MEEG 401: Senior Design

Automated Solar Panel Frame Attachment Mechanism
Final Report

University of Delaware Design Team
Andy Drysdale
Wilson Steele
Tony Warrington
Matt Boyd

AstroPower, Inc.
Dane Holland
Steve Ressler
Pete Gill
Mike Conway
Executive Summary

The problem to be considered is the improvement of AstroPower’s manufacturing process through the automation of the assembly step in which aluminum frame rails are attached to the solar power laminate. Our customers voiced a number of constraints and interests in the final product that determined both the nature of the concept developed and the criteria we used to test and evaluate it later.

We formulated AstroPower’s concerns into a list of wants and needs, and prioritized them by AstroPower’s importance. The most crucial considerations were shown to be the throughput rate of the finished mechanism and its ability to avoid damaging the panels during the attachment process. These wants were used to synthesize related metrics, or measurable features, for judging the effectiveness of potential concepts.

The concept we chose for further development incorporated the following features: magazines that held vertical stacks of presorted frame rails, three-position levers that could catch the dispensed rails, align them, and then drop out of the way for the attachment process, and a rotating table that allows two sides of the laminate to be free of machinery. The key element of the concept is that two frame rails are attached together into an “L-frame” shape before they are pressed onto the laminate instead of pressing each rail on individually.

We were able to test and evaluate several aspects of this system in some depth. The design appears feasible and with some further design work should provide a great deal of utility for AstroPower in its attempts to increase its manufacturing efficiency. Results of our testing, analysis and evaluation of the design, and recommendations for a path forward are presented in detail.
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Introduction

This is Team 2’s final report for the MEEG 401 Senior Design Project. It details the work completed for our sponsor, AstroPower, Inc., on the automation of a solar panel framing process.

AstroPower, manufacturers of various sizes of solar panels and related products, desires to increase the efficiency of its solar panel production process. Specifically, they wish to automate the assembly step in which aluminum frame rails are attached to the unframed panel, or laminate. Frames come in the form of two sides for two individual rails of varying sizes that are fitted together with screws and pressed onto the laminate. The panel’s frame provides extra strength and rigidity to the laminate so that the completed panel has a longer operational life and resists some types of damage. Also, AstroPower attaches its frames manually in a process that is both time-intensive and involves a significant potential for accidental damage. This leads to both increased labor payroll for AstroPower and lower revenues from the sale of damaged panels.

Therefore, a solution is sought in which a machine, capable of being integrated into the manufacturing process already present, is designed so as to accept the laminates from a previous station, attach the frame rails properly, screw the frame securely together, and export the panel to the next station without incurring damage to the panel or requiring a significant amount of operator attention. The machine must be safe to
operate, cost-effective, within a specific footprint, and capable of handling several different panel sizes without difficulty or excessive downtime for changeover. These critical features served to constrain and focus our conceptual development, as explained later.

The purpose of this report is: to communicate the design process we used to identify relevant customers, their wants and constraints, justify the target values we produced from those wants for various features of the concept, thoroughly explain the developed concept, its subsystems, and how it operates within the larger manufacturing process, and explain how we analyzed the acceptability of the current design. The deliverables to be discussed in this report are as follows:

- Total machine concept for the automated frame attachment process.
- Prototype developed to evaluate several key subsystems of the concept.
- Our analysis of the results of that evaluation.
- Discussion of the design process used to justify design choices in the concept.
- Our recommendations on how to proceed with further development.
- Describe the prototype we developed to test several critical design subsystems.
- Analyze the results of those tests in relation to the feasibility of the current design.

The report will conclude with a preliminary cost analysis and a recommended path forward for further development and refinement of the concept design.
Design Process Methodology

The Senior Design team closely followed the suggested concept development process for the duration of the project. First, customers were identified and ranked in order of importance. Their wants and constraints for the product were recorded and prioritized. From these wants a series of metrics, or measurable characteristics, were evolved for future analysis. The customers were then presented with these metrics and a related list of target values were synthesized; these values represented minimum acceptable performances that would satisfy the outlined metrics. After this stage, several competing concepts were generated and compared by their estimated ability to satisfy the metrics. The most suitable concept were selected for further development. It was designed on paper and its most critical (or most likely to fail) subsystems were prototyped for testing and analysis. Finally, our team assessed the suitability of the design for its requirements, and some suggestions were offered for how the customers should proceed with further development. In this way, the customers are given justifications for the current design, feedback on its initial successfulness, and recommendations on how to continue with its evolution and eventual fabrication.

Constraints and Wants

The first step in our design process was to accurately ascertain the requirements of the customers for the finished concept. AstroPower communicated several critical features of the mechanism in a series of interviews conducted to meet the individual customers and understand their perspectives on the priorities of the project. (Ap. A4) First, the mechanism would have to process panels at a minimal rate equal to the
throughput rate of the rest of the assembly line so that the frame attachment step does not become a bottleneck in the overall process. Second, the mechanism should not damage either the laminate or the frame. This requirement limits the amount of force and the materials that can be considered. Third, the process should be as automated as possible: there cannot be a need for constant operator interaction with the machine, so it must align the parts itself and store enough rails for a given period of operation. Fourth, the mechanism must physically fit into the assembly floor space provided, so that it can be integrated easily into the existing layout of conveyor belts and workstations. Fifth, the installation, maintenance, and operating costs of the mechanism would have to be lower than the costs of the current system. Sixth, the process must be safe and the mechanism must be relatively simple to operate and repair. Seventh, the mechanism must be capable of processing several different sizes of rails and switching between rail sizes within an allotted amount of time. Finally, the design should use available sources of power, such as electricity and pressurized air.

Our list of critical issues and constraints had to be divided into “tradable” features, absolute necessities, wants, and needs. Tradable features were designated as such because they could potentially be excluded, or traded away, for other (more important) features if the chosen concept could not accommodate both features. Needs, on the other hand, were not seen as tradable because the concept to be considered must provide for them: otherwise it would be immediately disqualified. Each want was then prioritized by factoring in the importance of the customers who suggested it and the relative importance that they placed upon it. The end result was a list of needs that must
be satisfied and a prioritized list of wants that should be satisfied in order to achieve as much of the project goal as possible. (Ap A5)

**Metrics and Target Values**

The next step was to create a list of metrics that would quantitatively measure how well each concept fulfilled the wants and needs expressed earlier. Each want was linked back to one or more metrics, such as units completed per hour or downtime per size changeover. These metrics were then re-prioritized based on how many wants of what importance they were helpful in measuring. Our ranked list of metrics then reflected what the crucial capabilities of the concept would be and how we would measure them (Ap A6). Target values for these metrics, the pass/fail boundaries at which a concept would either succeed or fail to satisfy a metric, were determined from customer feedback and our own calculations. This completed the initial design process by creating a list of specific, objective standards to be achieved by any concept that would be developed later.

**Concept Generation and Selection**

The process of creating concepts to satisfy the metric target values relied on two approaches: benchmarking, or research into existing solutions to problems encountered in the project, and brainstorming, or the generation of original solutions to the same problems. Benchmarking was preferred when appropriate because the utilization of pre-existing mechanisms or designs tended to be more convenient within the time constraints inherent in the project (Ap A1). Ideally, several key aspects of a potential concept would
be filled with benchmarked components and the remainder of the design would be fleshed out with brainstormed solutions. The design process called for the creation of several competing concepts that would be judged on how well they would likely meet the target values (Ap A7). Each concept would then be scored, and the highest scoring concept would be developed further.

Our specific project lent itself to the competition phase of the process rather well. We were able to divide the conceptual system into nine semi-independent subsystems that could be independently conceptualized and evaluated (Ap A2). Once we had competing concepts for each relevant subsystem, customer feedback narrowed down the list of potential designs to eight: two choices each for three independent subsystems. From that abbreviated list, the most advantageous overall concept was chosen that combined the best concepts from each subsystem (Ap A7). Defining each subsystem semi-independently of the others was helpful, because the relationship of one subsystem concept to another could be ignored. Considering the subsystems in this way made the evaluation process more straightforward and our judgments about the utility of the overall concepts more reliable.
Conceptualization, Design, and Analysis

Concept Subsystems

Our subsystems are, in effect, the nine steps ordinarily performed manually since the tasks are not changing with automation. They are as follows:

1.) Tape Removal and Lubrication

The solar panel laminate is delivered from the previous station face down (electrical box up) along a roller conveyor. Our concept must accept the laminate in this position in order to effectively streamline the assembly process without adding additional tasks for the line workers. All four edges of a solar panel laminate are covered with double stick tape, which fits snugly into the aluminum C-channel on the frame rails to increase the rigidity of the structure. This double stick tape is covered with a backing that must be removed before the laminate may be assembled.

To simplify putting the frame rails on and reduce the adhesiveness of the tape, the sides of the laminate are bathed in a soapy water solution. Once this evaporates, the tape returns to its original adhesiveness, but the temporary effect simplifies assembly.

2.) Laminate Acceptance & Alignment

As the laminate arrives from the conveyor, its must be properly positioned within the machine so the frame rails can be placed on. Done manually, this is a time-consuming process that results in a major bottleneck. Also, as the glass
laminate is roughly 1/16” smaller than the frame it goes in, there is a tolerance to be found concerning where the glass sits in the completed, rectangular frame. One of the wants for this project is that the tolerance between the frame and the laminate not all stack up on one side, as would happen if the glass was pushed into a corner of the frame and the other side just screwed on.

3.) Frame Piece Storage

In any automation process, the workers on the floor and the operators of the machine are supposed to devote their time to dealing with situations that arrive, watching quality, and filling out paperwork instead of actually working a machine. With this in mind, AstroPower wanted this machine to hold at least two hours’ worth of frame pieces in some type of magazine arrangement so that the operator would not need to constantly tend the machine.

4.) Frame Piece Dispensation

From the magazine, the machine must move the pieces to where they need to go for attachment to the laminate. The rails must be dispensed to an assembler of some type in a prescribed orientation and at prescribed intervals. There is a chance of scratching occurring in this stage since the dispensation mechanism will need to sort and handle the frame rails.
5.) **Frame Piece Alignment**

Once the rails are dispensed, they must be aligned with respect to each other for screwing together and then held in this position for subsequent attachment to the laminate.

6.) **Screw Insertion**

There are two #6 pan head sheet metal screws in each corner of a solar panel frame, which serve a structural purpose as well as to complete electrical congruity. The machine must insert these eight screws.

7.) **Frame Piece Attachment**

Once the laminate has been positioned in the machine and the frame rails delivered from the magazine, the frame needs to be pushed on the lubricated double stick tape on each side of the laminate.

8.) **Laminate Export**

After the second to last step in the manufacturing process, the laminates must be sent from frame assembly down to the cleaning and inspection station. They should leave in the same orientation in which they arrived, black box up and traveling long ways down the roller conveyor.
9.) Logic Control

Any automated system must contain some type of controller that holds the instruction sets for the automation. AstroPower has specified a type of PLC already in use on the manufacturing floor to be used for the control of this machine.

The paper designs of the whole machine takes into account all of the above steps. A process flow outline and time study for the operation is included as Appendix (Ap A3). Below is a brief summary of how the whole machine is envisioned to work.

Solution Concept Overview

An employee manually takes the double-sided tape off the laminate and lubricates the sides with his soap solution. He guides the laminate into the machine from the roller conveyor. The laminate sits in the machine on a rotating table. The table consists of two surfaces, a roller surface and a vacuum cup surface. The vacuum cups are vertically mobile, to stay out of the way of the laminate coming in, but rising and engaging to secure the laminate once entered in its aligned position. This variable surface provides for both of the tables’ functions: allowing the laminate to slide into its properly aligned position and holding it steady while the frame sides are pressed on.
Several hours’ worth of frame rails are held in two magazines that can be loaded in 10-15 min. The magazine is four pylons which allow the frame rails to stack vertically in only the desired orientation, as shown. If 65 panels are made per hour, with two of each type of rail, we need $(2\text{hrs}) \cdot (2 \text{ sides}) \cdot (65 \text{ per/hr}) = 260$ frame rails of each type stored in the machine. These are stored on Level 1.

The rails are fed, one from both the short and long side magazines at a time, to Level 2 by a sprocket mechanism that is sized to allow only one rail at a time to pass out through a slot cut in the magazine base under the rails. From there they fall onto a set of coordinated pneumatic levers (Ap B7), where they are held and positioned to make a corner while a laminate is being positioned alongside. The levers go through three positions (Ap B3): one used to “catch” the rails as they fall, one used to press them up against a backstop bumper for alignment, and one that allows the levers to drop below the plane of Level 2 so that the rails can be translated onto the laminate. They are powered by two pneumatic cylinders working in series and operated by different valves.

Once a corner is formed, the adjacent frame rails are screwed together with an automatic screw gun to be benchmarked and outsourced by AstroPower. (A screw gun mounted on a linear motion system could handle both of the screws in a corner to limit the amount of expensive equipment required.) Once the levers are rotated
out of the way, the affixed rails form an “L” shape that can then be pushed onto the edge of the laminate by the same pneumatic bumper that formed a backstop for the aligner levers, thereby framing two sides of the laminate at once.

The general design involves assembling two rails into an “L” for one corner, affixing this to the laminate, then lowering and rotating the laminate and performing this operation again to take advantage of the symmetry of the completed panel.

After the second frame rail is attached, two other screw guns complete the two corners that were not done in the assembling corner.

With all four sides screwed, the table lowers out of the way of the assembly machine and exports the laminate down the line to the cleaning and inspection station.

**Feasibility Testing**

After the customers approved the selected concept after the first phase review presentation, more detailed design work began. The second phase of the project focused on expanding the concept to a fully fleshed-out design and proving the feasibility of our concept through a small number of highly targeted tests. These tests were run on a model constructed to simulate specific aspects of the completed mechanism, and were used to prove the validity of the concept.

During this phase, we identified two stages of the assembly process that were mostly likely to fail under our current design: the frame rail dispensing stage and the “L”-frame attachment stage (Ap A5). We tested the dispensing stage by constructing a prototype magazine with an indexing sprocket installed in the appropriate position. The magazine was fully loaded with short-side (SS) rails, and we recorded whether turning the sprocket would dispense one rail at a time. For the attachment stage, we arranged
two bumpers perpendicularly and connected them to the same pneumatic cylinders we would use in later prototypes. A completed L-frame was placed in the corner of the bumpers and a half-framed laminate was placed on a flat surface several inches away. We recorded whether activating the cylinders would effectively press the L-frame onto the laminate (Ap D1), and whether the new “L” aligned itself with the previously attached “L” to an acceptable degree. Both tests were repeated successfully and our concept was judged to be feasible (AP D3). This justified further development of the current design, which began immediately.

Critical Subsystem Focus

Customer feedback at the second phase review presentation was positive but our team felt that it was necessary to re-negotiate the expected deliverables for the project. It had become clear during the first and second phases that the initial scope of the project (a fully operational and integrated machine) was beyond the capacity of the design team within the available time. (Ap C2) We agreed on a set of design subsystems to focus on for the large-scale prototyping phase of the project and a set of deliverables that would be expected for completion by the final presentation. It was decided that since the most critical subsystems were already identified and studied in the feasibility analysis, our future work should explore those same subsystems: frame storage and dispensation, L-frame alignment, and frame attachment.

This narrower focus characterized the fabrication of the prototype itself to a large extent. We concentrated on constructing a machine that would store and dispense individual rails, align and screw them together into the L-frame, and press the L-frame onto a waiting laminate. Importation and exportation subsystems would be largely
ignored for the purposes of prototyping, although we would consider them from a conceptualization standpoint. As for the rotating/aligning table itself, it was deemed to be a desired deliverable but of low priority. We focused our resources on the magazine and alignment/attachment mechanisms instead, with the justification that a table meeting our requirements would be more easily benchmarked than designed ourselves.

**Prototyping and Testing**

The final phase of this project involved the integration of our disparate feasibility tests and unmade elements of the concept design into one coherent device. The two subsystems feasibility models were produced separately and had to be combined into one system. Much of the pneumatic infrastructure (tubing, valving, etc.) that powered the moving parts of our design had to be connected to a common air and power supply. Finally, we had to construct a table to simulate the table we were hoping to benchmark for the final handoff. This would allow us to test the frame attachment mechanism that was a critical component of our design with greater realism than what was done for the feasibility tests in the previous phase. (Ap D4)

**Testing and Evaluation**

Once the final prototype was constructed with all the critical subsystems integrated it was necessary to test the system as a whole. Much of the testing done on each individual subsystem was done again to ensure reliability. It was also necessary to run certain tests that showed the integration of different subsystems and prove that they
worked together efficiently. The main tasks that our prototype needed to achieve are as follows:

- Drop single frame rail from magazine for each side
- Catch frame piece with alignment lever on each side
- Align frame piece against bumper on each side
- Push each frame piece into corner so screw holes line up
- Support frame pieces while being screwed (by hand) into “L”
- Alignment levers move out of way of bumpers
- Bumpers push “L” onto laminate

Each of these steps was run twenty times in order to find the reliability of each step. The results are mostly heartening. Both magazine systems were able to consistently drop a single frame piece. This shows that the gears on each side were designed correctly and the magazine supports held the frame pieces correctly. After the frame pieces are dropped by the magazine system it is necessary for the alignment arms to catch them. This task was preformed consistently on the short side, where the alignment lever in its middle position was able to catch the pieces. On the long side this was more of a problem, as here the reliability was only 40%. The frame pieces would fall in several different positions where the alignment levers were not able to catch them. There were several ideas for fixing this problem but they were not employed due to time constraints. This was the most unreliable part of the system. The next major task is to push the frame pieces into a corner where the screw holes need to be lined up. This is an extremely important step due to the need for the process to be automated. With the alignment arms still supporting the frame pieces against the bumpers the outside
cylinders were able to push the pieces into a corner where the screw holes lined up consistently. With the alignment levers supporting the frame pieces the corner was screwed together to form an “L”. Next the alignment levers were contracted below the table and the laminate was set in place for the “L” to be attached.

The testing of the frame attachment was not done in a manner that would reflect the actual process. With no table integrated into the system the height of the laminate and the support of the laminate were not correct. Therefore the testing here was not consistent. This is not a huge problem because the testing that was done on the feasibility model for the second phase review seems to bear out this task’s feasibility despite our lack of accurate testing methods. It is already known that the bumpers, when pressurized correctly, will complete the task.

**Derived Recommendations**

At this stage the design itself was, for the most part, frozen as far as our design team was concerned. The vast majority of the work involved the actual fabrication or purchase of various components rather than the design or revision of those components, tasks that had already been accomplished. By the outline of the class schedule, this was the final phase of the project. Therefore, instead of putting the test results into another iteration of design improvement we compiled our new insights into a comprehensive list of considerations for AstroPower’s benefit. The final step in the UD design process relates directly from the prototype’s performance: our “path forward” suggestions reflect problems with the design and the steps we feel should be taken to improve it absent our direct involvement from this point forward.
**Results and Deliverables**

The prototype itself is of minor importance to the eventual success of this project. It was constructed with materials that will likely differ from the ones used by AstroPower and is valuable more as a proof of concept than as a productive mechanism.

Related deliverables, instead, make up the bulk of our results. We have included AutoCAD drawings of all machined parts and the overall concept, a cost report, and perhaps most crucially a listing of outstanding concerns and problems that should be addressed in future work. Hopefully this will provide benefit to the customer by reducing the amount of redundant work done due to miscommunication at handoff.

**Cost Report**

The design team spent less than the $2000 allotted for prototyping and design with some material costs left to be considered. A more detailed accounting of costs was not given as a customer want with higher priority than finishing the machine as of the last meeting with AstroPower, as outside consulting would have been needed.

**Outstanding Design Issues**

The completed prototype will hold frame rails and align them for screw insertion consistently and effectively. There are, however, minor issues that should be resolved even within components that successfully perform repeatable tasks.

Problems may occur with the long rail in the future due to the extension that was placed at the end of Level 1. The longer rail magazine was sized incorrectly when first built. Therefore, we had to retrofit that side of Level 1 with an extension to correct this
problem. It will now take any size frame but there is a slight deflection due to bending moment that causes the magazine to be slightly misaligned. This misalignment sometimes causes the long rails to sit differently than what the magazine was designed for but can be corrected by adding support to the extension or clamping the magazine pylons together at the top.

The short rail magazine has a problem with the sprocket if there are not enough short rails sitting in the magazine. The rails will not stay in place if there are about five rails or less due to the fact that the rails will try to rotate unless there is a sufficient downward force on them from the weight of the other rails.

There are several possible problems concerning the actuation cylinders. We noticed that in several cases they appear to be binding and not retracting completely when finished operating. This is because there are forces operating perpendicular to the direction of the cylinder’s extension, causing the rod to bend or bind in the cylinder. This is a potentially significant problem because it will rapidly cause the cylinders to wear out and require replacement. Our team suggests switching the bolted mounting plates we made for the cylinders to a pivoted mount so that the cylinders can rotate when force is applied and avoid binding.

There are possible problems that may come up when implementing the rotating table as well. Since much less work was done with this subsystem our outstanding issues are less specific but are still worthy of consideration. The most obvious problem from our design is that the alignment levers are required to retract under the laminate after the frame pieces have been aligned on the bumpers but the laminate must be closer to the bumpers for the attachment task than the levers can accommodate. Even if the levers can
be rotated away from Level 2, these arms will be directly under the laminate, making it
difficult to lower the laminate for rotation.

This could be solved in several fashions, the first being adjusting the size of the
alignment levers so that they will be retracted under the table away from the laminate.
There is in extra material that can be cut away from the levers without a decrease in
performance. The second solution could be to raise the laminate for rotation instead of
lowering it. This would require a greater movement since it would have to be raised
above the top of the magazines, but the design of the table would be generally the same.
A third solution would be to design a table that would move the laminate both in the
vertical direction and also in the x and y direction. This would make it possible to move
the laminate away from the alignment arms and then move it vertically. This solution
would be the most complex and therefore the most costly.

In the original process for affixing the frame pieces to the laminate it was
necessary to lubricate the tape on the outside of the laminate. In our system, we simply
stated a worker would do this. Manual application of tape lubrication leads to several
issues; we must take care to provide comfortable ergonomics to the workers involved and
we must make sure that careless application of the lubrication does not risk the health of
the rest of the machine components.

Receiving the laminate into the system could provide a number of problems for
the system. If the laminates are not presented in a consistent manner, this could cause the
table to find the wrong corner or arrive in an orientation that makes alignment
impossible. The position of the laminate on the table is extremely critical due to the need
for having opposing corners for the correct position for the attachment of the frame.
Furthermore the nature of the “L”-framer means that the laminate will need to be rotated around its center point. The exact position of the laminate will need to be found before the frames are attached and this will depend on the presentation from the conveyor belt.

It is understood that the prototype that will be handed off will be used as a model for future design. There are several parts of our prototype that, while they don’t cause immediate problems, could be improved in a future design. These improvements generally involve the magazine and attachment subsystems.

There are several improvements that could be implemented into the magazine subsystem. One would be to use plastic gears instead of the aluminum and steel sprockets used in the prototype. The advantages of using plastic gears include cost, machinability, and reduced damage to the frame pieces. The damage to the long frame pieces was evident after rotating each frame piece through the sprocket multiple times; these scratches will be very minimal in frame pieces that are only rotated through once. Though this is not a major problem, the final appearance of the laminate is important to AstroPower’s customers and therefore either introducing a non-scratching coating or replacing the material entirely is an important consideration.

Another necessary improvement is an increase the number of long frame pieces that can be held in the system at one time. Presently with the nine-inch tall magazine pylons the number of small frame pieces that can be held is a great deal greater than that of the long frame pieces. The simplest solution would be to simply make the pylons taller, as there is a great deal of available vertical space. The problem with this is that it would lead to loading problems, and is frankly unpractical for several hours’ worth of frame rails. One more complicated idea that our group came up with was to have
multiple parallel magazines that would dispense rails onto a conveyor belt moving
towards the aligner bumper. When one magazine emptied the one behind it would be
activated, allowing for a large number of stored magazines at a reasonable loading height.

The last major contribution of our prototype to the entire system is the attachment
subsystem. Here it was determined through our second phase feasibility testing that the
corner will be best aligned if the cylinders closest to the corner of the “L” are actuated
first. If the corner of the “L” is attached properly there is a greater chance of the entire
“L” being attached properly. In order to limit the shear forces in the cylinders several
approaches can be taken. The first would be to have the laminate as close to the “L” as
possible when the cylinders are actuated. This would limit the difference in movement
along the bumper. Another trick that could help would be to time the actuations of the
cylinders so that the cylinders further away from the corner would actuate immediately
after the inside cylinders. These are both solutions that can be used with the prototype
that has already been produced.
Outline to Success

Team 2

Matt Boyd
Adrew Drysdale
Wilson Steele
Tony Warrington, Jr.

This outline was made to easily transfer knowledge of the design and prototype from Team 2 to our customers, AstroPower. This outline was written to allow for the path forward to be a smooth transition.
Long Side Rail

1. Magazine
   a. Coat magazine or make of some material to reduce scratches.
   b. Design magazine to hold more rails to handle full shift of work.
   c. If current design is the foundation, then account for deflection of sides of magazine (support will be needed).
   d. Make sure magazine is position to allow for long side rails to have a smooth drop to lower level (also help to reduce noise).

2. Gears
   a. Coat gears or make them of plastic (then wider teeth as well).
   b. Be sure that gears allow for a smooth drop to reduce noise and problems in catching
   c. Gears will possibly bind up if long side rails do not seat properly (relates back to 1 – c, magazine should have minimum amount of space as possible to hold long side rails in place).
   d. Be sure that axle used to hold gears in place can:
      i. Handle the weight of the magazines stacked for shift work without torsional deflection.
      ii. Be properly lubricated to rotate easily.
      iii. Be run by a system (motor, etc.) that can also handle the load of the magazines.

3. Level 1
   a. Level 1 does not have to be coated due to the fact that the long rails do not touch any part of it.
   b. Be sure that level 1 can handle the size and weight of the rails, magazine, gears, etc. without deflection.
   c. Be aware that long rails will be 50 + inches long therefore the cutout in level 1 will have to accommodate that.
   d. Cutout will weaken level 1 if there is not enough material on both sides of the cutout to support the load of the magazine. (Magazine will hold enough rails for shift work).
4. Frame Pushers
   a. Coat frame pushers or make of some material to reduce scratching.
   b. Frame pushers should be operated by pneumatic cylinders, which have flow meter (as in prototype), this assures that the pushers do not slam into the laminate.

5. Level 2
   a. Be aware in prototype that Level 2 is made of plywood, which we found to deflect.
   b. Level 2 should be made of material that would not allow for deflection. Deflection will cause the long rails to not seat properly once they are dropped and caught (as well as not be pushed to corner properly).

6. Aligners
   a. Coat aligners or make them of some material to reduce cosmetic issues.
   b. Aligners must be made to fit and hold the long side rails properly or damage can occur to the channel (channel in which screws are inserted at each edge).
   c. An extension may have to be added to the aligners to prevent the long side rails from going over the aligners and hitting the ground. Be aware that this could cause problems for the table and laminate, which will be close by, if the extensions are too long or not retracted/moved out of the way.
   d. Extensions should be coated or made of a material that will not cause cosmetic issues.

7. Level 3
   a. Level 3 supports the pneumatic cylinders for the aligners.
   b. Level 3 supports the whole sub-system.
   c. Allows room for some malignance and adjustments.
   d. Remake of Aluminum.

Short Side Rail
1. Magazine
   a. Coat magazine or make of some material to reduce scratching.
   b. Design magazine to hold more rails to handle full shift of work.
   c. If current design is the foundation, then account for deflection the higher up the magazine goes (support will be needed).
   d. Make sure magazine is position best as possible to allow for short side rails to have a smooth drop to next phase which is catching (also help to reduce noise).

2. Gears
   a. Coat gears or make them of some material to reduce cosmetic issues.
   b. Be sure that gears allow for a smooth drop to reduce noise and problems as they are dropped to the next level.
   c. If there are 5 or less short rails in the magazine then it will not seat against the gears properly due to the lack of weight keeping the short rails in position.
      i. Suggestion: A spring loaded wheel position opposite of the gears could be added to “push” that 1st short rail against the tooth of the gear to elevate this problem. (See red arrow in picture below)
      ii. Wheel must be coated or made of some material to reduce cosmetic issues (i.e. skate wheel)
      iii. Wheel must move freely and must allow for the gear to move the short rail without causing damage.
d. Be sure that axle used to hold gears in place can:
   i. Handle the weight of the magazines stacked for shift work.
   ii. Be properly lubricated to rotate easily.
   iii. Be run by a system (motor, etc.) that can also handle the load of the magazines.

3. Level 1
   a. Level 1 does not have to be coated due to the fact that the long rails do not touch any part
      of it.
   b. Be sure that level 1 can handle the size and weight of the rails, magazine, gears, etc.
   c. Be aware that short rails will be 32 + inches long therefore the cutout in level 1 will have
      to accommodate that.
   d. Cutout will weaken level 1 if there is not enough material on both sides of the cutout to
      support the load of level 1 and the magazine. (Magazine will hold enough rails for shift
      work).

4. Frame Pushers
   a. Coat frame pushers or make of some material to reduce cosmetic issues.
   b. Frame pushers should be operated by pneumatic cylinders which have flow meter (as in
      prototype), this assures that the pushers do not slam into the laminate.

5. Level 2
   a. Be aware in prototype that Level 2 is made of plywood, which we found to deflect.
   b. Level 2 should be made of material that would not allow for deflection. Deflection will
      cause the long rails to not seat properly once they are dropped and caught.

6. Aligners
   a. Coat aligners or make them of some material to reduce cosmetic issues
   b. Aligners must be made to fit and hold the long side rails properly or damage can occur to
      the channel (channel in which screws are inserted at each edge).
   c. An extension may have to be added to the aligners to prevent the long side rails from
      going over the aligners and hitting the ground. Be aware that this could cause problems
for the table and laminate, which will be close by, if the extensions are too long or not retracted/moved out of the way.

d. Extensions should be coated or made of a material that will not cause cosmetic issues

7. Level 3
   a. Level 3 supports the pneumatic cylinders for the aligners
   b. Level 3 supports the whole sub-system
   c. Allows room for some maintenance and adjustments.
   d. Remake of Aluminum.

8. Table that can rotate.
   a. Must hold laminate securely.
   b. Be able to drop out of the way of the aligners.
   c. Accept and deliver laminate to and from conveyors.
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Appendix B 1: Long Bumper
Appendix B 2: Short Bumper
Appendix B 3: Alignment Sub-System
Appendix B 4: Long Frame Gear

Mat'l Thickness: 25 Inch
Fillet Edges 25°
Appendix B 5: Long Frame Gear Holder
Appendix B 6: Level Separator
Appendix B 7: Alignment Lever
Appendix B 8: Magazine Drop Down Frame
Appendix B 9: Magazine Drop Down Frame
Appendix B 10: Magazine Support
Appendix B 11: Table Support
Appendix B 12: Gear Holder
Appendix B 13: Magazine Sub-System
Appendix A 1: Benchmarking

Design Problem:
Automate the assembly of a range of sizes of the AstroPower “screw” type laminate frame.

Design Goal:
Take laminate as received from previous station, with black box in upward position, attach four “screw” type laminate sides, affix eight #6 pan head sheet metal screws, and export to next station (glass down) in a maximum of 1.71 min (35/hr) during runtime.

Time Goal: \(\frac{(300 \text{ unit})}{((7.5 \text{ hr shift})-(1 \text{ hr setup})}=(300 \text{unit})/(390\text{min})=(1\text{unit})/(.76\text{min})\)

Machine Sub-System Concepts

Tape removal System
1.) Bob the worker

Lubrication System
1.) Soak Extrusions
   a. Lincoln Industrial PLC Control QLS 301 Lubrication System
2.) Sponge on Panels
   a. Bob the Worker Again
3.) Spray on Panels
   a. The ORSCO Series 300 Lubrication

Laminate Receive/Positioning System
1.) Vacuum Cups
   a. Astro Power Light Tester
2.) Conveyer
   a. Grainger - Horizontal Belt Starter Conveyor, 800 pound, Capacity, 3/4 horsepower, 12 feet Length, 18 inch, Belt Width - $2237
3.) Gravity Down Angle Slope
   a. Gravity Conveyor 12” 10’ Straight, Galvanized Steel, Wheeled $146.35

Extrusion Feed System
1.) Indexing Slat Conveyor
   a. perfectly aligned, but time consuming for worker)
2.) Hopper Feed
   a. (like straws at McDonald’s), this will have alignment problems.
3.) Stacked Feed
   a. Take ‘em out of box, place them properly, and out the come. Will require testing to see if they will “self-orient”, stay oriented, or jam in machine.

Extrusion Attachment/Press System
1.) Pre-assemble L (with or without rotation)
   a. Roll on (with a Skateboard Roller, to not fight force of friction of whole Al
2.) Multi-Level – Frame assembly in vertical steps
   a. Astro Power Light Tester

Screw Attachment System
1.) Belt Feed – Like a nail gun or drywall screw gun with disposable plastic magazines.
a. Dura-Spin Cordless Screw Driver Model DS162-14v

2.) Vibratory hopper & Track Delivery
   a. DTI - Inline Automatic-Feed Screwdriver System - Multifeeder

3.) Vibratory hopper & Blow Feed

4.) Computer Controlled Systems.
   a. Deprag – Complete Screw driving station for tour bus seat back

Export System
1.) Linear Actuator – Like in pinball, slam it away
   a. Warner Linear Motion Systems ELECTRAK - Electromechanical Linear Actuator

2.) Belt Driven Conveyor (as seen at AP, out of Grainger)
   a. Grainger - Horizontal Belt Starter Conveyor, 800 pound, Capacity, 3/4 horsepower, 12 feet Length, 18 inch, Belt Width - $2237

Logic Control System
1.) PLC
   a. Name of system to use from AstroPower
Appendix A 2: Sub-System Components

Design Problem:
Automate the assembly of a range of sizes of the AstroPower “screw” type laminate frame.

Design Goal:
Take laminate as received from previous station, with black box in upward position, attach four “screw” type laminate sides, affix eight #6 pan head sheet metal screws, and export to next station (glass down) in a maximum of 1.71 min (35/hr) during runtime.

Time Goal: \( \frac{300 \text{ unit}}{(7.5 \text{ hr shift})-(1 \text{ hr setup})} = \frac{300 \text{ unit}}{390 \text{ min}} = \frac{1 \text{ unit}}{.76 \text{ min}} \)
\[ 1.31 \text{ Units/min} = 78.6 \]

Machine Sub-System Concepts

1. Tape removal System
2.) Bob the worker

2. Lubrication System
4.) Soak Extrusions
   a. Lincoln Industrial PLC Control QLS 301 Lubrication System

3. Laminate Receive/Positioning System
   - Vacuum Cups
   - Astro Power Light Tester

4. Extrusion Feed System
   - Indexing Slat Conveyor
   - Perfectly aligned, but time consuming for worker)

5. Extrusion Attachment/Press System
   - Pre-assemble L (with or without rotation)
   - Roll on (with a Skateboard Roller, to not fight force of friction of whole Al

6. Screw Attachment System
   - Vibratory hopper & Blow Feed
   - Visumatic Machine Builder Systems – VPD-4.2 Power Driver Systems)

7. Export System
   - Linear Actuator – Like in pinball, slam it away
   - Warner Linear Motion Systems ELECTRAK- Electromechanical Linear Actuator

8. Logic Control System
   - PLC
   - Name of system to use from AstroPower

1. Laminate Leaves previous station, glass down, black box up, travels to Bob and Machine
   - Bob the Worker removes Green Tape
   - He pushes Laminate into machine.
     - He is standing at entrance to machine, next to roller-skate conveyor.

2. Four hinged guards rotate up 90° from flat and push on laminate from all sides
   - Orients part to center.
   - Vacuum Cups attach from bottom, secure part in “origin” position.

3. “L” is pushed diagonally onto Laminate
   - A Skateboard wheel rolls down the side,
     - Secures Laminate, Frame and tape.
     - So as not to fight friction of whole side at once.

4. Laminate is spun 180°.
   - Machine Re-Orients and indexes Un-Framed side of Module to “origin” position.

5. “L” is pushed on diagonally to Laminate.
   - A Skateboard wheel rolls down the side,
     - Secures Laminate, Frame and tape.
     - So as not to fight friction of whole side at once.
   - Two screw-guns on non-horizontal slide affix unattached sides, 1 side per gun.
   - Laminate is Exported to next station, glass down, parallel to line of import.

Continuous Maintenance
- Load Al Extrusions in proper orientation
- Load Screw Hopper
- Replenish Lubricant
- Remove Tape
- Push Laminate onto Machine

Time Study
Max - 1.71 Units/min - 102 sec.
Min - 1.31 Units/min - 60 sec.
1. 15-20 sec.
2. 15-20 sec.
3. 10-15 sec.
4. 15-20 sec.
5. 20-25 sec.
# Appendix A 4: Customer Wants

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<tr>
<td>2</td>
<td>want1 throughput rate</td>
<td>25</td>
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<tr>
<td>3</td>
<td>want3 no damage to panels</td>
<td>12</td>
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<tr>
<td>4</td>
<td>want6 structural integrity</td>
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<td>5</td>
<td>want4 ergonomics</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>want7 flexibility</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>want8 changeover downtime</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>want5 cost</td>
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<td>9</td>
<td>want14 reliability</td>
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## Wants as Edited by Customer

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<tr>
<td>4</td>
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<td>want5 cost</td>
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<tr>
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## Appendix A 5: Wants Formulation
# Customer Data and Wants Formulation

**Project Title:** AstroPower Module Frame Installer  
**Mission Statement:** Develop an automated system for installing a screw-frame onto a variable-sized solar power module

## Customer Information

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<tr>
<th>Name</th>
<th>Organization</th>
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<th>4th Want</th>
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<td>AstroPower</td>
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<td>Mike Conway</td>
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<td>Danie Holland</td>
<td>AstroPower</td>
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<td>Dr. Glancey*</td>
<td>University of Delaware</td>
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*Wants of this customer not calculated into matrix because they are unrelated to other wants*

## Constraints

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<td>Safety (pinch point) regulations</td>
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Appendix A 6: Metrics

**Metric Key**

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<td>b</td>
<td>sizing</td>
<td>7</td>
</tr>
<tr>
<td>c</td>
<td>percentage of modules rejected</td>
<td>3</td>
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<tr>
<td>d</td>
<td>floor space area (sq. ft.)</td>
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<tr>
<td>e</td>
<td>lbs lifted</td>
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<tr>
<td>f</td>
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## Appendix A 7: Concept Selection

### Concepts Concept Descriptions

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<tr>
<td>B</td>
<td>Multi-level, Magazine Feed, Simple Screw</td>
</tr>
<tr>
<td>C</td>
<td>Pre-L, Hopper Feed, Simple Screw</td>
</tr>
<tr>
<td>D</td>
<td>Multi-level, Hopper Feed, Simple Screw</td>
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<td>E</td>
<td>Pre-L, Magazine Feed, Complex Screw</td>
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<td>Multi-level, Magazine Feed, Complex Screw</td>
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### Concept Selection Table

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**Better than benchmark**

**Worse than benchmark**

**Same as benchmark**

**Unknown relationship**: Sum-Up Score

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**Compared to benchmark**

- **Symbol**: b
- **Value**: 1
- **Description**: Perform this check in a round robin fashion.

- **Symbol**: w
- **Value**: -1
- **Description**: Let the prevailing concept from one round be the benchmark in the next!

- **Symbol**: u
- **Value**: 0.0

### Concept Best Bets:

1. E: Pre-L, Magazine Feed, Complex Screw System, 53%
2. A: Pre-L, Magazine Feed, Simple Screw, 27%
3. C: Pre-L, Hopper Feed, Simple Screw, 22%
Appendix C 1: Phase 1 schedule
### Appendix C 2: Phase 2 Schedule

<table>
<thead>
<tr>
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<td>1 Matt, Tony</td>
<td>3 days</td>
<td>Mon 10/22/01</td>
<td>Wed 10/24/01</td>
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<tr>
<td>2 Team 2</td>
<td>2 days</td>
<td>Tue 10/23/01</td>
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<td>Thu 10/25/01</td>
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### Calendar

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- Test Model
- Wrap up Phase Two Presentation
- Feedback on Phase Two Presentation
- Redesign of Prototype 1
- Re-testing Prototype 2
- Redesign of Prototype 2
- Final Testing of Prototype
- Hand off Procedure
- Poster Presentation
- Finish and Hand off Prototype
- Evaluation
Appendix D 1: Test Results Data

Test Results for Independent Cylinders:

<table>
<thead>
<tr>
<th>Trial</th>
<th>Pressure</th>
<th>Bore Area</th>
<th>Force</th>
<th>Accuracy</th>
<th>Timing</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
<td>1.77</td>
<td>141.3</td>
<td>100</td>
<td>All at once</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>1.77</td>
<td>141.3</td>
<td>75</td>
<td>short side first</td>
<td>long side slightly off</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>1.77</td>
<td>141.3</td>
<td>50</td>
<td>long side first</td>
<td>corner not affixed</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>1.77</td>
<td>141.3</td>
<td>50</td>
<td>All at once</td>
<td>corner not affixed</td>
</tr>
<tr>
<td>5</td>
<td>80</td>
<td>1.77</td>
<td>141.3</td>
<td>100</td>
<td>All at once</td>
<td>-</td>
</tr>
<tr>
<td>Avg</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>75</td>
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Test Results for Synchronized Cylinders:

<table>
<thead>
<tr>
<th>Trial</th>
<th>Pressure</th>
<th>Bore Area</th>
<th>Force</th>
<th>Accuracy</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
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<td>1.8</td>
<td>106.0</td>
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</tr>
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<td>106.0</td>
<td>50</td>
<td>corner not affixed</td>
</tr>
<tr>
<td>Avg</td>
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<td></td>
<td>50</td>
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<tr>
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<td>123.6</td>
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<tr>
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<td>1.8</td>
<td>123.6</td>
<td>75</td>
<td>end side slightly off</td>
</tr>
<tr>
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<td>1.8</td>
<td>123.6</td>
<td>50</td>
<td>corner not affixed</td>
</tr>
<tr>
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<td>70</td>
<td>1.8</td>
<td>123.6</td>
<td>75</td>
<td>end side slightly off</td>
</tr>
<tr>
<td>Avg</td>
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<tr>
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<td>132.5</td>
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<tr>
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<td>132.5</td>
<td>75</td>
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</tr>
<tr>
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<td>132.5</td>
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</tr>
<tr>
<td>Avg</td>
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<td>100</td>
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Cylinder Connection Scheme Analysis (80 psi air)

- Independent Cylinders
- Synchronized Cylinders
Appendix D 3: Pressure Testing Graph

**Accuracy vs. Pressure for Synchronized Cylinders**

![Bar graph showing accuracy vs. pressure for synchronized cylinders]

- **X-axis**: Pressure (psi)
- **Y-axis**: Accuracy (%)
Appendix D 4: Reliability Testing of Prototype