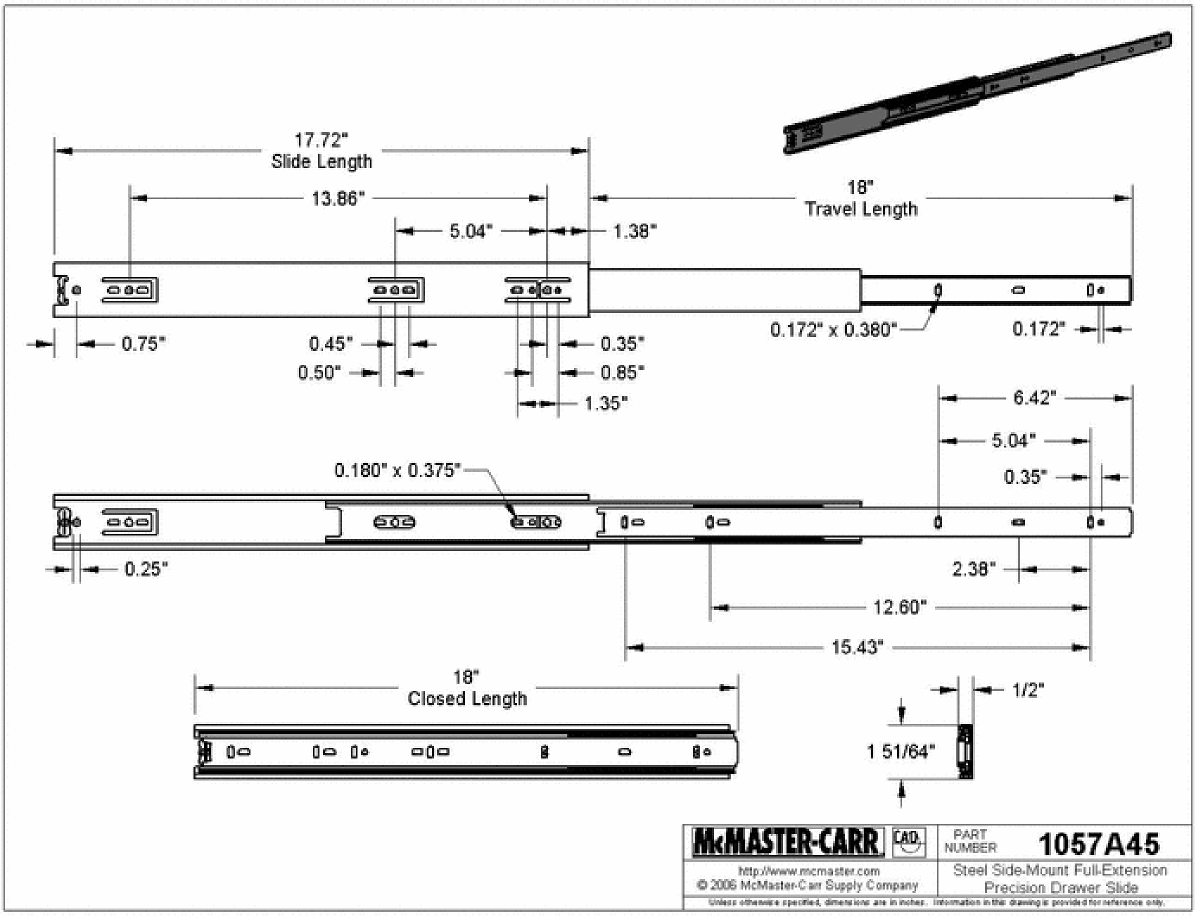
Stock Parts Used for Prototype:

<u>Prototype Oven:</u> The rack system was assembled inside a prototype oven purchased for ~$90 at the end of October shown in Figure 26. This oven has wedged ridges on either side that supported the racks in a traditional manor. We tried working around these ridges, but our rack system components fit such that we needed to plasma cut the front 3” of the second and third rungs from the top on either side. To fill the hole left there, we cut 1/8” aluminum sheets and bolted their 4 corners to the top and bottom of the sidewalls using 3/8” bolts. Our solution for offsetting the sliders as described in the problem analysis section was to offset them using aluminum spacers that could be easily cut from stock in the machine shop and drilled using the drill press.

Figure 26: Inside the prototype oven

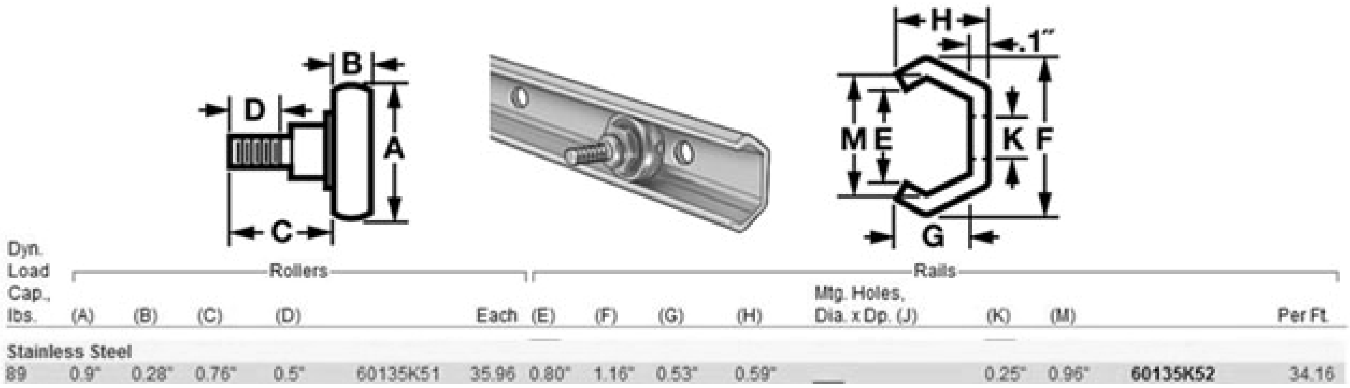
Drawer Slides: Breaking down the design components, we needed to purchase four drawer slides from McMaster-Carr. We couldn't attain the actual oven slides manufactured by Accuride since our correspondent to their sales department would not sell us slides individually without a design contract with them of purchasing $100,000.00 + of their product. There are no other manufacturers of slides that can withstand very high temperature, but there are many manufacturers who sell drawer slides that support the 40 lb maximum load that the Accuride slides are rated for. We found slides made of zinc-plated cold-rolled steel that were of similar travel dimension to the Accuride slides and hold 100 lb /pair. They cost $20.82 a pair from McMaster-Carr and were purchased and used in our prototype. Upon receiving them, we found that the manufacturer of these slides was also Accuride. A CAD drawing provided by McMaster-Carr is shown below in Figure 27. It is important to note that for mass manufacturing, the height and width of this slide differs from the Accuride oven slide's respective cross-section dimensions as shown in Appendix C.

Figure 27: McMaster-Carr part number 1057A45 drawer slide used for prototype



<u>Track Stock and Roller:</u> The tracks attached to the upper slides were originally going to be fabricated from square stock, cut appropriately, and then welded together. Searching through McMaster-Carr we found a combination set of rollers and tracks specifically engineered with roller/track tolerance to nearly the same dimensions we had designed for. We purchased three feet of the track and two rollers of the respective highlighted part numbers in Figure 28. Each of the rollers can withstand an 89 lb load, meeting our design requirements. We assume that if their roller can hold that much weight, their track itself can also withstand the load. The overall track's fabrication will be discussed in the fabrication section to follow.

Figure 28: McMaster-Carr part numbers 60135K51 and 60135K52 roller and track stock used for prototype



Dyn. Load Cap., lbs.	Rollers						Rails								
	(A)	(B)	(C)	(D)		Each	(E)	(F)	(G)	(H)	Mtg. Holes, Dia. x Dp. (J)	(K)	(M)		Per Ft.
Stainless Steel															
89	0.9"	0.28"	0.76"	0.5"	60135K51	35.96	0.80"	1.16"	0.53"	0.59"	—	0.25"	0.96"	**60135K52**	34.16

Oven Door Hinges: The oven door hinges we used are rated to hold at least approximately 26.5 lb each as required by our analysis. We chose to use two McMaster-Carr strap hinges, part number 1264A12.

***Fabrication**:*

Only the tracks, T-bars, square pin, connection bar, handle, and rack needed extra time to be fabricated. Among these parts were also two aluminum channels to be fabricated as a design change was necessary.

Stainless Steel Tracks: Manufacturing was rather difficult in fabricating the track with its close tolerance on the diagonal member's angle to the horizontal and associated dimensions to still allow the rack to fit inside the oven at the slide's non-extended position. The stock track needed to be bevel cut using a vertical band saw. A fixture was fabricated to run the stock into the saw and get straight cuts. After cutting one corner from two pieces of stock, we but the bevels together and ran a roller through to judge its dynamics. The roller had no difficulty transitioning through the butted angle. Welding was done through Bob Coury to tack all beveled members together.

Connection Bars: The connection bar between the slide and the track was fabricated out of steel stock. It was cut to size with the vertical band saw and had a hole drilled at one end and the other end welded directly to the steel tracks 1" from the right edge of the top of the welded track as described above. The completed track and welded connection bar is shown below in Figure 29.

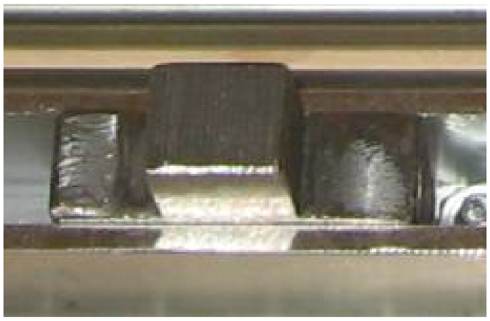
Figure 29: One completed track and connection bar shown attached to the slide.

<u>T-bars:</u> The T-bar was fabricated from steel stock within the machine shop. The T consisted of two rectangular stock pieces, with the vertical piece slotted by step-milling using a 3/8", 4-flute end-mill and drilled for an M5 x 0.8 hole to be tapped for the roller. The two square stock pieces were fillet welded together by Bob Coury. The completed T-bar is shown below in Figure 30. Note that there is an extra 5/8" of material welded between the horizontal and slotted pieces. This was a design change when we first laid the assembly out with proper spacing of the slides as they'd be installed in the oven and discovered that the T-bars would be too short to properly function with the thicker square pin discussed below Figure 30.

Figure 30: Completed T-bar. Note the added material as described above.

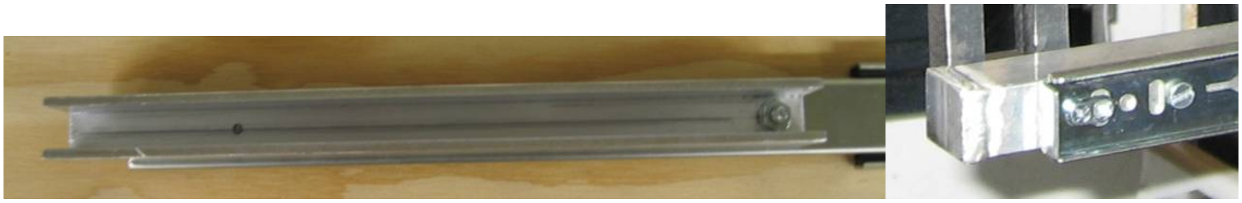
Square Pins: The square pins were made from the shop's stock steel and cut to size using the vertical band saw and a surfacing mill. One is shown sitting in its aluminum channel in Figure 31. Note the design change from fastening the pin to the slider directly to fastening an aluminum channel to the slider and allowing the pin to slide freely within the aluminum channel. This was done due to a miscalculation on the dynamics of the entire system in that the pin must be able to move along the slider as the T-bar moves.

Figure 31: Completed square pin shown in its aluminum channel.



Pin Channels: The pin channels were made out of the shop's stock aluminum hollow bar stock. We cut the bar stock in halves using the vertical band saw to give us two U-shaped channels. The same length as that of the steel tracks was used to cut these channels to size. The channels had their tops milled such that they were 7/8" tall. This gave a much better surface finish and tolerance as the T-bars would be gliding along the ledges of the channel. One hole was drilled and tapped to allow for a short screw to hold it in place on the slide while another hole was drilled on the opposite end to allow a stopper bolt to attach the channel to the slide and act as a stopper for the square pin. To have an effective stopper on the non-stopped end, a small piece of aluminum plate stock was cut with the vertical band saw and welded by Bob Coury in place. One channel is shown below in Figure 32.

Figure 32: Completed aluminum channel shown mounted to the slide.



Handle: The handle was fabricated out of 1" aluminum hollow bar stock. The bar stock was bevel cut to achieve the shape given in the engineering drawing. The cuts were 15° from the straight piece to the cane and 30° on every piece thereafter to achieve proper shape. The pieces were welded together by Bob Coury. The straight end of the handle was notched ½" through the stock to allow for a 3/16" thick rounded aluminum piece to be welded once dropped in the slot. The aluminum piece itself was from the shop's plate stock and was cut using a vertical band saw and filed. The end prong was cut and filed in the same manner along with the circular end stop for the cane end. Both end stops were welded into place by Bob Coury.

The hand grip end of the aluminum handle was painted with Plasti-Dip. The control of this process was critical so to eliminate uneven application around the surface. The completed handle is shown below in Figure 33.

Figure 33: Completed rack handle.

Rack: Two racks came with the oven, only one was used. It was cut down in length roughly 4” by cutting material from the center of the rack. Bob Coury welded the two halves back together. The reason we would not cut from one side is that both sides have a thicker bar on the edge that is the rack’s main support frame. We’d rather the weld be in the center as to keep the weld residual stresses centered for loading.

Installation:

Installation is the essence of our prototype. With the fabricated pieces made, all components were ready to be assembled. Subassemblies included the track and channel to the detachable pieces of the slides and the T-bars/rollers/rack subassembly. Subassemblies and full assembly of the rack system inside the oven as well as the assembly of the door to the oven wall are discussed in sections below.

Track to Slide Subassembly: The track was assembled to the detachable slide member as shown in Figure 29. A hole was drilled into the slides at 9” from the right side as shown in Figure 19. A connection bar facilitated the connection between the track and the slide at 1.03” from the right side of the slide. These three pieces were all secured using flathead bolts, washers, and nuts.

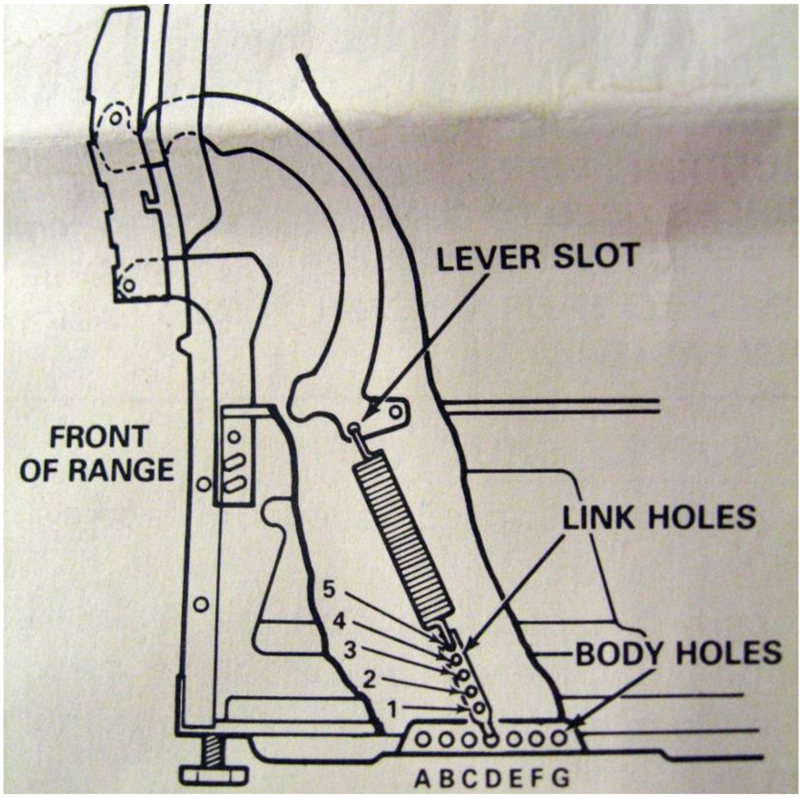
Aluminum Channel to Slide Subassembly: The aluminum channel was installed in the same locations as the Track to Slide discussed above. Note that the one short bolt was threaded through the slide and into the channel while the other longer bolt held the other end in place and will act as a stop. See Figure 32 for the subassembly image.

T-bars/Rollers/Rack Subassembly: The T-bars were carefully positioned to maintain perpendicularity to the oven rack while welding the rack to the T-bars. This was difficult and took a generous amount of time to do correctly. Once welded, the rollers were screwed into the T-bars.

Full Rack System Assembly: All four slides were carefully installed to the oven walls centered on the peaks of the second and third ridges from the top and pushed against the back oven wall. Holes were drilled through the oven wall and support plates during installation rather than all at once. The slides were secured using flathead bolts, nuts, washers, and steel spacers to offset them from the oven ridges. The tracks and channels to slides subassemblies were slid back into the sliders. The T-bar/rollers/rack subassembly was carefully aligned to the tracks and rolled in, placing a bolt stopper to each track end to prevent it from falling back out when pulled upon. All slides were fully extended and the square pins were placed in their respective aluminum channels. Our system had incorporated a 1" tolerance to ensure complete closing of the oven in case we ran into problems manufacturing specific parts or even installing the purchased slides. This was important as upon installing the door, we found the tracks were at the correct length for proper closing.

Door Assembly: The door was disassembled by removing the hinges shown in Figure 34. We disassembled the door and plasma cut grooves where the hinges were to be installed given our analysis of the door force. We realized that the stability of the installation points to the door and sidewall were going to be an issue and remedied them by making 1/8" thick shop stock steel support plates to sandwich the door and wall material. We installed the hinges to the door and then, with holding support from each other, placed the door against the opening of the oven and marked the installation points on the oven wall. We took the wall back off the oven, drilled the proper holes, and installed the hinge/door to the wall. Securing the wall back onto the oven, the door installation was complete

Figure 34: Prototype oven's bottom-swing door hinge to be disassembled.



Completed Prototype: The completed prototype with all subassemblies installed is shown below in Figures 35, 36, and 37.

Figure 35: Finished prototype side view

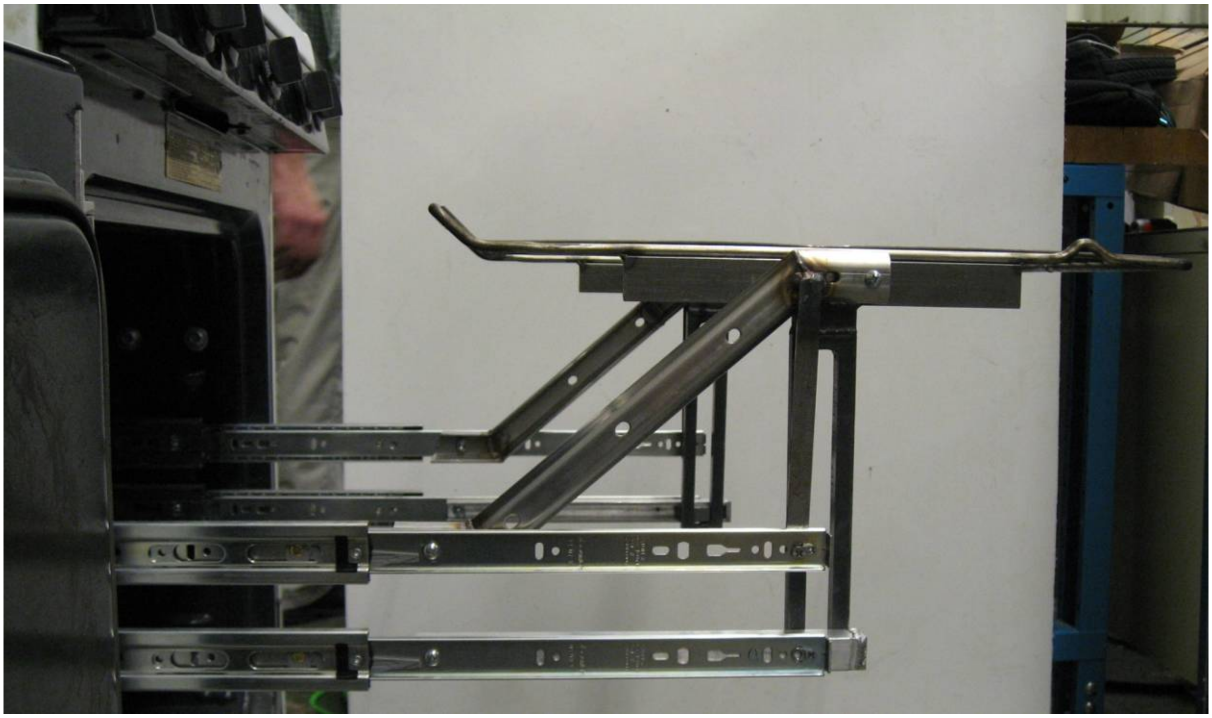
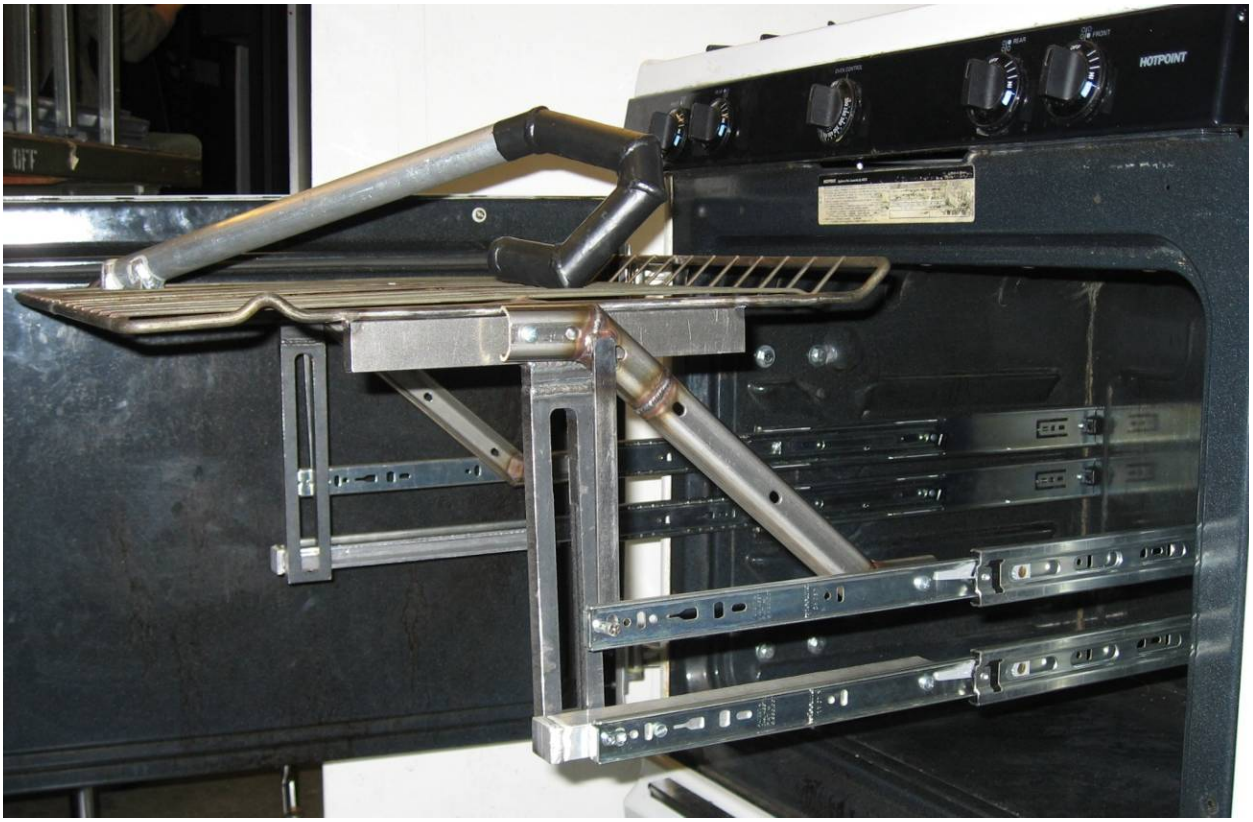


Figure 36: Finished prototype top view

Figure 37: Finished prototype isometric view



Description of Validation Approach

The volume swept by the door and the projected floor area are set by the oven door. The volume swept spec will be determined from a calculation based on the dimensions of the door and a 90° sweep. We know that the project floor area spec will be met due to the difference in opening methods, as a side-swing door will always occupy less floor area than that of an open-down door. This will also be based on the dimensions of the door. The force needed to open and close the door will be determined using a force gauge fixed to the handle of the door, kept perpendicular to the door through the swing motion. The force used to extend and retract the racks will also be determined with a force gauge. We expect this value to be significantly greater than similar racks we benchmarked due to additional force needed to pull the load on the racks forward and up. The maximum temperature in the oven will not be tested, as the oven will not be functional.

Table 8: Validation values compared to target values based on engineering specifications.

Engineering Specs	Validation Values	Target Values
Volume Swept	6.45 ft^3	< 5.5 ft^3
Projected Floor Area	0.30 ft^2	< 4.2 ft^2
Force Needed to Open Door	2 lb	< 13.3 lb
Force Needed to Close Door	2 lb	< 4.3 lb
Force Required to Pull Rack	13 lb	< 5 lb
Vertical Rise of Oven Rack	7 in.	6 in.

Table 8 shows a comparison of our validation numbers against our target values. It was expected that the volume swept and force to pull rack would be larger than their respective target values. By lowering the other values, we feel that we have successfully met our engineering specifications.

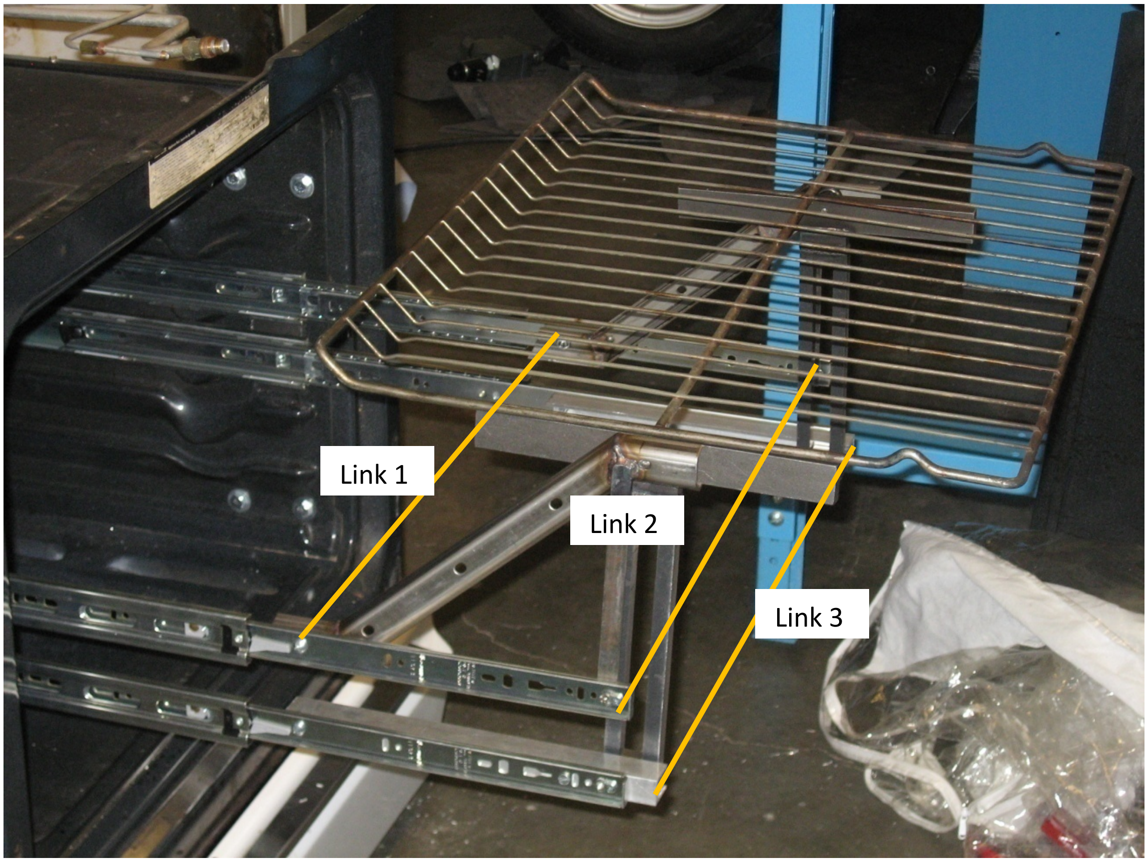
We measured the volume swept by the door as a quarter cylinder with radius equal to the door length and height equal to the door height. The door is 30" long and 21.5" tall which gives a swept volume of 6.45ft^3. This value is slightly larger than our target value, however the volume swept criteria was not as highly weighted as the projected floor area. The length of the door is 30" and the width is just 3". These values make the projected floor area 0.30 ft^2, which is much less than our target value of 4.2 ft^2. We used a force gauge to measure the forces required to open and close the door, as well as the force required to pull the rack out of the oven. Our modified side-swing door design required much less to open and close than traditional fold-down doors. We measured both the force to open and the force to close the door at 2 lb. We expected that the force to pull the rack out of the oven would be larger than our targeted test values, because our alpha design requires that the user lift the rack vertically, not just horizontally. We found that pulling the rack assembly out of the oven, without any load on the rack, was 13 lb, and with 15 lb. weights resting on the rack the force required was 24 lb. We measured the vertical rise of the oven rack with a tape measure, and found that the new height was 7" higher than the original. This rise of 7" was higher than our target value of 6", and brings the rack almost to the height of the stovetop.

Safety and Functionality Discussion

The project turned out very well, and was equally well received at the Design Expo, particularly by the occupational therapists and those in related professions who saw the immense practicality of such a design. As expected, the design significantly decreased the cumulative amount of motion required in operation of the unit. The design was also tested to 15lbs, and can take on greater load, were the original oven itself heavier (anything greater than 15lbs tips the oven, but the mechanisms were intact and structurally sound).

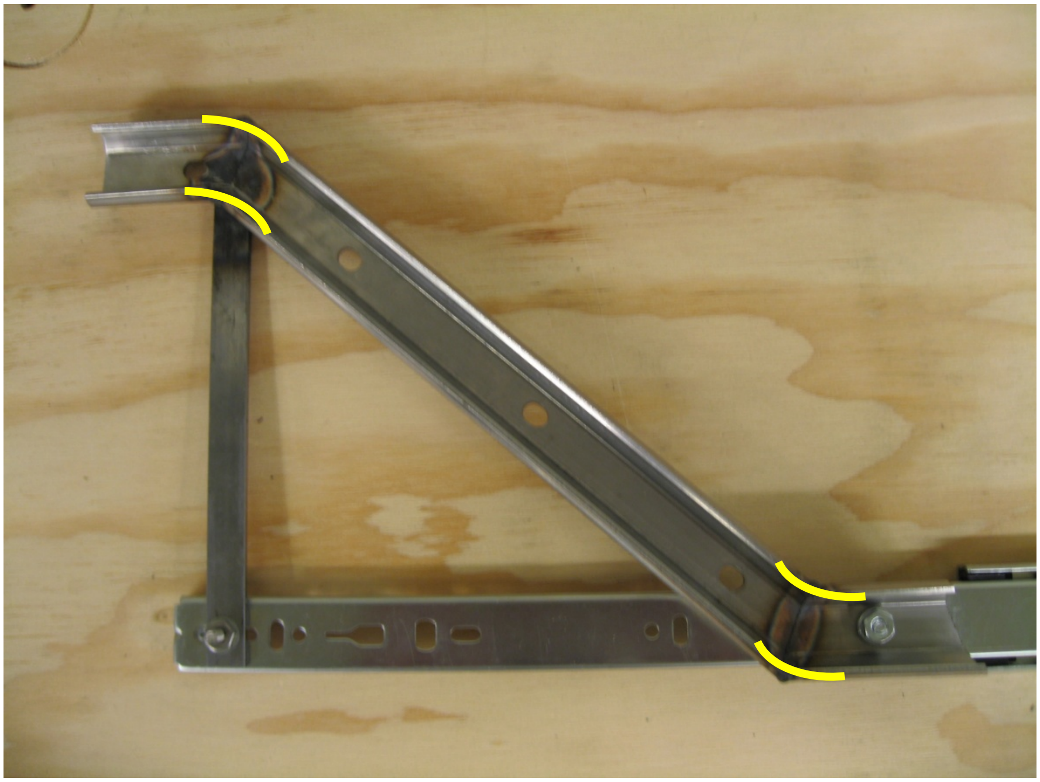
There of course are some improvements that can be made. Firstly, though the design intent was for the mechanisms on each side of the oven to move independently of each other, slight variations in how the load from the handle is applied (angle, or where the handle is applied to the rack), result in the mechanisms moving completely out of sync and result in the mechanisms binding. To rectify this, we would add rigid links between corresponding points of the mechanisms seen in Figure 35.

Figure 35: Linkages to be added to improve stability



Also, the angled features on the goosenecks would be changed to rounded edges that would also result in smoother motion in extraction and retraction of the racks as seen in Figure 36.

Figure 36: Corners to be rounded



Finally, were there to be significantly more time, the overall cause of reducing motion and effort put forth by the user would be aided by motorization of the mechanism. This was the original design intent but was dropped due to time and cost constraints. Using a motor would eliminate the need for the handle and would eliminate the associated motion and effort of the use of the handle in extracting and retracting the oven racks.

SimaPro Calculations

We used SimaPro to test simulate the environmental effects of our prototype. We compared values for stainless steel (420) and aluminum alloy (7075). For the simulation, we assumed 10 times more steel (by mass) than aluminum; 10lb of steel and 1lb of aluminum (4.5kg and 0.45kg, respectively). The figures below show that the aluminum alloy emits 7 times more raw materials (by mass) than the steel. This was mainly due to the water used during the processing of aluminum (separate from the water emission). The other 3 categories were approximately the same for both stainless steel 420 and aluminum alloy 7075.

Figure 37: Emission

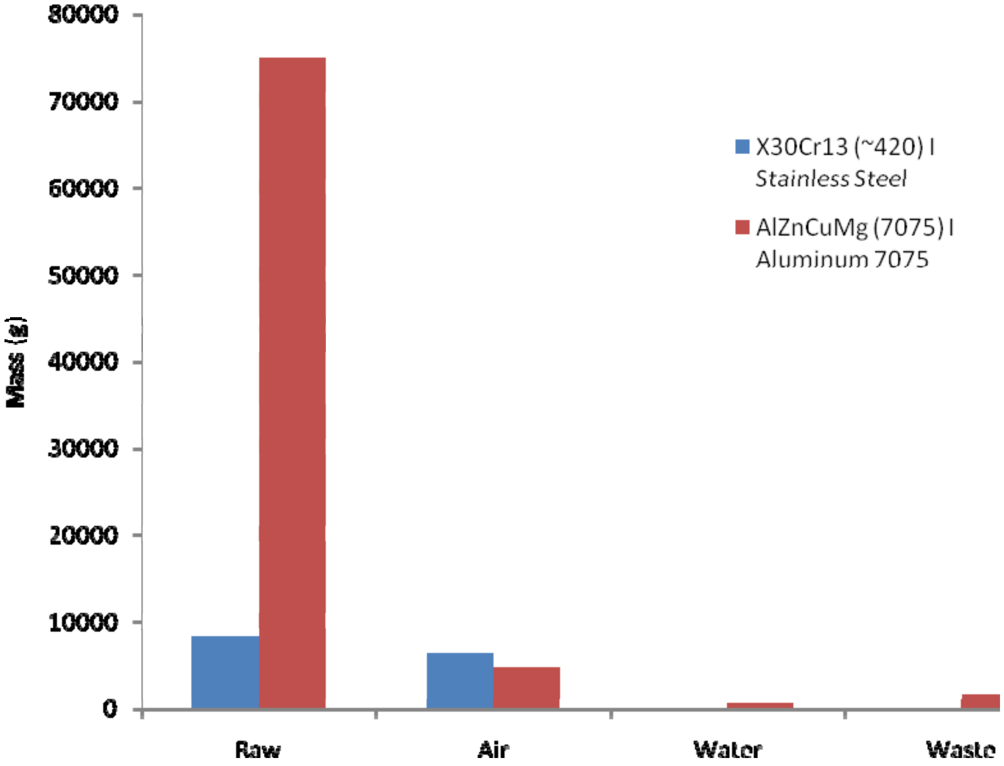
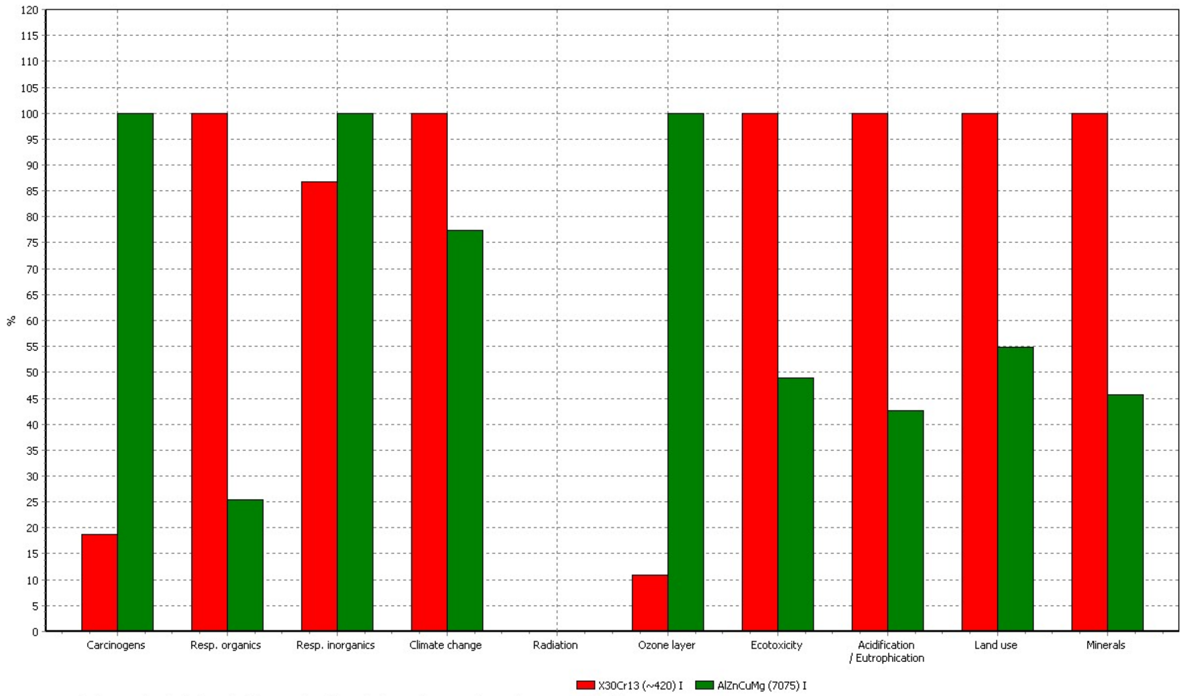
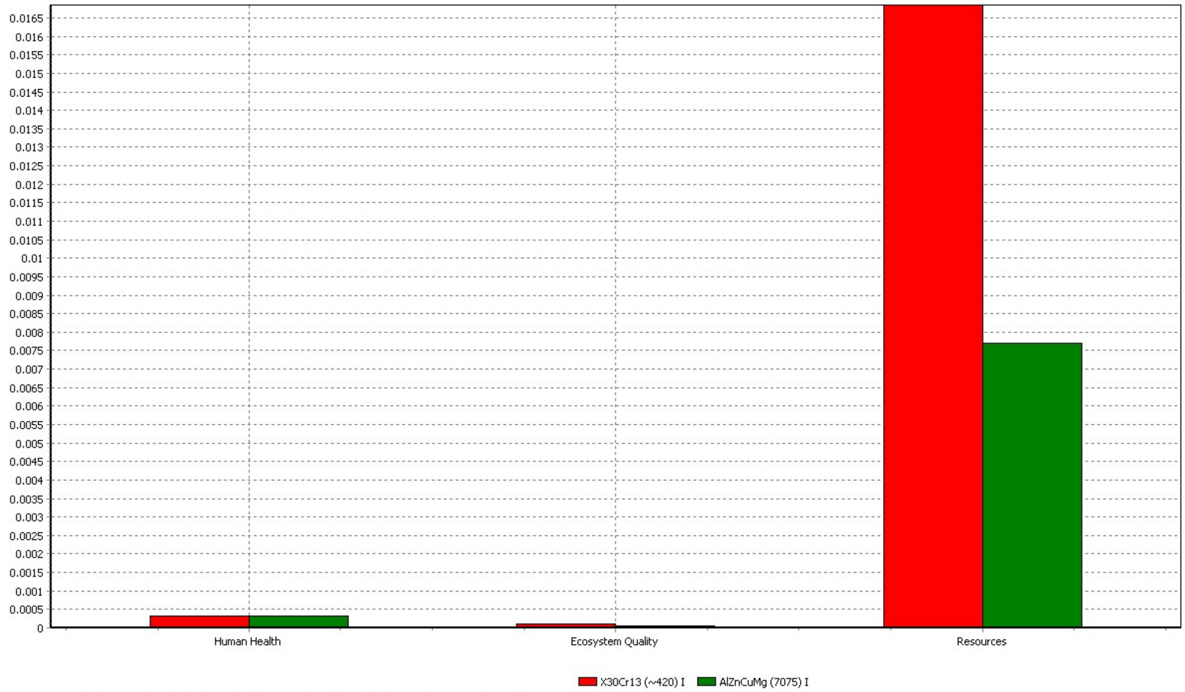


Figure 38: Characterization



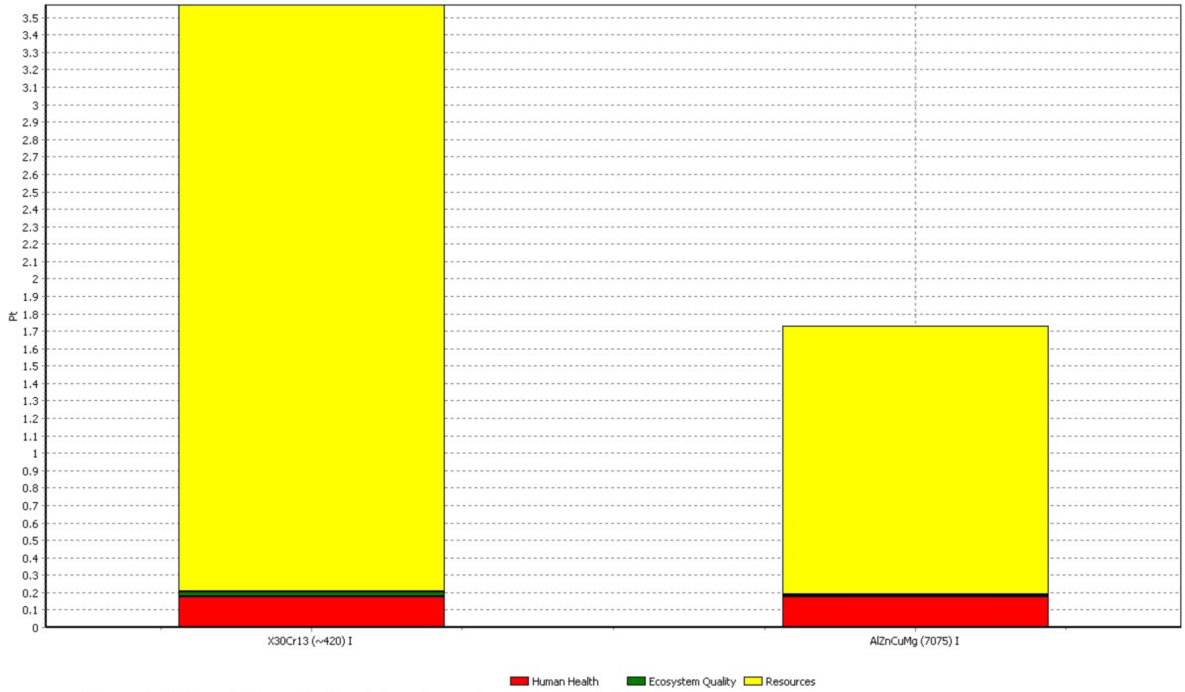
Comparing 4.5 kg 'X30Cr13 (~420) I' with 0.45 kg 'AlZnCuMg (7075) I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / characterization

Figure 39: Normalization



Comparing 4.5 kg 'X30Cr13 (~420) I' with 0.45 kg 'AlZnCuMg (7075) I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / normalization

Figure 40: Single Score



Comparing 4.5 kg 'X30Cr13 (~420) I' with 0.45 kg 'AlZnCuMg (7075) I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / single score

Conclusions

The world’s elderly population is increasing rapidly, and the U.S. is no exception with the baby boomer population quickly reaching retirement age. This creates a need for products designed with more of an eye to the needs of this growing population. We have identified such a possible product in an assistive oven door/rack, which would target to decrease the amount of bend at the waist the user would need to access food in the oven. A possible secondary target demographic for this product would be the wheelchair impaired.

With our engineering requirements and specifications we’ve quantified a number of criteria against which we can compare our design, such as the force required to open the door, the floor area the door occupies when open, height of rack travel etc. These criteria were quantified through benchmarking commercially available range units. Using quality function deployment, we prioritized these criteria, and found the three aforementioned criteria to be of top priority.

Following this activity, a number of concepts were developed, primarily categorized by the method of door opening. These were narrowed down to an alpha concept that we intend on moving forward with, using three criteria: safety (also considering force to operate), functionality (inclusive of rack travel and floor space occupied when open), and feasibility. The alpha concept has been fully developed and engineering analysis has been completed. Through validation we found that our concept works the way we planned, however there are minor adjustments that can be made to improve the design. Most importantly, we suggest that the left and right side sliders be connected by rigid bars, promoting uniform movement of the entire oven rack assembly.

Resources

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Kenneth Chin

Originally, I was born in Hong Kong and moved to the Glen Rock, NJ at the age of ten. At the age of seventeen, I decided to attend the university furthest away from home out of the handful that I applied to. The reasoning for this was for the engineering school. I decided on mechanical engineering because it combined my strongest suit, math, and my desire to use my creativity. Though, engineering is not the only way I employ my creativity. I enjoy playing and writing music on both the piano and the guitar. With becoming a rock star as a pipe dream, I see myself working somewhere in the engineering field and then going to graduate school in business administration in the future.

Lawrence Okwali

My name is Lawrence Okwali and I am a member of Team 17, working on the adjustable stove/oven. I’m currently in my 5th and final year in the mechanical engineering program at the University of Michigan. My passion for math and science is what led me to choose engineering, and I ventured all the way to UofM (I’m originally from Maryland) to learn more about that passion at one of the top-ranked universities in the country in that area. Experience wise, I have four co-op/internship rotations between Johnson Controls and the Toyota Technical Center. Outside of my academics I enjoy weightlifting, playing lacrosse (used to play on the UofM team), and volunteering with Dance Marathon.

Lucas Vanderpool

My name is Lucas Vanderpool, and I am a 5th year mechanical engineering student at the University of Michigan. I am originally from Jackson, MI, and have been wearing maize and blue since I was a couple days old. I chose to pursue mechanical engineering because of my success with math and science in grade school and high school, as well as my interest in the automotive industry. I am also pursuing a minor in German studies. I’ve studied German since 8th grade, and have been to Germany twice, most recently working for BMW in the summer of 2006. I have also had an internship with Volkswagen of America, previously located in Auburn Hills, MI, and another with Eaton Aerospace in Jackson, MI. I enjoy spending my time watching and playing sports, reading, and traveling when I can.

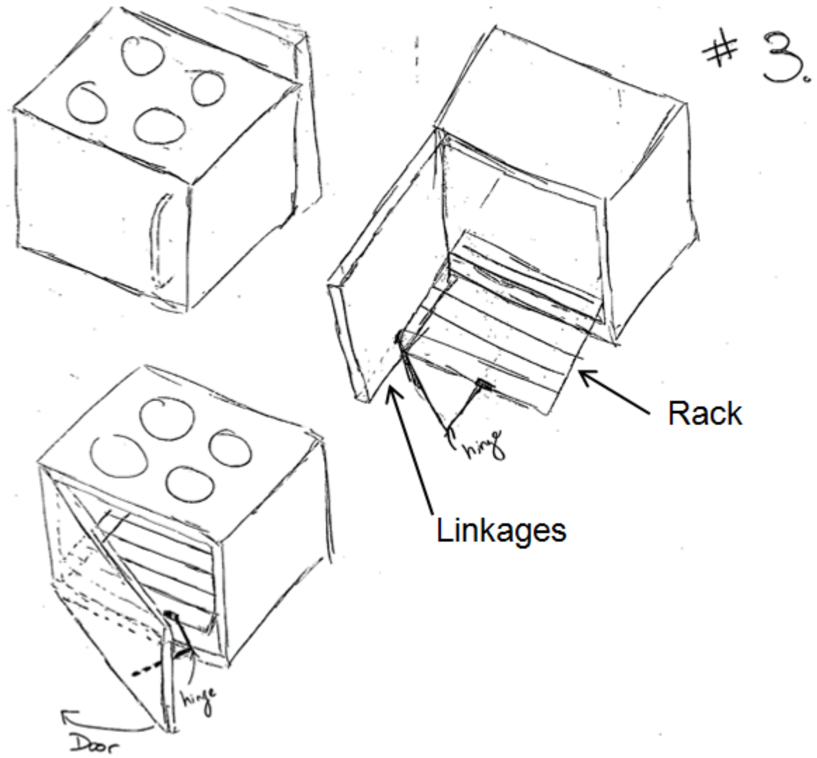
Matt Winowski

I’m from Sterling Heights, MI, located about an hour northeast of Ann Arbor. My interest in mechanical engineering has been sparked from a love of making other people’s lives and my own easier to live through enhancing tasks done at home, work, and leisure. My background supports this in that I’ve worked with Muscular Dystrophy and Cerebral Palsy patients for the past 10 years. This work has led to many close friendships and the bettering of life for many. One example of this is my work with my best friend, who has Muscular Dystrophy and uses an electric wheelchair as his mobility, to make wheelchair modifications such as stereo systems using boxed speakers and car stereos, neon lights, an intercooled computer case, and a trailer hitch with accompanying rolling cart to transport his assistants or heavy objects. My future plans are to practice mechanical engineering in either the medical or military industry but never lose the friendships and connections to the amazing people I’ve met through high school and college.

APPENDIX A: Scored Concepts

Concept 3:

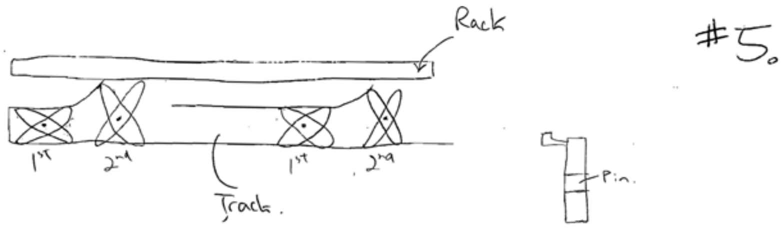
This concept is an oven door and rack design that links opening motion of the door to the extension of the racks by a hinged linkage. A link is welded to the bottom of the door in the same horizontal plane as the rack. This link is hinged to another link that connects to the front of the rack, thus linking the motion of the oven door to extension of the racks. This concept presents a simple solution to the user being required to insert their hands into a hot oven to place or extract food. However, it lacks a lift feature, which still requires the user to bend over just as much to access the food. The concept was rated a 3 for safety because it will require considerable force to operate. For functionality, the lack of rack lift requires the user to bend at the waist more to access the food, and for this reason was rated a 3. Due to the difficulty of containing the door to rack linkages, the design was scored a 4 on the criteria of feasibility. This concept has a rating of 10.



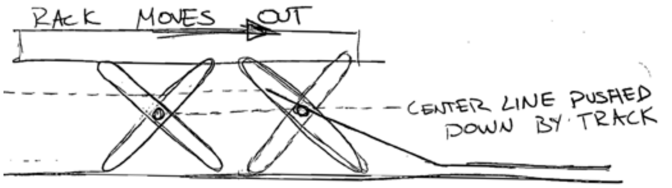
Concept 5:

This concept is strictly a concept pertaining to the rack assembly. We tried to come up with a simple idea that would allow for the rack to move out of the oven, as well as rise. The idea was that the rack would rest on pins located in the middle of two linkages forming an 'X'. This "scissors" of linkages would be connected by springs, and would move in and out of a telescoping track. The rack would telescope outwards, and after reaching a certain point, the scissors would open up, thus raising the rack.

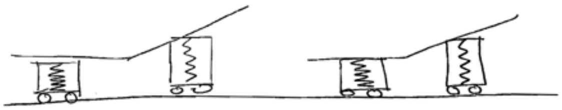
Concept 5 received a 5 and 4 on our rankings of safety and functionality, respectively. However, it scored a 1 on feasibility. We don't know a lot about how we would make the scissors effect work, meaning this would be time consuming to manufacture. We also don't think it is feasible, because it is not likely that any spring would be able to withstand the high temperatures of an oven over many years of use. The total score for this concept is 10.



OR

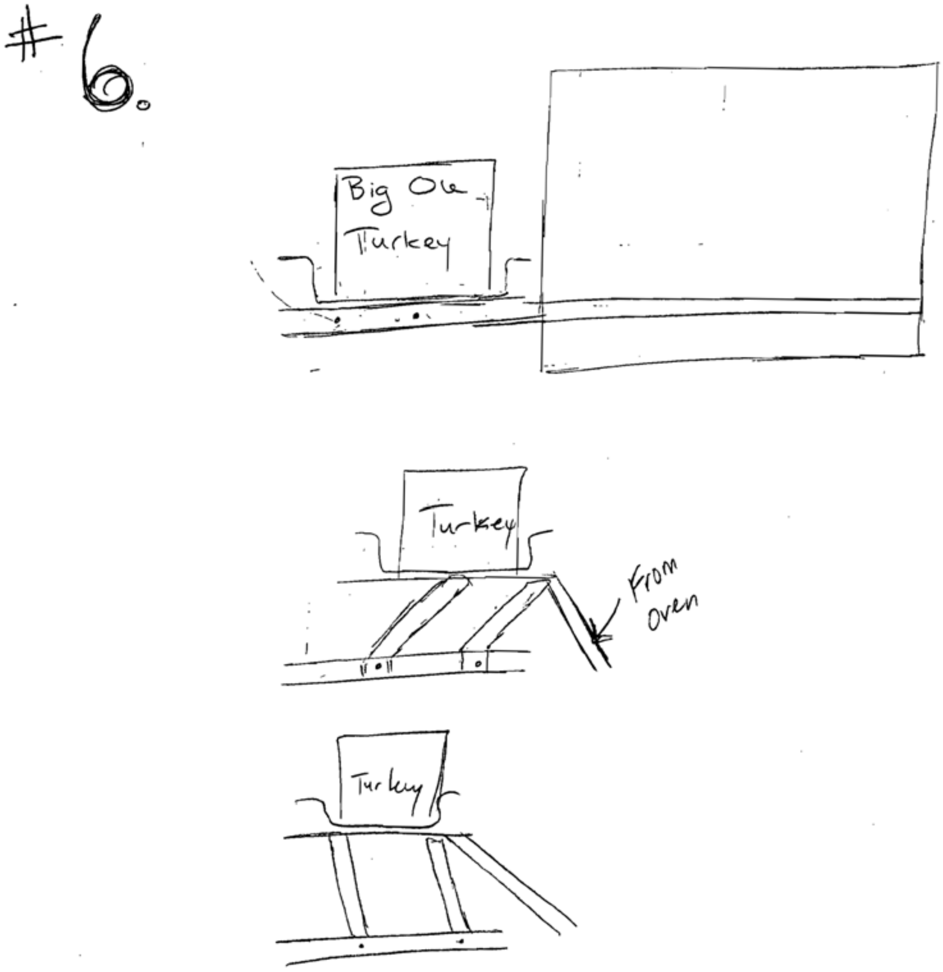


OR



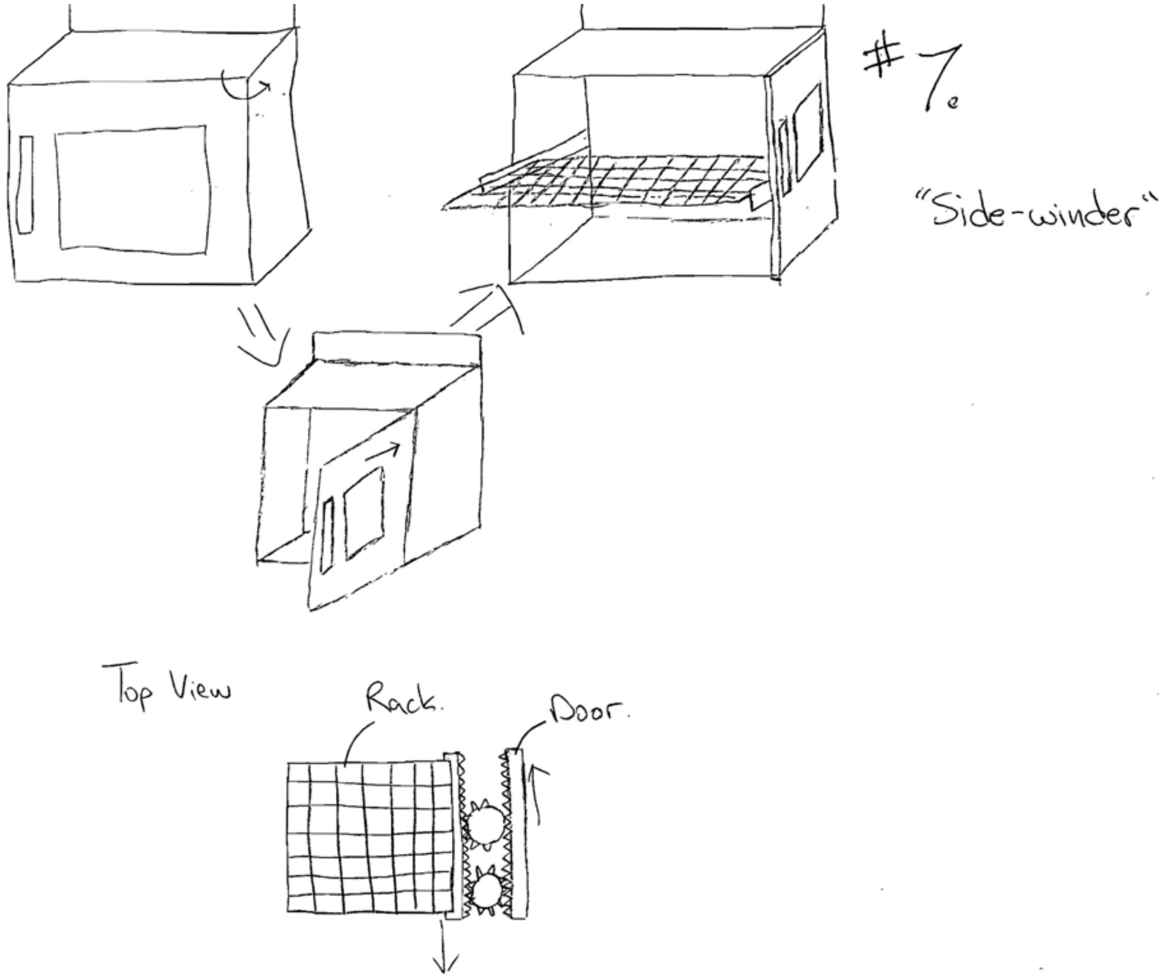
Concept 6:

Concept 6 is purely a linkage concept for how to extend and lift the racks. The idea is to link the motion of opening the door (which could open downwards) to a four bar linkage that supports the weight of the rack and its load via a lever that would exert an upward force on the rack. This force not only lifts the food but due to the four-bar linkage, extends the rack forward. This linkage design scored a 2.5 for safety due to the combination of having to open the door downwards while having food coming out at the user. For functionality, the design scored a 4 due to the fact that it incorporated a lift function to the rack, decreasing the amount of bend at the waist of the user. For the relative simplicity of creating a four bar linkage system, the design scored a 4 on feasibility, which brought it to total score of 10.5.



Concept 7:

Concept 7 is a design of a side-swinging door that pairs the movement of the door with the rack coming out. The door is to swing sideways and pushed into the oven to spin the gear. As the gear spins, it brings the rack out of the oven. The downside of this design is a functionality and a safety issue. It does not rise up to decrease the distance a person has to reach to get to the rack. The safety issue is that as the person is pushing the door in towards the wall, the hot food is coming outwards at them, most likely causing burns. The manufacturing of this would also be difficult. We would have to open up one side of the oven to allow the door to slide in and fit the gear within the space. Reflected ratings are 2, 3 and 3.5 for safety, functionality, and feasibility respectively, yielding a total rating of 8.5, relatively low.

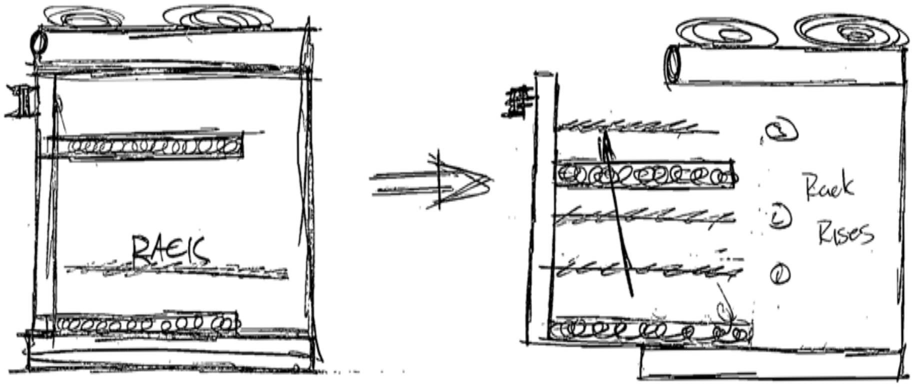


Concept 8:

Concept 8 is mostly a new idea for the door opening, and does not have a well developed rack system. Our idea was that the door could remain vertical, and pull out much like a drawer. There would be no bottom or sides to the ‘drawer’, rather the door would rest on four telescoping tracks. We thought we could develop a linkage system that would raise the rack as the door opened.

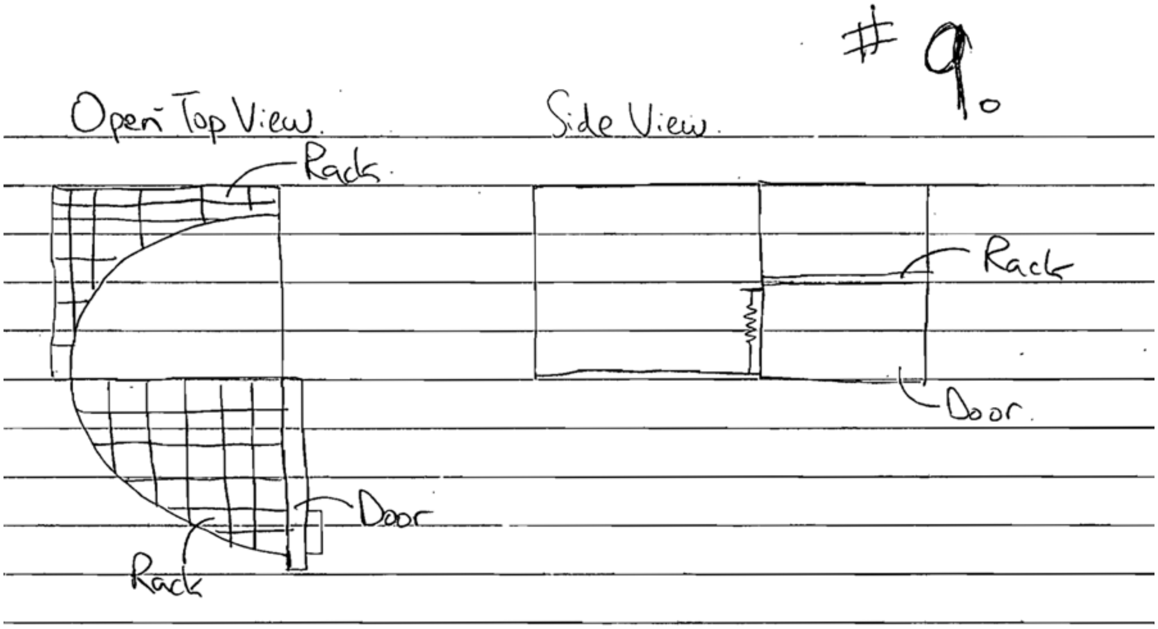
We never got around to designing a rack to fit this concept, because we thought the weight of the door would create too much torque on the tracks. We also concluded that this design was dangerous because a person could grab onto the hot tracks, and didn’t meet our requirement of minimizing the occupied floor area. We gave this concept a 3 for both safety and functionality, and a 2 for both feasibility, yielding a total rating of 8, relatively low.

#8.



Concept 9:

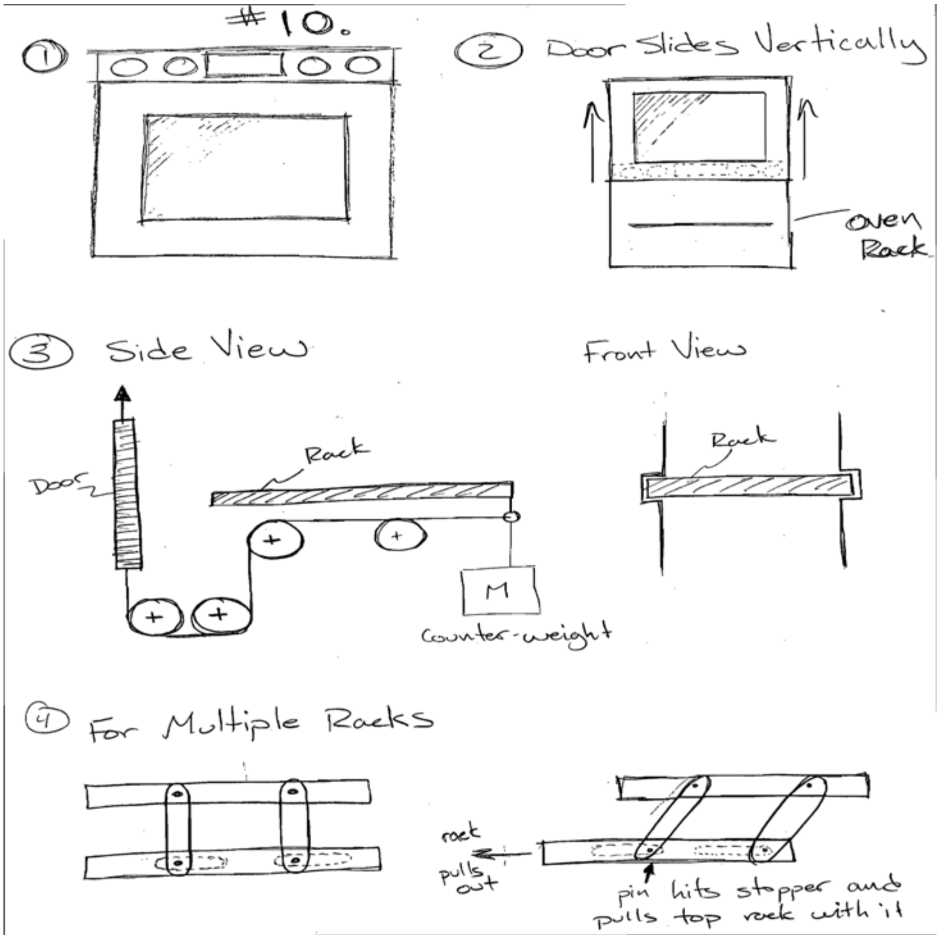
This concept is a side-swinging door with part of the rack attached to the door. The regular rectangular rack is cut into 2 pieces, one piece being the quarter circle that is attached to the door and the other being the remainder of the rack attached to the inside of the oven. The two racks are attached to each other by a track that can slide to allow for opening and closing of the oven. Supports for the quarter circle are its attachment to the door and the rolling contact it has with the rack attached to the oven. The rack attached to the oven is to be supported on 3 corners. The safety for this is very high, 4, because the rack is not a different motion that is coming out at the person. Functionality, 3, of the rack is a problem because the rack does not move up, increasing the distance to reach. Feasibility, 2.5, of this would be tough due to the strange shapes of the racks, the placements of the supports, and attaching the rack to the door. The total rating for this concept is 9.5.



Concept 10:

Concept 10 has a vertical sliding door, as well as its own rack design. The door moves out from the stove, and then slides vertically out of the way of the oven opening. This minimizes the volume swept, as well as the occupied floor area by the door. As the door lifts it pulls on a cable, which through a series of pulleys will move the rack out of the oven. If we wanted to utilize this concept for multiple racks, the bottom rack would be linked to the top rack, and as they pulled out they would offset much like a toolbox or tackle box.

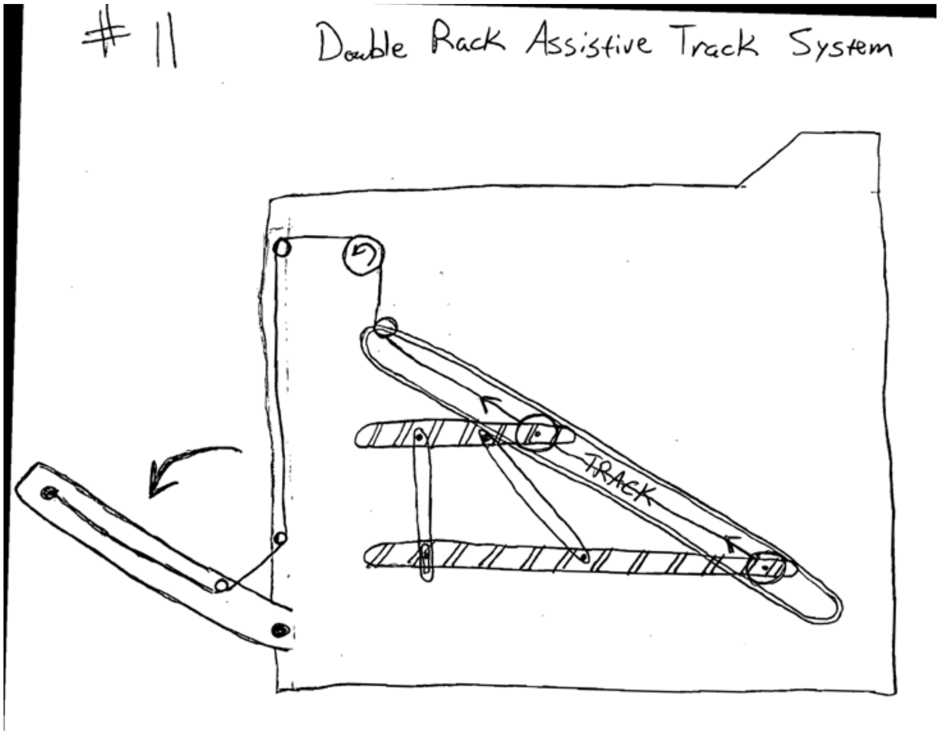
We found a couple problems with this design. First, we gave it a ranking of 1 for safety because the door would be hot, but also because the food would potentially hit the consumer in the stomach as the door lifts. Secondly, we found that it would not be easy to manufacture a pulley system with a cable that could withstand the heat, and we thought it would be very difficult to use the cable system to close the oven. Our concept drawing also shows a counter-weight, which we do not know how to implement. This concept scored a 2 for feasibility, and it received a 3 for functionality because the rack would move out and up, yielding the lowest relative total rating of 6.



Concept 11:

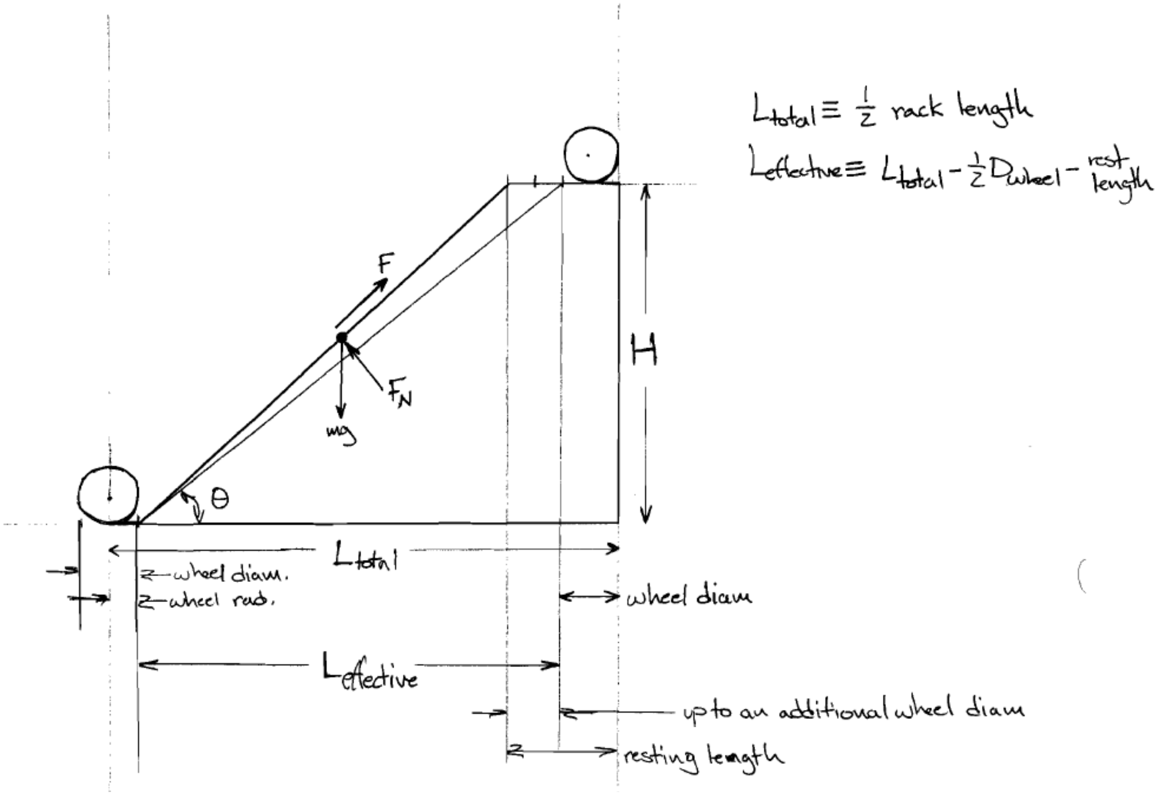
Concept 11 is a pulley oven system design. It incorporates a bottom-hinged door and a pulley system that is attached to the door and track wheels of one rack. The supporting links connecting the racks keep them horizontal as they rise. The ends of the racks have wheels that sit in diagonal tracks on either side of the oven. The opening of the door pulls on the racks along the diagonal track.

Due to the intricate weaving of wire and associated continuous thermal expansion and contraction of the wire and pulley wheels, we gave a safety rating of 3. The racks would simultaneously come out laterally and rise but the design uses a bottom hinged door that takes up a lot of projected floor area and is difficult to close, tending us towards an functionality rating of 4. The design and manufacturing of this system is very difficult and time consuming as we'd need to consider the how exactly the pulleys interact as well as account for thermal expansion and possible failure after cycling the heat over so many years of use. For these reasons, we gave concept 11 a feasibility rating of 1.5. The total concept 11 rating is 8.5, relatively low.



APPENDIX B: Hand Calculations

Force to lift rack up slope
(drawing):



$$\theta = \tan^{-1} \frac{H}{L_{effective}}$$

$$F = mg * \sin \theta$$

Force to lift data (Microsoft Excel 2007):

🟧 defined
🟦 determined

assume load = 40lb mg = 40
assume wheel diam = 1in d = 1
assume rack length = 18in L_rack = 18

resting length on top = 2*d

L_tot* (in)	l_eff** (in)	H (in)	Theta (deg)	F (lb)	Percent of load
9	6.5	6	42.7	27	68%

L_tot* (in)	l_eff** (in)	Theta (deg)	H (in)	F (lb)	Percent of load
9	6.5	0	0.0	0	0%
		5	0.6	3	9%
		10	1.1	7	17%
		15	1.7	10	26%
		20	2.4	14	34%
		25	3.0	17	42%
		30	3.8	20	50%
		35	4.6	23	57%
		40	5.5	26	64%
		45	6.5	28	71%
		50	7.7	31	77%
		55	9.3	33	82%
		60	11.3	35	87%
		65	13.9	36	91%
		70	17.9	38	94%
		75	24.3	39	97%
		80	36.9	39	98%
		85	74.3	40	100%

resting length on top = 1.5*d

L_tot* (in)	l_eff** (in)	H (in)	Theta (deg)	F (lb)		Percent of load
9	7	6	40.6	26	26	65%

L_tot* (in)	l_eff** (in)	Theta (deg)	H (in)	F (lb)	Percent of load
9	7	0	0.0	0	0%
		5	0.6	3	9%
		10	1.2	7	17%
		15	1.9	10	26%
		20	2.5	14	34%
		25	3.3	17	42%
		30	4.0	20	50%
		35	4.9	23	57%
		40	5.9	26	64%
		45	7.0	28	71%
		50	8.3	31	77%
		55	10.0	33	82%
		60	12.1	35	87%
		65	15.0	36	91%
		70	19.2	38	94%
		75	26.1	39	97%
		80	39.7	39	98%
		85	80.0	40	100%

resting length on top = d

L_tot* (in)	l_eff** (in)	H (in)	Theta (deg	F (lb)	Percent of load
9	7.5	6	38.7	25	62%

L_tot* (in)	l_eff** (in)	Theta (deg)	H (in)	F (lb)	Percent of load
9	7.5	0	0.0	0	0%
		5	0.7	3	9%
		10	1.3	7	17%
		15	2.0	10	26%
		20	2.7	14	34%
		25	3.5	17	42%
		30	4.3	20	50%
		35	5.3	23	57%
		40	6.3	26	64%
		45	7.5	28	71%
		50	8.9	31	77%
		55	10.7	33	82%
		60	13.0	35	87%
		65	16.1	36	91%
		70	20.6	38	94%
		75	28.0	39	97%
		80	42.5	39	98%
		85	85.7	40	100%

*(L_tot) is definied as: half the rack length

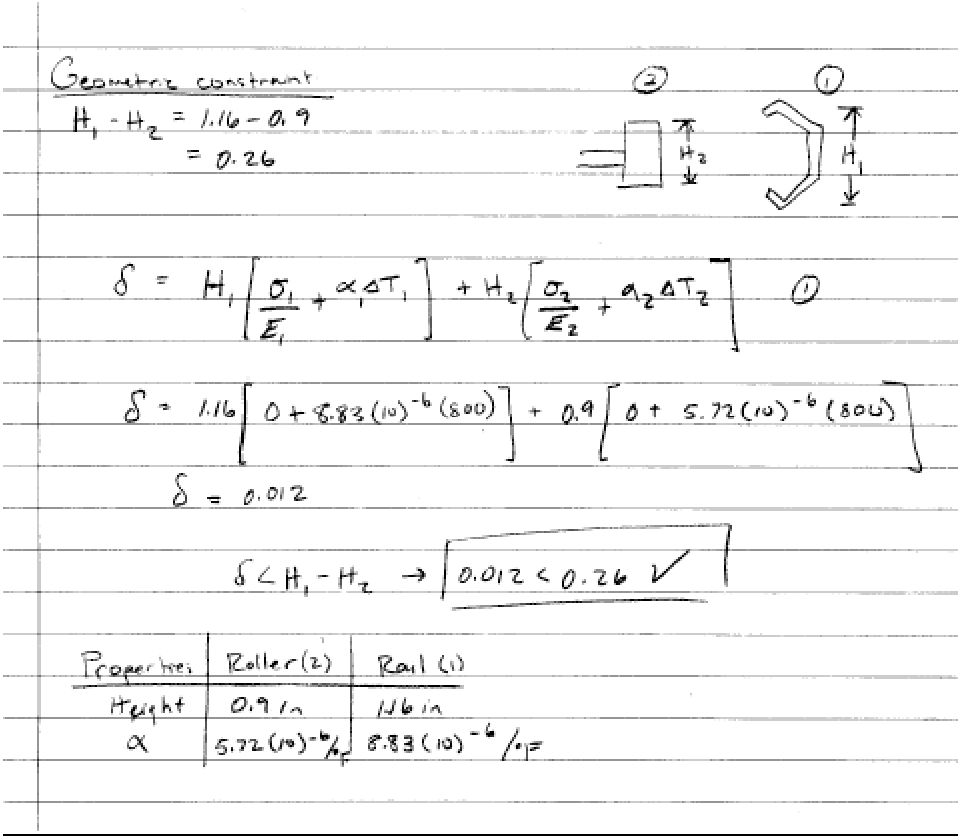
*(l_eff) is definied as: (L_tot) minus 0.5 diameters of the wheel (for the bottom resting spot) minus the resting length on top

__Code used to solve force matrix (MATLAB):__

```
% gauss.m
% Matt Winowski   ME 400   10-5-2008

function x = gauss(A)

% gauss takes a user input augmented matrix, A, and performs scaling and
% partial pivotting to solve the matrix of equations using gaussian
% elimination.

m = size(A,1);
L = eye(m);                          % create identity L matrix
U = eye(m);                          % create identity U matrix

for k = 1:m                          % Scale all rows
       [temp,s] = scale(A,k);
       A(k,:) = temp(k,:);               % Set as the new A matrix
end

for j = 1:((m-1))                     % performing scaling for all
                                 % rows and partial pivoting
                                 % for all but the last row

   [A,p,num] = partialPivoting(A,j);      % Perform partial pivoting
                                 % on the current row

   for i = (j+1):m                    % zero the values below pivot

       w = A(i,j);

       if p*w > 0                     % determining whether the factor     must be added or subtracted
          A(i,:) = A(i,:)-((w/p).*A(j,:));
          L(i,j) = w/p;               % account for scaled factor for L matrix
       else A(i,:) = A(i,:)+((w/p).*A(j,:));
          L(i,j) = -w/p;              % account for scaled factor for L matrix
       end
   end
end

U = A;                               % the gaussian elimination is complete, leaving the U matrix

x = zeros(m,1);
b = A(:,(m+1));                        % set the b matrix from the augmented A matrix

x(m,1) = b(m) / U(m,m);                   % solve the last x value

for h = 2 : m                        % resetting t and temp2 for next x value solved
   t = m + 1 - h;
   temp2 = 0;
   for g = 1 : (h-1)                  % simplify left side of equation
      temp2 = temp2 + U(t,(m+1-g)) * x(m+1-g);
   end
   x(t) = (b(t) - temp2) / U(t,t);        % subtract from right side of
end                                % equation and divide by matrix
```

% value of x value being solved for

Thermal Expansion Calculation



Geometric constraint

$H_1 - H_2 = 1.16 - 0.9$

$= 0.26$

$$\delta = H_1\left[\frac{\sigma_1}{E_1} + \alpha_1 \Delta T_1\right] + H_2\left[\frac{\sigma_2}{E_2} + a_2 \Delta T_2\right] \quad ①$$

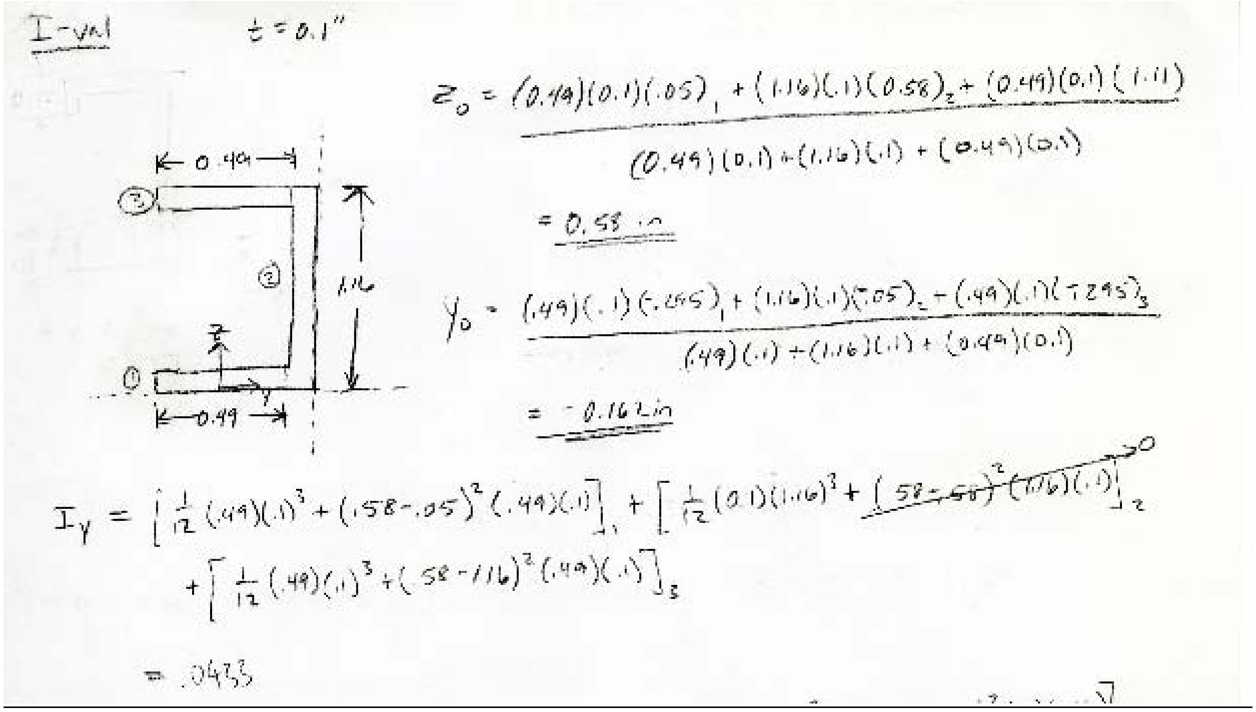
$$\delta = 1.16\left[0 + 8.83(10)^{-6}(800)\right] + 0.9\left[0 + 5.72(10)^{-6}(800)\right]$$

$\delta = 0.012$

$$\delta < H_1 - H_2 \rightarrow \boxed{0.012 < 0.26 \checkmark}$$

Properties	Roller (2)	Rail (1)
Height	0.9 in	1.16 in
α	$5.72(10)^{-6}$ /°F	$8.83(10)^{-6}$ /°F

Second Moment of Area Calculation



I-val t = 0.1"

$$z_0 = \frac{(0.49)(0.1)(.05)_1 + (1.16)(.1)(0.58)_2 + (0.49)(0.1)(1.11)}{(0.49)(0.1) + (1.16)(.1) + (0.49)(0.1)}$$

$$= \underline{\underline{0.58 \text{ in}}}$$

$$y_0 = \frac{(.49)(.1)(-.295)_1 + (1.16)(.1)(-.05)_2 + (.49)(.1)(-.295)_3}{(.49)(.1) + (1.16)(.1) + (0.49)(0.1)}$$

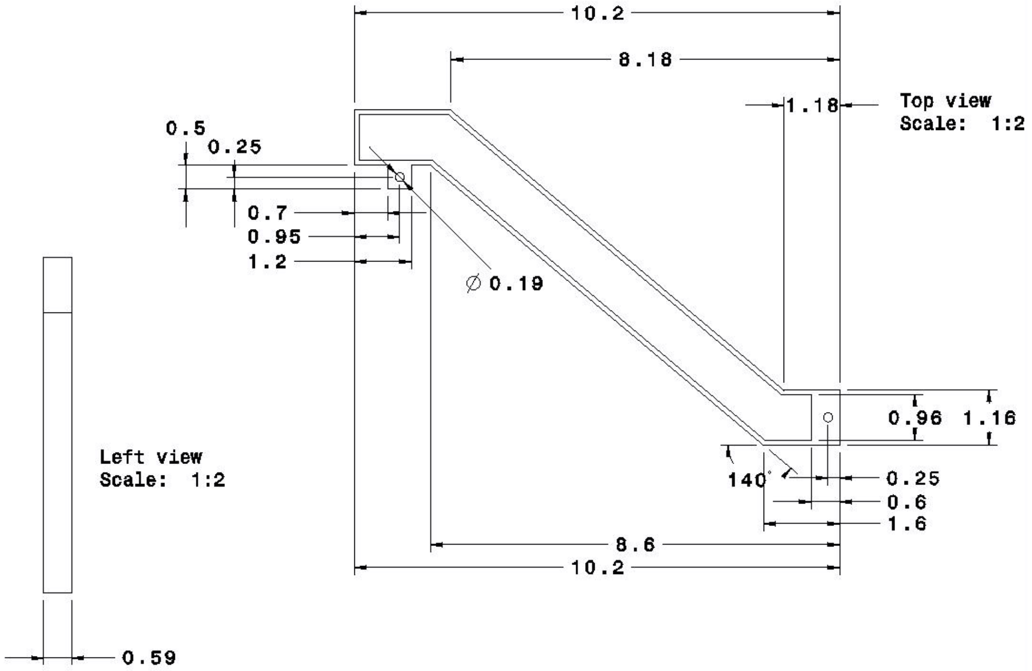
$$= \underline{\underline{-0.162 \text{ in}}}$$

$$I_y = \left[\frac{1}{12}(.49)(.1)^3 + (.58-.05)^2(.49)(.1)\right]_1 + \left[\frac{1}{12}(0.1)(1.16)^3 + \cancelto{0}{(.58-.58)^2(1.16)(.1)}\right]_2$$
$$+ \left[\frac{1}{12}(.49)(.1)^3 + (.58-1.16)^2(.49)(.1)\right]_3$$

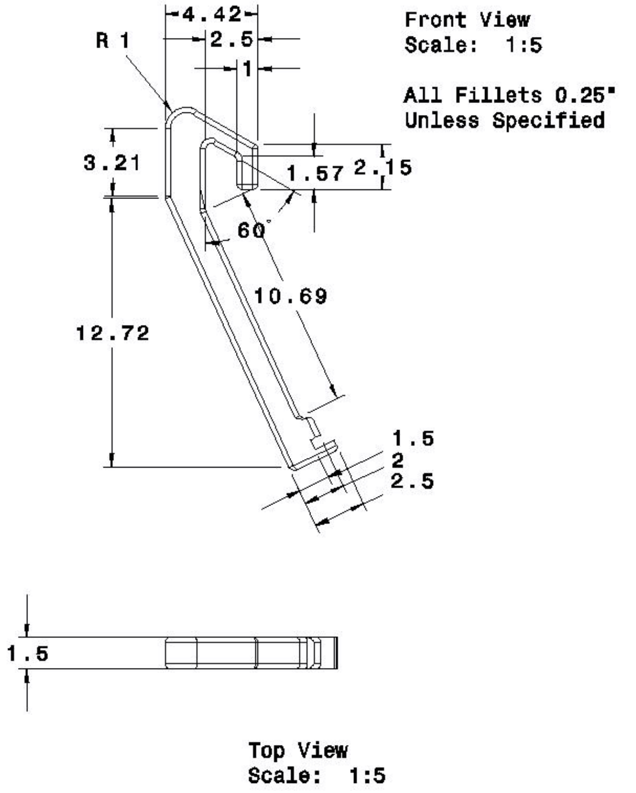
$$= .0433$$

APPENDIX C: Engineering Drawings

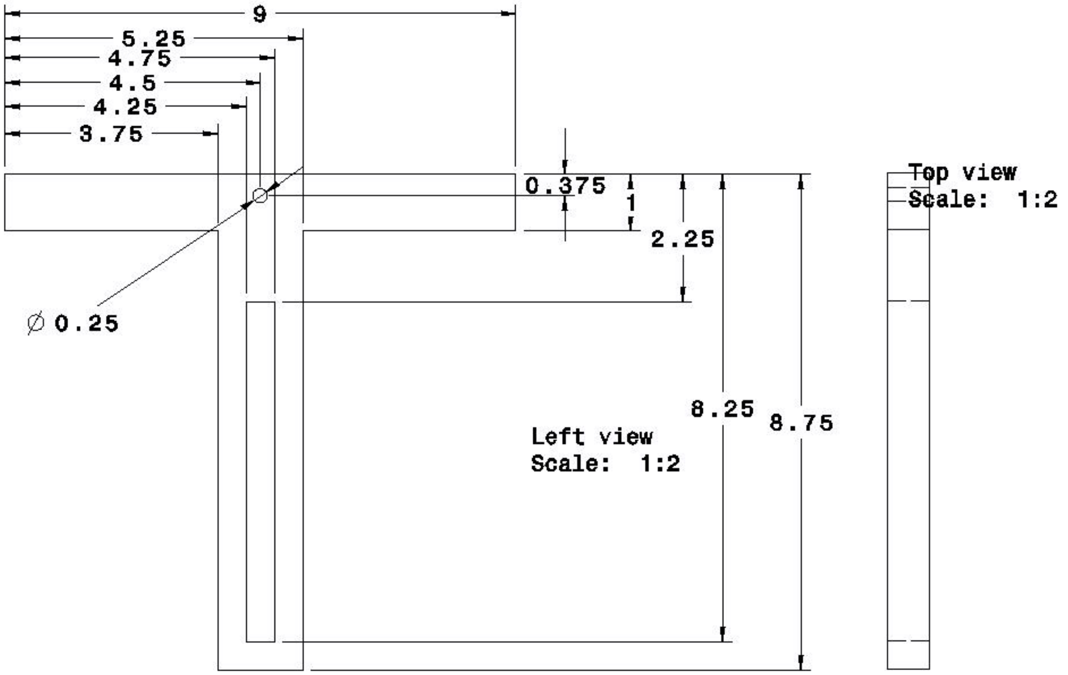
“Goose Neck” – Vertical Rise Track



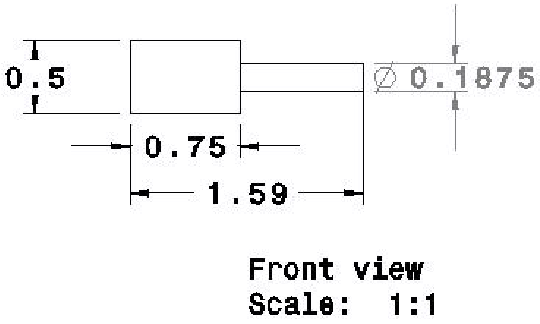
Old Handle

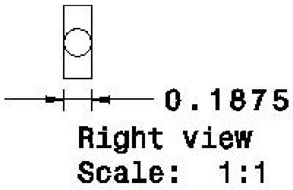


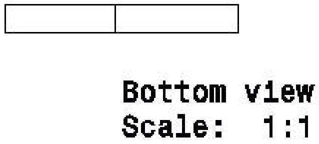
'T-bar' member



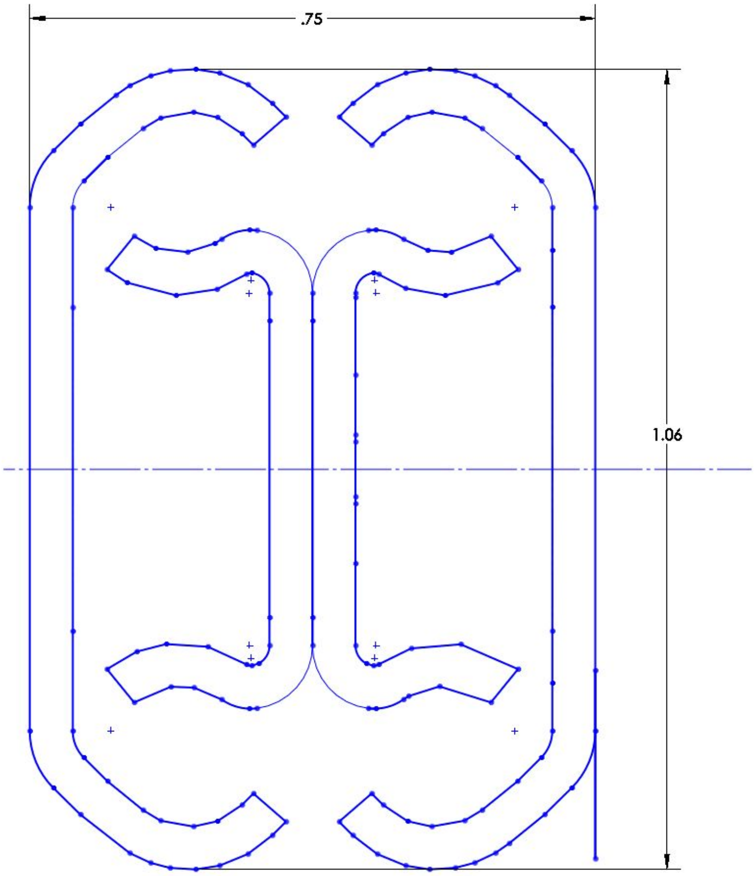
Square Pin





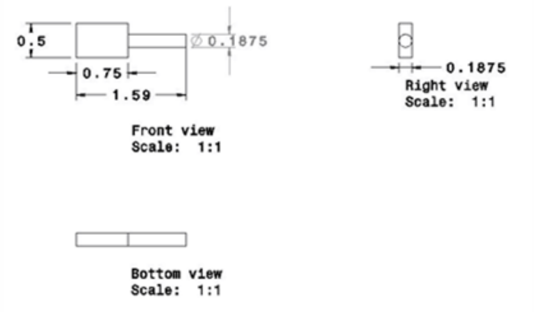


Accuride’s actual oven cross-section dimensions provided by Frank Gerk, National Sales Manager of Accuride International’s Appliance Market.

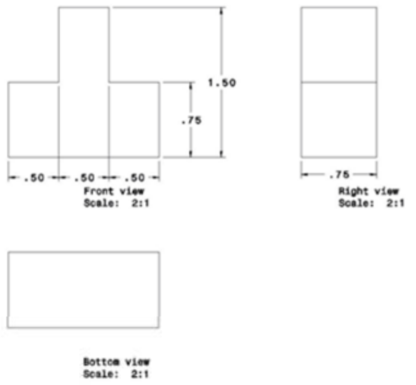


Engineering Change on square pin

Was:



Is:

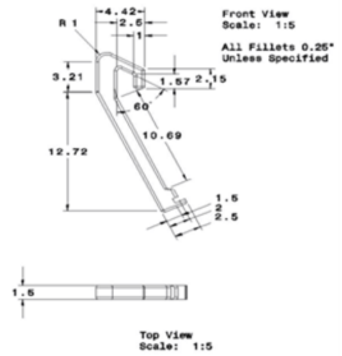


Notes:
Redesigned square pin so it allows the whole mechanism to slide inside the aluminum track

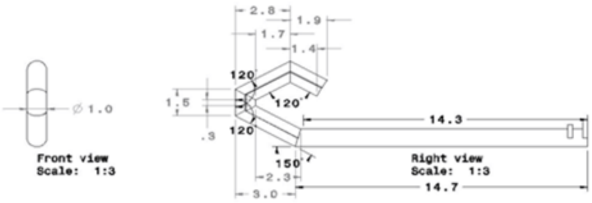
The Accubakers	
Project: The Elebake Oven	
Ref Drawing: Square Pin	
Engineer: KC, LO, LV, MW	11/24/08
Proj Mgr: D. Johnson	11/25/08
Sponsor: A. Shih	11/25/08

Engineering Change on Handle

Was:



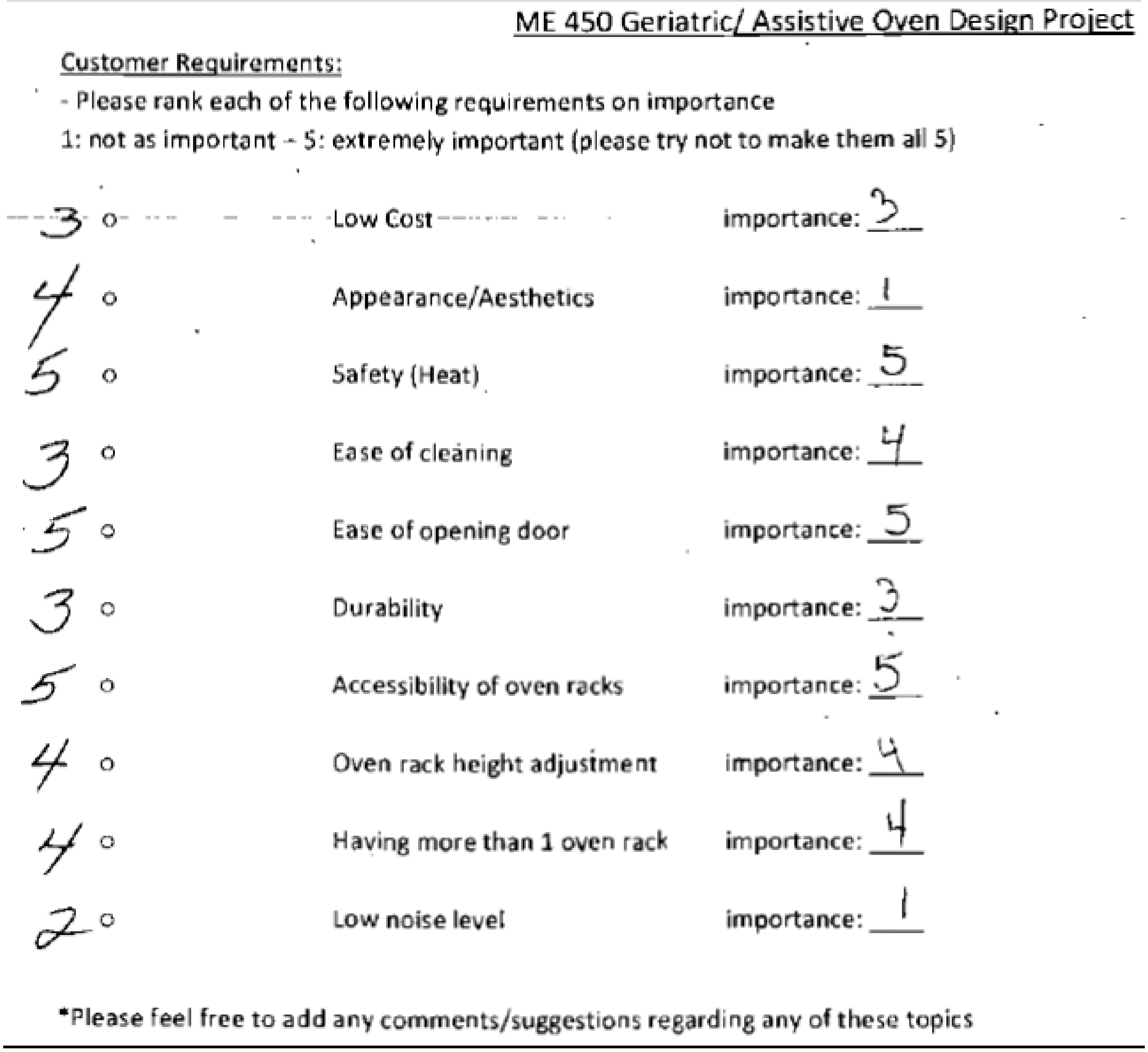
Is:



Notes:
Redesigned handle to make it more ergonomic by making it out of bar stock and easier to manufacture by replacing edge round with chamfer

The Accubakers	
Project: The Elebake Oven	
Ref Drawing: Handle	
Engineer: KC, LO, LV, MW	11/24/08
Proj Mgr: D. Johnson	11/25/08
Sponsor: A. Shih	11/25/08

APPENDIX D: OCCUPATIONAL THERAPIST SURVEYS



ME 450 Geriatric/ Assistive Oven Design Project

Customer Requirements:

- Please rank each of the following requirements on importance

1: not as important - 5: extremely important (please try not to make them all 5)

3 ○ Low Cost importance: 3
4 ○ Appearance/Aesthetics importance: 1
5 ○ Safety (Heat) importance: 5
3 ○ Ease of cleaning importance: 4
5 ○ Ease of opening door importance: 5
3 ○ Durability importance: 3
5 ○ Accessibility of oven racks importance: 5
4 ○ Oven rack height adjustment importance: 4
4 ○ Having more than 1 oven rack importance: 4
2 ○ Low noise level importance: 1

*Please feel free to add any comments/suggestions regarding any of these topics

APPENDIX E: BILL OF MATERIALS

Quantity	Part Description	Purchased From	Part Number	Price (each)	Price (Total)
2	Track Rollers	McMaster Carr*	60135K51	$36.00	$72.00
3	1-ft long Track	McMaster Carr*	60135K52	$34.00	$102.00
2	Accuride Drawer Slides	McMaster Carr*	1057A45	$21.00	$42.00
1	Plasti-Dip	Home Depot	N/A	$7.00	$7.00
2	Hinges	McMaster Carr*	1264A12	$21.00	$42.00
	Steel Stock	University of Michigan	N/A	$0.00	$0.00
	Aluminum Stock	University of Michigan	N/A	$0.00	$0.00
	3/16" Bolts	University of Michigan	N/A	$0.00	$0.00
				Total =	$265.00

* http://www.mcmaster.com