Engineering Stories

Short Stories (Realistic Fiction) in Science, Technology, Engineering, and Math (STEM)

Come into my office, conference room, and laboratory - Experience my adventures, teams, challenges, thoughts, travels, and sudden insights

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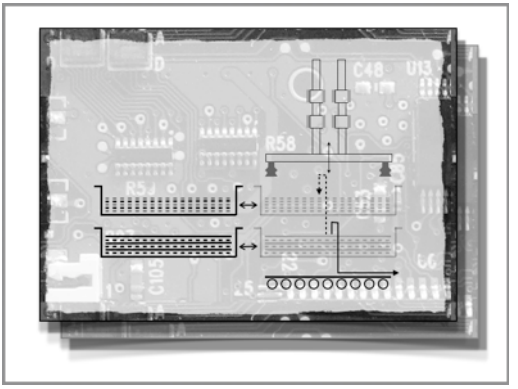

1 - GET A GRIP

"Okay everyone, listen-up." Brandon leaned forward bringing the Monday morning staff meeting to attention. "The rumors are true."

"Oh no." Melissa thought, arms crossed, hands gripping her upper arms. "Was everyone against hiring me?"

Brandon, middle-aged with brown hair, was the engineering manager at International Custom Automation (ICA), reputable creators of special robotic machines. Each Monday, the Automation Group met in a small conference room on the third floor.

"The good news is," Brandon continued, "the board of directors approved launching their new smart phone

to compete with the latest technology."

Melissa relaxed her hands into her lap.

"The bad news; the new phone must hit the market in ten months; we have eight months to develop, test, and install new automation at LIC (Long Island Circuits) in New York for the printed circuit board (PCB) processing line."

"Cool." Melissa sat against the wall thinking. "My first week on the job and there's a major announcement." For a moment, her eyes wandered to the window overlooking part of Jersey City. She could see the Statue of Liberty, the Hudson, and the Manhattan skyline.

Mike, another engineer asked. "Is this automation for the inner layers, or rigid PCBs?"

Brandon responded while glancing from Mike over to Melissa. "Our machine will feed inner-layer cores into the DES line."

"DES line?" Melissa moved her lips without speaking.

Brandon paused. "Before we go any further, let's welcome our newest engineer to ICA, Melissa Stewart."

Melissa raised her hand slowly, head tilted down slightly. The seven other engineers in the room nodded in her direction.

"Aaron?" Brandon addressed a thin haired older man, white shirt, no tie, sitting near the head of the conference table. "Melissa came to us top in her class, but there's a lot of terminology she'll need to know about printed circuit boards, and the kind of

automation we develop."

Aaron rubbed the back of his neck.

Turning to the corner of the room Brandon continued. "Melissa, go ahead and take notes, but please ask Aaron anything you don't understand. Don't wait till later, go ahead and ask him during the meeting if you like, or any time."

Aaron looked over his glasses and nodded to Melissa.

"Okay, let's get started. Here's what we know so far about the automation we need to design. The final circuit board inside each phone will be two inches wide by three and a half inches tall; about two millimeters thick. Each board will be cut from panels about two feet square, twelve layers thick."

Melissa made notes in her crisp new company notebook pretending to understand what Brandon was talking about.

Aaron looked preoccupied, then interrupted, "Brandon?" Aaron tapped his fingers on his well used, dog-eared notebook.

"Yah Aaron."

"Could we take a few minutes right now and get some of these fundamental terms out for Melissa? I may not have time later, and I can see already she's scratch'n her head."

"Sure." Brandon looked at his watch, then at the whiteboard. "Aaron, why don't you give us all a review. This'll be good for everyone. We'll listen while you explain it to Melissa."

"Okay." Aaron got up slowly, walked to the

whiteboard and carefully drew a matrix, a rectangular array of horizontal and vertical lines, with a border around the whole thing.

"It looks like a checkerboard." Melissa thought.

Looking around the room Aaron said. "Everyone hold up your cell phone. Inside every phone, smart phone, e-book reader, and just about every electronic device you can think of is a printed circuit board. I'll just call it a PCB. It's made of laminations of many layers of thin copper, each layer separated by non-conducting layers." Aaron placed his cell phone on the table and pulled from his notebook a picture of a circuit board with shiny copper traces, like a labyrinth trail separated by faded green material.

"This seems kind'a fundamental." Melissa thought. "I learned about PCBs in EE 101."[1]

"The copper traces provide electrical pathways between components that will be mounted later on the board like memory chips, resisters, touch screens, keyboards, and capacitors. Having multiple layers allows the product to have many combinations of circuit pathways or traces in a small package. Melissa, hold up your cell phone."

Melissa did so.

"Looks like you could use a new one." Aaron said.

Brandon leaned forward and inserted. "I'll have a comment about that in a minute."

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[1] The acronym EE is short for Electrical Engineering. 101 is usually a fundamental class catalog number at a university.

Aaron raised an eyebrow and continued. "The circuit board in your device may be a few square inches in surface area." Aaron pointed at the picture again. "When manufactured, these circuit boards were fabricated one core, or layer, at a time in large sheets, four to six square feet, laminated to create a muti-layer board or panel of 2 to 30 layers then cut into the final size like cutting brownies from a cookie sheet into small pieces to be populated with components, then packaged in your phone."

Aaron lifted the edge of a page of his notebook with his thumb and let it flip back down. "Before lamination, each core is very thin, paper thin, and very flexible. While in this state, each core has a pattern of copper traces photographically exposed on it and then the unwanted copper is chemically removed in an etching process. In this way, very large quantities of small electrical pathways can be created. These thin flexible cores must be taken from trays and placed onto the chemical conveyor, then after etching away the unwanted copper, they must be lifted from the conveyor and stacked while waiting for the next process. They must be handled with care causing no damage to the base material, the copper traces, or any other features on the core or it must be scrapped. If damage is not detected until after later steps, like lamination, and de-panalization, then the cost of scrap is high."

Aaron's phone rang. He retrieved it from the table and looked at the phone's screen. He turned to Brandon and said, "It's our customer. Should I..."

"Take the call," Brandon insisted. "They are as anxious as we are to get started."

"Yes, this is Aaron." Everyone listened while Aaron spoke to his phone. "Yes I have that information at my desk." Aaron looked out the window. "Oh, really?" "Let me get to my office ... hold on." Aaron looked at Brandon.

"Go. Go." Brandon said to Aaron. "I'll take over from here."

Aaron grabbed his notebook and left.

Brandon continued the lecture. "Each inner layer core starts with a full thin layer of copper on the surface, then it's coated with a material that's resists or blocks light called photoresist. The photoresist coating is exposed with a circuit image using a special optical projector, then the unwanted copper is etched away in a chemical bath; that's what they call DES, or develop, etch, strip. The photoresist is developed, the copper is etched, and the photoresist is stripped off. That's where we come in; we need to create a machine, a robot that will take each exposed layer from a tray and place them one at a time onto the chemical process conveyor, and then at the other end of the chemical process, we need a similar machine to lift each developed core off the conveyor and place them into another tray for further processing and inspection."

Melissa rubbed her nose. "I think I understand."

"Okay." Brandon said. "So, each core is about two foot square. One of our machines will pick it from a tray before copper etching, the other machine will pick

it from the conveyor with much of the copper removed and place it in a tray. Typically we use vacuum cups to grip panels and lift them, but these new technology cores are so thin, there is some concern that the vacuum cups will wrinkle, peel, or damage the copper traces."

"You were going to say something about Melissa's cell phone." Mike asked.

"Oh yah. ICA plans to give each member of the team a new smart phone on the first day they hit the market..."

Each person in the room sat up in their chairs.

"If we make the deadline." Brandon clarified. "And ICA is going to pay for each data plan for two years, maybe longer."

"Double cool—finally, a smart phone." Melissa thought, having been a poor college student.

Brandon handed a small stack of papers to Mike and asked him to pass them around.

"Okay." Brandon said looking in the direction of Mike and Melissa. "I'm assigning Mike, Aaron, and Melissa to develop the overall PCB handling and gripping machine architecture."

Melissa opened her eyes wide.

Brandon continued. "This project is similar to past panel handlers we've done so I would like the core team, the rest of you to develop the main structure, electrical, and safety features. The software team will do what they do best. In one week, we will have a high level system review to go over the main functions and see some initial ideas from the gripping team. Okay

everyone, study what I just gave you and get to work on your subsystems."

The meeting adjourned.

Mike introduced himself to Melissa. "Welcome. Here, I'll show you where Aaron's office is. I think he'll be waiting for us."

Mike and Melissa made their way from one corner of the third floor to another passing rows of cubicles, the lunch room, and the water cooler.

"Why did Brandon choose me?" Melissa held one palm up while holding her notebook in the other hand. "Isn't the gripping part of the machine the most technically challenging? I mean, I'm excited at the opportunity, but I thought it would take some time before I..."

"Oh Brandon is like that." Mike replied. "He's pretty smart, actually, putting the newest person together with the most experienced engineer like Aaron. It's a good way to pass on knowledge. The others don't mind too much because everyone gets opportunities to work on different parts of the machine. Besides, some of the other team members are skilled doing the electrical, or the structure, or software. Maybe you have some particular skill Brandon thinks will be needed on this project."

Melissa thought about her resume and job interview with Brandon four weeks ago. "I don't have any experience with printed circuit board handling. I wonder what Brandon is thinking..."

"Hey, get in here you two." Aaron was waiting at the

door of his office and rushed them inside. "That was our big client on the phone. How soon can you guys be ready for a trip to Israel?"

Melissa dropped her jaw.

Mike got his words out first. "Are you serious? How soon do they need us?"

"Well, Brandon was serious; this is a huge deal for LIC and they are ready to lay out their factory process and determine what kind of machines and floor space are needed for the chemical process lines. They would like us there tomorrow, but a day later is probably the best we can do."

"I thought the client was in New York?" Melissa asked.

"They are." Aaron said. "But as it turns out, the printed circuit board layers that we need to handle are similar to some prototype boards being made by their branch in Israel. LIC wants us there to learn some specifics about the process and develop a concept for our machines."

"I can't believe it." Melissa said under her breath.

"Melissa, is this going to be a problem for you?"

"No, not at all. Actually it's exciting. I just didn't think things would happen so fast."

"Actually," Mike said. "I know for a fact that Brandon wanted you here sooner, but it took a while for Human Resources to get your job offer ready..."

"Well," Aaron said. "I've got our travel department ready to make reservations as soon as we tell them the time. I was planning on having a brainstorm session in

my office today but that will have to wait 'till we are on the plane. In the mean time, get your... Oh wait, Melissa, do you have a Passport?"

"Yes, I got one a couple years ago when I..."

"Oh good. So, get your personal information to me in the next hour and I'll work with travel to get us all sitting next to each other on the plane so we can go over these requirements." Aaron held up the sheet of paper distributed in the conference room.

A day later, 3:30 in the afternoon, Melissa arrived at the El Al Airlines departure gate at Newark, their Jumbo jet filling the window. The gate sign read, "Flight 52 to Tel Aviv Departing at 4:45 p.m."[2]

"Good afternoon Melissa." Mike said. "Have you seen Aaron yet?"

"Not yet but I can't imagine our leader being late."

"Well, it's happened before." Mike said with a small snicker. "Sometimes at work he gets pretty preoccupied thinking deeply and..."

"Hello Mike. Hi Melissa." Aaron said, a little out of breath. "Hey did each of you bring your notebooks, or..."

"Yah, I've got mine." Melissa patted a flat spot on her carry-on bag.

"Yep, I'm ready." Mike added. "Aaron, last time I flew across the Atlantic, I remember not getting enough sleep on the plane and I was seriously lagged for a

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[2] Tel Aviv is a major city in Israel

couple days. I'm thinking we should start our discussion early in the flight so we can close our eyes for the last few hours."

"Yah, you're right." Aaron said looking around the gate seating area. "Actually, we don't board for another thirty minutes, shall we get started? There are a few seats over there in the corner." Aaron pointed.

"I need to use the restroom." Mike said. "I'll join you in a couple minutes."

"Okay." Aaron pulled out the specification sheet Brandon provided. "On my way out of the office, Brandon told me that the inner layers, or cores will be one mil thick (that's one-thousandth of an inch) and separated by slip-sheets to protect the photoresist."

"I remember about the inner-layers and photoresist," Melissa said, "but what's a slip-sheet?"

"It's just a piece of paper interleaved between each core to protect the photoresist coating while stacked in the tray. The challenge is, our machine must detect the top item in the tray and determine whether it's an inner layer or a slip-sheet. If it's a slip sheet, then our machine needs to remove it and place it in a stack somewhere, and if it's a inner layer, then our machine needs to place it on the DES conveyor."

Melissa understood, then sat back in her chair.

"We've done this before so it shouldn't be a problem. It just makes our machine bigger because we have to have a tray for PCBs and a separate tray for..."

"Aaron." Melissa interrupted. "I'm still stunned at being put on this team my first week of work; first day

actually. Why did Brandon choose me for this assignment?"

"Well," Aaron paused sitting back. "I know of three reasons."

"Three?" Melissa gave Aaron her full attention.

"First, some of us won't be around forever and senior management is putting a lot of pressure to get us to teach the new engineers all we can."

Melissa nodded understandingly.

"Second," Aaron squinted, "actually the second reason is because I asked for you specifically to be on this team."

"You did? Why?"

"Because on your senior project in college, you had experience working with compressible flow and with small membrane or thin film mechanics. When I saw those two skills together, I knew we needed you on the gripping team. As PCB technology advances and the layers get thinner and thinner, we need to consider them as thin membranes. We are approaching the edge of our technology gripping these sheets with vacuum cups."

"I see." Melissa said.

"Well, I sure think your expertise will help as time goes on," Aaron added.

"Thanks, I think." Melissa said scratching her neck. "That makes me feel nervous, and useful at the same time."

"Join the crowd." Aaron said as he looked back at his notes. "Now, where were we?"

"You said there were three reasons."

"Oh yah. We noticed from your interview portfolio that you have good drawing and presentation skills. Most of the young engineers don't learn how to sketch anymore and communicate their ideas with free hand or technical drawing. It looks like you made the effort to develop this skill. You'll find it to be a powerful asset in your career."[3]

Melissa thought back to her senior project. "Thanks. I'll do my best."

"Now, where were we?"

"Oh yes, Brandon also said that this DES line is a little longer than most so there won't be a lot of room at each end of the line for our automation."

"There's never enough floor space." Mike overheard Aaron as he approached from behind then sat down and drew a sketch of the DES line with material handling automation at each end.

"When the PCBs come off the other end of the line," Melissa pointed at Mikes sketch, "do they need to be re-stacked with slip-sheets?"

Aaron's face wrinkled. "I'm not sure, Brandon wasn't clear on that. I'll call him while we board the plane."

Melissa opened her notebook and drew something

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[3] "Technical sketching is used as a means of rapid graphical communication that enables the engineer to quickly express, explain, and record her or his ideas." Dale H. Besterfield, Robert E. O'Hagan, *Technical Sketching with an Introduction to CAD For Engineers, Technologists, and Technicians. 3rd Edition.*

similar to what she saw in Mike's book.

"What are the rest of the specifications and constraints?" Mike asked.

"Just the ones on the sheet." Aaron replied. "Melissa, why don't you read it out loud for us and let's discuss it."

"DES Inner-Layers: Panel size: 24 by 24 inches. Panel thickness: 1 mil. Panel material: Glass reinforced epoxy dielectric core coated with copper and dry film photoresist. Panel surface properties: Full copper before DES; Copper traces after DES."

"Oh I forgot." Aaron reached into his travel bag. "Here's a sample." He handed a business card sized piece of inner-layer core to Melissa.

Melissa flexed it between her thumb and forefinger then handed it to Mike. "It really is like a piece of paper."

"Please continue." Aaron said nodding at the specification sheet.

"Maximum tray stacking depth: two inches. Slip-sheeting material: To Be Determined."

"What does that mean?" Melissa asked.

Mike responded. "It means that when this was written, they hadn't chosen the type of paper yet."

"Well," Aaron said. "Now we know from Brandon that there will indeed be slip-sheets between each core."

Melissa continued. "Feeder: A means to remove panels from a tray one at a time and place them on a conveyor adjacent to the tray. One core must be placed on the conveyor every eight seconds continuously 24/7

(30 minutes allowable downtime per day for maintenance). Receiver: A means to remove one panel at a time from the conveyor placing it in an adjacent tray."

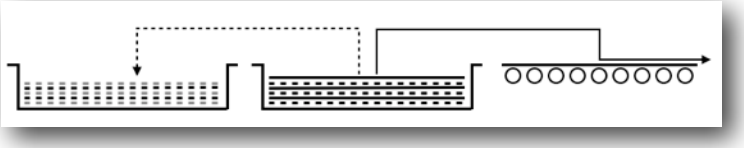
Mike handed the sample back to Aaron. "One way to approach this is to consider the 'material path' options. I did a little thinking on this last night."

"Great." Aaron said. "I have some thoughts on it as well. Mike, go ahead and get us started. For now I suggest we each keep notes in our individual lab books and later, perhaps when we get there, we can combine our ideas."

The waiting area was filling in.

Mike sat between Aaron and Melissa, pointing at notes and sketches in his notebook and began. "For the Feeder, each sheet, whether core or slip-sheet, starts from a horizontal position in the tray but at a progressively lowering elevation as the stack is depleted. In this first concept, the vacuum grippers lower until they touch the top item in the tray. Vacuum cups are all around the perimeter of the panel avoiding the exposed area to be etched. The vacuum is energized, gripping the top item and raising it a couple inches to clear the height of the rim of the tray. I didn't know about the slip-sheet requirement when I drew these last night, but in each case, there needs to be a sensor of some kind to determine if the top panel is a slip-sheet or an inner-layer core. Again, in this first concept, if the top layer is a core, it moves horizontally toward the conveyor, then it is lowered and released onto the conveyor."

"Suppose," Aaron said rubbing his chin pointing his pencil at Mike's sketch. "Suppose if the top piece is a slip-sheet, then it moves in the opposite direction, away from the conveyor over a slip-sheet tray, is lowered and released into another tray."



"I see where you're going with this." Melissa bravely added. "With this concept, the platform holding the vacuum grippers would have three stations, one over each of the two trays, and one over the conveyor." Now Melissa was pointing at Mike's drawing. "It would essentially pick a panel from the main tray in the middle and alternately place one to the left and one to the right."

"But what if for some reason," Aaron said, testing Melissa, "there are two slip-sheets in a row, one on top of the other?"

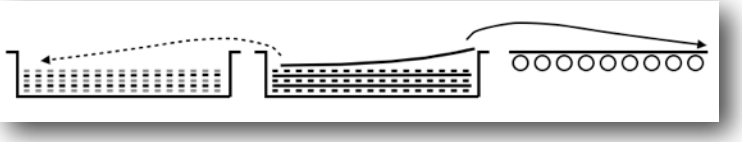
"A sensor or camera would have to detect that condition so the controller can take the right action." Melissa clutched her pencil tightly.

"Excellent." Aaron acknowledged. "Mike, I see you have some more concepts."

"The second option is similar to the first, except cores are not lifted from all four sides around the panel,

they are lifted by the leading edge and dragged onto the conveyor. There would need to be a set of vacuum grippers for the slip-sheets to be dragged one direction and a set of grippers for the cores to be dragged in the other direction."

"Can we do that?" Melissa squinted and looked up at Aaron.



"Probably not." Aaron said. "But Mike is pretty good at generating a lot of concepts, even ones that don't pan out, but usually we learn something from each one."

Melissa nodded.

"This next concept is not very practical, but I think we should include it. The inner-layer core edge farthest from the conveyor is gripped and elevated high above the tray passing over the other edge flipping the sheet over and lowering it onto the conveyor. It's like the dragging option but the panel gets flipped over."

"Hmm." Melissa thought. "That looks risky."

Mike looked up at Aaron for a second, then over to Melissa then continued.

"Now this next option is like the first, except the leading-edge of the panel gets swapped. The horizontal

sheet is raised vertically from the tray as before, then pivoted 180 degrees about a vertical axis to the side of the tray and the conveyor, then lowered onto the conveyor. I don't see any big advantage here, it just allows for a different type of translation of the panel; option one uses linear motion to move the gripper assembly, and this option uses rotational motion."

"Very creative." Aaron said.

"You're good at this." Melissa said to Mike.

"Well, that's what I have so far."

Aaron adjusted his posture then held his open notebook in front of Mike. "What do you think of this option?" Suppose our machine hangs over the end of the chemical DES conveyor such that our inner-layer tray is installed by the operator into a compartment directly over the end of the conveyor. Then, like your first option Mike, the gripping head raises the top panel up out of the tray, and then, instead of moving the gripping assembly and core horizontally, it's the tray that is moved horizontally away from the conveyor, then the gripping head lowers the panel all the way down onto the conveyor for release. The head then raises back up and then the tray returns horizontally to the starting position."

"That's good thinking." Mike said. "That kind of configuration could save floor space."

"But what if the top piece is a slip-sheet?" Melissa asked.

"Well," Aaron thought for a moment. "If you combine this concept with the one that drags the slip

sheet out of the way, then maybe it'll work."

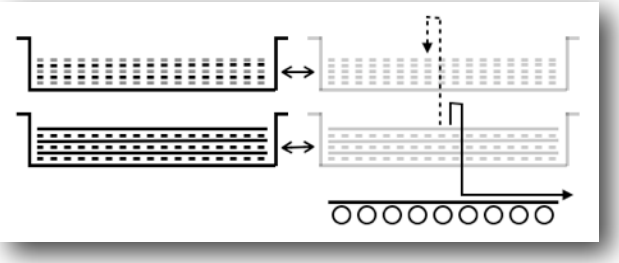
"Yah." Mike added. "If the top piece is a slip-sheet, then the main gripping head doesn't pick it up, a secondary vacuum bar reaches in and pulls the slip-sheet out to a compartment below or above the tray elevation."

"Why not have two trays above the conveyor?" Melissa blurted out.

Aaron and Mike turned to Melissa for an explanation.

"Suppose the gripping head has enough vertical travel to access panels at three elevations, the conveyor, the main core or slip-sheet tray, and one even higher, the slip-sheet only tray." Melissa sketched the concept in her notebook showing Mike and Aaron the details of her thought."

"I see what you're talking about." Aaron said.



"This way, there is no separate slip-sheet gripper. There is only one set of grippers and it only has to travel up and down. The trays are the only things that

move horizontally."

"I'm impressed." Mike said.

"I see what you mean by ideas building on each other." Melissa remembered.

"Melissa." Aaron asked. "Do you have any other ideas?"

"Well, I was thinking of copy machines and printers. A ream of paper is loaded into a compartment, then some rubber rollers drag or grip the top piece and send it through rollers and guides through the process." Melissa looked up to see the response from Aaron and Mike. "Well, I guess it isn't a good idea because the rollers could damage..."

"Wait." Mike said. "Let the ideas flow freely, even ideas that seem unrealistic or potentially bad."

"That's right." Aaron added. "Like the dragging grippers, experience tells me that part of every concept could be useful. Keep thinking like that..."

"Good afternoon passengers." A voice over the airport speakers interrupted their discussion. "This is a pre-boarding announcement for flight 52 to Tel Aviv. We are now inviting those passengers with small children, and any passengers requiring special assistance, to begin boarding..."

"I guess we'd better get ready to board. This has been a great start."

After boarding the 747, seated in the center seats of coach class, Aaron, Mike and Melissa listened to the inflight safety briefing, then continued their discussion.

The tight working space, meal interruptions, and flight noise prevented open and free conversation but with the use of sketches, they developed a few more concepts and began evaluating the pros and cons of each. Four hours into the eleven-hour and twenty-two minute flight, they began to wind down. After an in-flight movie, most of the passengers, including Mike and Aaron were asleep. Melissa couldn't sleep; this was here first trip over the Atlantic.

The flight was smooth, except for some turbulence descending over the Mediterranean and into Tel Aviv. At the baggage claim, each explained why they were visiting the country and then met their driver at the curb. When asked what the purpose of her trip was, Melissa pulled up a blank for a second—she had been so busy being fascinated by the flight, the plane, and the new destination. During the car ride from Ben Gurion International Airport to LIC-Asia on the north west corner of Tel Aviv, her face was against the window as she examined the people, the buildings, and the markets.

"Hello, My name is Gad Shalev. Aaron, it is good to see you again. Thank you for coming on such short notice."

Introductions were made and Mike, Melissa and Aaron received a tour of the facility before going to a conference room for discussions with several PCB process specialists. It was 2:00 p.m. local time on Wednesday and Melissa was beginning to drag from the jet lag and loss of sleep, but she had been encouraged to

stay awake until it was time to sleep locally. The group did not have as much time as they hoped, to compile all their notes.

"Okay," Gad began the conference room discussion. In the center of the table was a bowl of oranges, tangerines and pomelit, and a dish of flatbread and hummus. "We know you are tired and probably hungry, but, actually, we are all tired as well. The new smart phone announcement and aggressive time schedule has taken us by surprise and we are working hard to develop our chemical process concepts for all of our process lines. I think we should get right to it. Please help yourself to some fresh fruit and flatbread."

"We have come with a few potential automation concepts." Aaron opened his notebook and pulled out the specification sheet provided by Brandon and handed it to Gad. "Gad, would you please review this spec' sheet and tell us if it is the latest revision? We understand we will be focusing on the Feeder and Receiver for the new DES Line."

Gad scanned down the list of requirements. "Actually, this looks pretty good except we are not certain of the feed rate, or panels per minute, yet. We are still working out the chemistry and etch rate for these thin cores."

"That's okay." Aaron continued. "Can you describe the physical interface with the feeder and receiver? What does the end of the DES line specifically look like? What is the conveyor height? And how much room will there be at each end for automation?"

Gad removed a rubber band from a large roll of paper and smoothed the sheet out on the table placing books and coffee cups on each corner. It was a layout of the new process line. "Here is the LIC New York facility DES room. There will be three complete DES chemical lines needing three feeders and three receivers." Gad pointed sequentially at three long rows of equipment.

"It looks like we'll be building three of each." Mike said to Aaron.

"Actually," Gad added, "we are hoping that the feeders and receivers are very similar, and..." Gad pointed at another section of the layout. "This is our overflow area. If the product does well on the market, which we all hope it does, then we will add more DES lines here." Gad looked up at the visitors. "We plan to order six feeders and six receivers up front."

Aaron turned to Mike. "I expect we will actually build a total of fourteen machines. The first two will be the prototype feeder and receiver." Aaron then turned to Gad while pointing at the layout on the table. "I see something here that concerns me."

All eyes turned to Aaron and then to the layout where Aaron pointed.

"You show only two and a half meters from the end of each DES line to the wall. How much room do you need for operators and other personnel to walk around the end of each line?"

"A minimum of one meter. The panel carts are 80 centimeters wide."

Melissa did some quick calculations in her head.

"Only one and a half meters for the automation?" Aaron asked with concern. "That's gonna limit our options. We understand that the inner layer cores will arrive at this point with slip-sheets. So we need a machine that will remove the sheets before placing the panel on the conveyor. That usually takes more floor space. Has the DES chemical line design been finalized? Can it be shortened?"

"Like I said," Gad offered, "the line speed hasn't been finalized. Copper etching depth is a function partly of the amount of time the panel stays immersed in the chemicals; the longer the time, the more etching. The DES line has to be longer if we go faster..."

"I understand." Aaron acknowledged. "But with the very thin copper layer, wouldn't that make the etching time shorter?"

"Just in case," Mike spoke up, "we'll have to focus on automation options under one point five meters."

Mike redrew one of the lines in his notebook with a rectangle offset from the line. "Is there room for the automation to extend off to the side of the chemical line? And what are our height constraints?"

Jet-lagged, Melissa yawned and tried to stay connected with the conversation.

The team continued for another half hour, then Aaron suggested they depart, check into their hotel and rise a little early the next day to evaluate concepts and determine ways to develop a machine that can use minimal floor space and still reliably handle the slip-sheets.

"When we return tomorrow," Aaron said to Gad as they walked to the door, "let's look at inner layer core samples and discuss what type of gripping systems will be acceptable."

Thursday morning, the trio from America met in the hotel restaurant a little ragged. With the rush, some had forgotten some personal supplies and electrical adapters for the country. Mike was unshaven and Melissa wasn't able to plug in her hair dryer. During a breakfast of fruits, fish, cheeses, and breads they evaluated the material handling options discussed in route, settled on a likely approach, then returned to LIC and the same conference room.

Gad presented several samples of the inner-layer core material, explaining features and areas of concern. He was very insistent that if the photoresist was damaged by the gripping device, then the panel would not etch correctly and would be scrapped. He also stated that the panels had to be lowered slowly onto the conveyor and that they could not be dropped.

Various details of the feeder and receiver were then discussed considering safety, electrical requirements, operator interaction, and maintenance.

The ICA team then explained their main option for the feeder and receiver configuration, the one where the gripping head places the core directly on the DES conveyor.

"No, no, I don't think that will work." Gad stated. "We have requirements to contain the DES chemical

fumes. We always have complete enclosures over our chemical conveyors so there wont be any room for your machine to hang over the end of our machine."

"But in order to have space to put the slip-sheets somewhere," Mike explained, "we need to have two compartments, one for the core tray, and one for the slip-sheets, and I don't think we can do that in one and a half meters of floor space. We have to put our control box and pneumatic panel somewhere."

"I'm sorry," Gad insisted, "but we can only have a small opening on the end of the DES line for the panel to enter. It's the only way we can comply with air cleanliness regulations and protect our operators."

Mike pressed again, "There must be some..."

"Wait, Mike." Aaron interrupted. "We will just have to find a way." Aaron turned to Gad. "We will put our best minds on it and figure out how to fit all the requirements into one and a half meters off the end of the DES equipment. Are there any machine height constraints?"

The meeting continued for a while then after lunch the team met other participants throughout the facility and learned various perspectives on the PCBs, ergonomic requirements, preventative maintenance, and safety regulations. Then by 3:00 p.m. the group was headed south back to the airport along Samuel Street.

Melissa pressed her nose against the window on the right side of the car impressed with the deep blue Mediterranean Sea. They passed a sign that read, Golden Beach. "It's a lot warmer here than at home."

"It's too bad we can't see any historical sites while we're here." Mike said.

"I was thinking the same thing." Melissa added.

"Well," Aaron looked at his watch, thinking a moment. "Our flight is at 6:30. Driver, are there any historical sites on our way to the airport?"

"Oh yes, Jaffa, oldest city in the world. It's the place where Jonah set sail..."

"Is there something we can see in Jaffa and still make our 6:30 flight?" Aaron asked.

"I know just the place." the driver said.

For an hour the group walked quickly and enjoyed archeological sites, old stone buildings, ancient fortifications, a flea market, art galleries, shops, and the Jaffa harbor. Satisfied that they were able to experience at least a sample of the local culture, they returned to the car and on to the airport for the long flight home.

"Welcome back." Brandon greeted Aaron, Mike and Melissa in his office on Friday afternoon in Jersey City. "I know you're dog tired but I need a briefing from you so I can make plans for the team discussion planned for Monday. Good news? Or bad news?"

"Mostly good news." Aaron said looking to Mike and Melissa for confirmation. "There are some constraints that will be difficult to manage, but..." Aaron stopped, thought for a moment then said. "Melissa, why don't you give Brandon a run-down of our trip?"

Melissa took a quick breath, feeling put on the spot, but honored by the opportunity. She began from the

discussions in the Newark Airport on Tuesday, and within twenty minutes covered the whiteboard with most of what happened, with a little help here and there from Aaron and Mike.

Brandon listened intently, glancing occasionally to Aaron and Mike with a businesslike smile. "Okay, let's proceed with our system design review on Monday after lunch. Do you think you can have your suggested machine concepts drawn up and illustrated? I'd like to project them on the wall, or post them for all to see while we go through assignments."

"I can do that." Melissa said.

"Thanks Melissa." Aaron said.

"Aaron or Mike," Brandon said, "Could one of you update the specification sheet based on your meeting and make copies for Monday? I'd like to see specific DES interface requirements included."

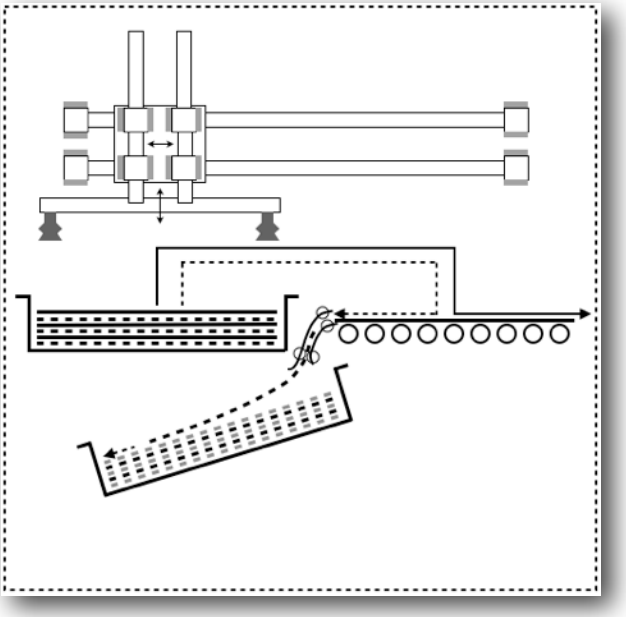
Melissa went to her desk. "I started work here almost a week ago and haven't spent any time at my desk." Since time was short, she decided to use her artistic skills and hand draw the automation concept instead of using the company computer aided design (CAD) tool. This would allow her to work from home for a couple hours over the weekend.

On Monday, Melissa finished her drawings between staff meeting and the design review and had them scanned so they could be projected.

During the design review, Aaron gave a trip report then explained the updates to the specifications including the limited floor space on each end of the

DES line.

Mike summarized briefly the various concepts that were considered, then Melissa explained the proposed solution that the trio had finalized while on their flight back from Israel.



"The machine will sit in line with the DES." Melissa explained pointing at her illustration with one hand and at the facility layout drawing on the table with the other. "There will be two compartments; one right next to the DES line with a conveyor, and one away from the DES line with a tray for the cores and slip-sheets. An overhead gripping assembly will pick up the top sheet,

move it over the conveyor, lower it, then release it onto the conveyor. The conveyor will be stopped when a sheet is placed on it. A sensor will detect if the sheet is a core or slip-sheet. If it is a core, then the conveyor will turn on and move the core into the DES to the right. If it is a slip-sheet, then the conveyor will turn in the opposite direction moving the sheet into these slots guiding it under the tray into this slip-sheet stack right here."

After the overview, the three responded to questions from the structures, software, and electrical teams, then action items were given and a rough schedule laid out. While the other groups began making preliminary plans, Melissa was assigned to design and build a prototype gripping head with input from Aaron and Mike. Mike was assigned to design the horizontal and vertical lifting system based on well proven actuator technology. In thirty days, the gripping system would be demonstrated on the samples they brought home, then the final go-ahead would be given for detail design on all the other parts.

For the next few days Melissa performed calculations to determine vacuum cup size and quantity as well as vacuum or suction levels necessary to lift the panels securely, minimizing the chance of dropping a sheet. She studied similar systems, online pneumatic catalogs, and anything else she could find to understand the issues associated with vacuum gripping. She ordered parts and began testing vacuum cups on sample panels.

A few days before the prototype demonstration,

Mike and Melissa put the final prototype hardware together and hooked up the vacuum cups and tubing to a vacuum generator. They made their first attempts on a workbench.

"Wow, it sure grabbed the core." Mike clenched his teeth looking at the core wrinkles on the panel opposite the cup. "I think we'll need to back off on the suction level."

"Do you think it will be a problem?" Melissa asked.

"Remember the thin layer of copper?" Mike said. "We can't buckle it or we might introduce hairline fractures. With your experience with thin membrane theory, you should do some analysis and see what the stress is."

"Okay."

"Also, the buckling might cause the photoresist to peel from the copper, causing etching in the wrong places."

"Oh my." Melissa wiped some sweat from her forehead. "It may take some time to study this thoroughly."

"Well, let me suggest that you get some vacuum cups that have supporting ribs inside. They're pretty common. That should reduce the buckling."

Melissa acquired a pressure regulator and found some rib-reinforced vacuum cups online and got them on order, but she didn't sleep that night. "Fewer cups, larger diameter, lower vacuum level..." She thought through the opposing constraints and decided on the best combination.

The demonstration turned out satisfactory so Brandon gave approval for everyone to move into full scale development. A full CAD model was developed, detail parts and drawings were defined, electrical schematics and functional diagrams were created, and the parts were ordered and fabricated.

Five months into the project the machine was coming together. LIC provided trays, stacks of inner layer cores, and slip-sheets for testing. Excitement was building on the third floor.

"Melissa!" Mike joined Melissa in the machine test laboratory. "Are you ready to show off your stuff?"

"What do you mean? Your horizontal servo slide and vertical pneumatic lifts are the real cool part of this machine."

"Well, I'm pretty excited about them, but it's gonna be nice to finally see some panels moved from the tray onto the conveyor. Shall we load the trays before everyone gets here?"

Mike and Melissa loaded a couple trays alternating cores with slip-sheets then loaded one of the trays into the machine.

Brandon was the last member of his automation group to enter the lab. "Okay everyone, I want to congratulate all of you for your accomplishment, a fully functional machine in just five months. It's time to work out any minor glitches, if any, before the customer preliminary demonstration next week. Aaron, are you guys ready?"

Aaron looked at Melissa and Mike, who nodded.

"Yep. Let's do it." Aaron said.

Mike turned the red emergency stop button and it popped out to the enable position. He then turned the power on and the machine made a few sounds and movements arriving at its 'Ready' state. The green light on top illuminated.

Melissa then pressed the "Cycle" button to start the process.

The gripping head moved horizontally over the tray of cores and slip-sheets, then the vacuum cups descended smoothly into the tray. A hissing sound was heard. The gripping head slowly ascended out of the tray with a core attached nicely to each cup. The core moved horizontally away from the tray over to the conveyor compartment, then it was placed gently on the conveyor and released as the hissing sound stopped. The conveyor moved the panel onto the makeshift DES conveyor. Everyone cheered.

The gripping head then repeated the same motion and descended once again into the tray. A hissing sound was heard. The gripping head slowly ascended out of the tray with...

"Wait!" Someone shouted. "That's not right is it?"

Melissa panicked, bent over looking through the safety glass of the machine at something she had not imagined would happen.

"The vacuum is sucking right through the slip-sheet." Mike said. A slip-sheet and core were attached to most of the vacuum cups. A corner of the core was dangling in midair. "Shall I hit the stop button?"

"Yes," Aaron said. "We don't want to drop the panel and damage these cores if we can help it."

Mike hit the E-Stop[4] which halted all motion and also removed the vacuum. The panel, and slip-sheet dropped from the grippers laying half in the tray and half on the conveyor.

Aaron rubbed his head.

No one spoke; no one knew what to say. Melissa and Mike stared at the machine and at each other. Aaron stayed calm and after a moment began to discuss the problem.

During the next few hours Melissa, Mike, and Aaron ran and reran the machine cycle varying vacuum pressure levels, vacuum cup size and placement on the panels, ascension speed, and any other variable that could be quickly adjusted. They found that if the vacuum suction was too small sometimes the slip-sheet would not stay attached to the cup; if the suction was too large, they would nearly always suck and grip the core right through the slip-sheet. At medium suction, sometimes the machine would only grip the slip-sheet as planned, but sometimes it would suck through and grip the core below. The machine was not at all robust and would not be successful. They certainly could not demonstrate it to their customer this way.

"What if we blow air somehow at the edge of the slip-sheet to get air separation between the paper and

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[4] E-Stop is a common abbreviation for the emergency stop button on machinery and automation.

the core?" Mike suggested.

They tried it but slip-sheets ended up sliding around and sometimes being blown out of the tray. It wasn't pretty.

"What if we reduce the suction level and add some adhesive pads next to the vacuum cups to grip the paper?" Melissa said.

They tried it but after a dozen cycles, the adhesive was depleted and gripping was unsuccessful as before. "Besides, adhesive residue on the photoresist could be a problem during etching." Mike observed.

"What if..." They continued with anything they could think of, but without success.

It was clear that the general solution they had built was not going to work and they would have to start over and do some major rethinking.

"This is so embarrassing." Melissa said hiding the true fact that she was terrified to have such a major failure on her first assignment. Determined, she did some analysis of the physics involved with the interaction between the layers. "How do we induce separation between the two layers while gripping the slip-sheet securely?" she thought. "These guys had a lot of faith in me. Now what am I going to do?"

By now it was late in the evening so everyone went home, down and discouraged.

It was dark, cold and rainy in Jersey City and the chilled humid air penetrated her hoody so she grabbed an extra layer to take a little walk. "Why didn't I think

of this problem before?" she thought. "Why didn't Aaron or Mike see this coming? They have years of experience. I was counting on them to keep me from making a fool of myself." She walked along a lighted street between tall buildings shielding her from the wind then into her favorite cafe and sat in the corner. For a moment, she remembered the warm blue Mediterranean.

"Hi Melissa, how's that new job going?" the waitress said. "The other day you were all excited about a big project you were working on."

"Oh, it's going pretty good." Melissa lied, wiping her nose with some tissue. "We had a bit of a challenge today."

"Oh yeh, you look a bit down."

"Could I have a strawberry shake?" Melissa avoided explanation.

"That's not your usual. On a cold night like this I would expect extra rich coffee."

Melissa just looked down at the napkin on the table. The waitress pulled a straw from her apron and laid it beside the napkin then went back to the kitchen.

Melissa picked up the straw, put one end in her mouth and, leaning over put the other end vertical on the flat napkin and breathed in. Slowly raising her head and straw, the napkin rose with the straw.

"Paper is porous." Melissa thought as she slowly reduced the suction until the napkin dropped to the table. She then looked in her wallet, pulled out a business card, and placed it flat on the table with the

napkin on top.

Again she picked up the straw, placed it vertically on the napkin and breathed in, a little harder this time. Slowly raising her head and straw, the napkin and business card rose with the straw. "I wonder if they will both drop at the same suction level?" Ever so slowly she reduced the suction and both napkin and card dropped at about the same time. "It takes more flow to keep the napkin gripped. Less flow for the business card. The card is less porous."

The waitress delivered the strawberry shake.

"The porosity is the problem." Melissa said in a quiet voice.

"No one has ever said that about our shakes before."

"Oh, I'm just thinking out loud. Thanks. Could I have another straw please?"

Before putting the other straw into the shake, Melissa put both straws in her mouth, placed the card and napkin on the table such that the card was sticking out from under the napkin enough for one straw to be on the card and the other straw on both the napkin and the card. Melissa sucked and raised her head lifting the layers from the table.

The waitress looked over her shoulder at Melissa.

As she slowly reduced the suction, the straw on the napkin lost grip first. "Air is flowing through the napkin all around the straw and into the straw losing suction and grip. We need paper with less porosity."

Melissa put one of the straws into the shake, then for the next fifteen minutes alternated putting her mouth

on each straw as she continued her experiments. She tried tissue, napkins, and even the check from the waitress. The less porous the top layer of paper, the better the probability of gripping the paper and not gripping the card below. "I wonder if our customer would allow us to choose the type or porosity of slip-sheets used in the process?"

Melissa paid the bill then walked to the cafe door. "Where could we get dense paper immediately so we can try it tomorrow, or even tonight?" Melissa pulled out her phone and selected Mike's number.

"Hey Mike, I've been thinking hard on this one and..."

"Yeh, me too. I really think this solution could be made to work if we change the slip-sheet paper. We need heavier bond, less porous paper that won't scratch the photoresist."

Melissa balled her fist, stunned that Mike had taken her thunder, but excited that someone else agreed with her theory.

"Melissa, are you there?"

"Yes, I was just amazed that we were thinking the same thing."

"I'll take that as a compliment." Mike said.

"Where can we get some nonporous paper, large in size and lots of it for our testing?"

"Well," Mike said. "I was just at Walmart the other day with my daughter picking up colored poster board for her science display. Let's pick up a stack of posters for starters."

"Good idea." Melissa responded. "I wasn't thinking of paper that thick. I live near the market and I could ask the meat department if I can get a roll of butcher paper. It's thick and coated with some kind of shiny surface. It doesn't leak so it's probably..."

"Excellent." Mike interrupted. "Let's try to get them tonight or at least first thing in the morning so we can cut them to size and run some more cycles."

"I won't be able to sleep. I'm too anxious. Is there any way we could try it tonight?"

When Aaron arrived at the lab the next morning, he found Mike and Melissa running cycles on the new machine. "What's going on?" There were pieces of butcher paper on the floor. "Have you guys been at this all night?"

"Well," Mike said. "After we left last night, some ideas came up and we came back in to give them a try."

Melissa adjusted the straw tucked behind her ear and noticed that Aaron was carrying a large roll of something. "What's that under your arm?"

"I realized last night," Aaron said, "that the machine works fine on cores, without slip-sheets, so we just need a way to have it respond to the slip-sheets in the same way it responds to the cores. Everything needs the same..."

"Porosity?" Mike and Melissa called out in unison.

"Yes." Aaron acknowledged. "So, I remembered a roll of mylar in the old drafting room closet. We haven't used this stuff for years, now that everything is done on

CAD. Anyway, we can cut it into two foot squares and use it as slip-sheets."

"That's what we were thinking."

"Do you think we can persuade our customer to use mylar or heavier paper slip-sheets?" Melissa asked.

"What they care about," Aaron explained, "is that the photoresist on the PCB is protected. If we can demonstrate our machine successfully using one of these materials, I'm certain an appropriate paper or mylar film can be found that will be acceptable to them."

Aaron, Mike, and Melissa spent the next thirty minutes cutting slip-sheets and re-stacking the PCB trays for trials. As they began a machine cycle, Brandon came into the lab along with several others from the automation group.

"Just in time." Aaron said with years of experience behind his confidence. "We'll explain in a minute, but first, watch these next cycles."

It worked perfectly and correctly every cycle. The core went into the DES and the slip-sheets went into the slip-sheet tray. No double-gripping, and no panels were dropped.

Alternating batches between mylar, poster boards, and butcher paper, the whole automation team watched and listened as the gripping team related their rise from discouragement to optimism over the past twenty four hours. Melissa was still carrying a straw around like a baton leading an orchestra.

Brandon's smile was for the success of the prototype,

and for the growth of the team including his newest hire.

For the next month, refinements were made, and work began on the other production units. The prototype was exercised continuously to check for endurance problems. One month before the production line was to be in full operation at LIC, the first machine was installed on the DES line and demonstrated. The customer was very pleased. Gad was in town for the demonstration. For four weeks prototype PCBs were fabricated on the new process lines and shipped to the phone assembly facility. Phones were tested and the green light was given for full production go-ahead.

The whole automation group from ICA was on hand for the jump to full PCB production at LIC. After a brief celebration, Brandon pulled-out some gifts; small boxes wrapped in butcher paper. He asked Melissa for her old cell phone then, with a smile, swapped it for a package.

Mentor Discussion and Exercises

Your experience as an engineer could be similar to Melissa's. You could be teamed with senior engineers to learn from them as well as to contribute new ideas from your perspective.

1. How did Aaron, Mike, and Melissa react, individually and as a whole, to surprises, setbacks

and problems?
2. Would you say that Aaron and Mike were good mentors?
3. Was Brandon a good manager?
4. How would you have led the team through each phase of this program?
5. What role did Mike play?
6. Should the most experienced person make all the decisions?

Product Development is an exciting adventure creating new or improved technologies, combining creative and academic skills, managing and nurturing relationships to bring the best out in everyone involved.

7. What engineering skills were necessary for this project?
8. What communication and personal skills were important?
9. Where did they go to get inspiration?
10. What did this team do well?
11. What could this team have done differently to be more successful?

Some engineering problems can be solved immediately, by applying good sense and skills; other problems take time, deep thought, experimentation, study, and conversation.

12. What happened when the team discovered that the

vacuum cup suction was reaching through the slip-sheet and gripping the adjacent panel?

13. What did the team do to solve the problem?

They experimented, adjusted variables, then took time to think, removing themselves from the present environment to rest and get fresh ideas.

14. Are all problems solved by one person, by the expert?
15. What is the advantage of working as a team?

If you like solving these types of problems and working with teams, you should seriously consider the satisfying profession of engineering.

SYNOPSES OF OTHER ENGINEERING STORIES

In **Get a Grip**, a young engineer is astonished to be assigned to an experienced team responsible for developing critical automation in the manufacture of smart phones. She travels with the team on a foreign customer visit, participates in creative concept generation, and helps the team through difficult setbacks and technical problems.

In **The Orbital Mechanic**, a solar flare knocks a space probe off course endangering a costly mission. A simple solution comes just in time from an unlikely source to save the spacecraft. In this story, learn how engineers use science, math and physics to get spaceships from Earth out to distant planets and beyond.

In **Foot Notes**, an engineer is faced with the daunting task of inventing a cost effective foot scanner in a short amount of time, driven to search for and consider possible solutions, taking clues from the near and far, the past and present, the people and objects all around. After much effort, old impractical perceptions are pushed aside by new achievable techniques.

In **Quick Step**, an engineering team is required to create a way to make customer arch supports (orthotics) in 30 minutes. They face hurdle after hurdle as they try to find an answer to a fundamental friction problem. In the end, after much frustration, determination and creativity, they stumble onto a completely different yet very elegant approach.

In **Cutting Edge**, a student engineering team wins a bid to develop an automated synthetic diamond cleaning

(blasting) machine. They familiarize and immerse themselves in customer needs, write specifications, research similar equipment, brainstorm solutions and evaluate their options. They experience the pain of unforeseen problems and the thrill of success looking externally and internally to find answers to complex questions.

In **Speed Reader**, two engineers have been working hard for weeks to prepare for and demonstrate the capability of their design. On the Friday of their last week of testing, the customer is not fully satisfied, launching the engineers into a last minute creative mode to find a quick and reliable solution, and to save their weekend plans.

In **The Ribbon Cutting**, three engineers work to create a complex system, a cutting machine with a blade that automatically morphs into shapes needed for unique products. Ideas and solutions are found all around them, in their hobbies, in other machines, in books and online. Their specific talents unite as they help each other move their company forward.

Use the following key words to search for additional Engineering Stories.

"Hardman" AND "Engineering Stories"

ABOUT THE AUTHOR

Ken Hardman graduated from Brigham Young University with a Master of Science degree in Mechanical Engineering. He is a Licensed Professional Engineer. As of this writing, he has worked 30 years in the aerospace and industrial automation fields defining, creating, researching, evaluating, managing, testing, and supporting satellites, aircraft, test equipment, and industrial automation. As an Adjunct Faculty, Ken has mentored and coached engineering students for many of those years. He loves to solve design problems, create useful solutions and encourage others to do the same.