ME 218: CARRY Us to Victory
Build Me a Forklift

Project Presentation on March 5 starting at 7:00 pm.
Revision 3: 2/5/25

Goal:

The goal of this project is to provide you with an opportunity to apply your knowledge to solve an open-ended problem. The task is to design and build, from scratch, a machine that can autonomously orient, navigate, and manipulate various elements of a pre-designed game in order to best an opponent, whether or not that opponent is an active player.

Purpose:

The underlying purpose of this project is to give you some experience in integrating all that you have learned in ME218 as well as your prior courses, with a particular emphasis on material learned in ME218b. To gain this experience, you and your team will design and implement an autonomous, untethered mobile robot.

Background:

After 3 months of searching for alien life (and avoiding listlessness with the help of your SPaDLs), your search crew finally encountered a planet with alien life. Unfortunately, the aliens were not friendly, and ended up capturing your crew, destroying the spaceship, and dividing your crew into teams of 3-4, forcing each team to work in a giant warehouse that receives many shipments. However, all is not lost. After seeing the ingenuity of your SPaDLs, the head of the warehouse (an alien by the name of Pharryl Dilbin) has made a proposition: whichever team builds an autonomous device that most efficiently transports/stores all incoming shipments will be allowed to return back to Earth.

The Task:

The shipments that the warehouse receives are delivered in boxes called CRATEs (Container Really Attracted To Electromagnetism). Your team's task is to design and build the highest performing CARRYER (CRATE Acquiring Robot that Raises Your Entities Readily), which is an untethered, autonomous, mobile platform capable of transporting newly arrived CRATEs to one of two designated STACKs (Station That Accumulates CRATEs Keenly). To evaluate which CARRYER is the highest performing, each CARRYER will face off against another CARRYER in seeing which CARRYER can transport the most CRATEs to their designated STACKs, with the winning CARRYER being the one with the most CRATEs in its designated STACKs. During the development phase, the arena will be located in SPDL, and for public presentation, it will be moved to the Building 550 Atrium.

"Quiz, Mike: Should you drive the forklift?"

Darryl Philbin, The Office

Specifications

Overview:

- ☐ Each team will construct a CARRYER.
- ☐ The CARRYERs compete in the arena to pick up and place CRATEs into slots in their two STACKs.
- ☐ While the goal of the project is to have CARRYERs compete head-to-head, the grading standard is to score in the absence of an opponent.

The Arena, The CRATEs, The STACKs, and The WALL:

- ☐ The Arena is an approximately 244 cm by 244 cm with exterior walls 8.25 cm tall. A top view is shown in Figure 1.
- ☐ The Arena is divided into two equal-sized regions by the WALL (Warehouse's Artificial Loading Limit) which contains the four STACKs (two for each CARRYER).

- ☐ No portion of any CARRYER may trespass the WALL into opponent part of the field in Figure2.
- ☐ Entering the opponent's side of the field in a manner that interferes with their robot's movement or operation will result in immediate disqualification. On the alien planet you are on, this is punishable by up to 1000 years in jail and a fine of up to 10,000 Blipper-Blops (Penal Code §442.17(a)) (a fine which you certainly can't afford to pay since you aren't paid for your work).
- ☐ A side view of the and STACK is shown in Figure 3.
- ☐ While the STACK is finalized, the aliens reserve the right to add additional components to the or the exterior of the STACK for decorative purposes.
- ☐ Each STACK is marked by a modulated IR beacon, with emitters located 31 cm above the surface of the Arena. The modulation frequencies of each beacon are shown in Table 1. Each half of the Arena only has 2 of the 4 beacons facing it. The STACKs with beacons facing the region are those in which a CARRYER can score. Beacons G and R will face one side while Beacons B and L will face the other side.
- ☐ A strip of 2.54 cm-wide black tape runs along the centerline of the Arena, parallel to the line of WALL. This tape is designed to aid in navigation.
- ☐ On each side of the Arena, there are a secondary strips of 2.54 cm-wide black tape, orthogonal to the WALL, that extend from one STACK to the Arena barrier on the other side. These strips have, at the end with the STACK, a 10.2 cm wide orthogonal "tee" to denote the end of the tape.
- ☐ At the other ends of these tape lines, 6 CRATEs will be placed prior to the start of the game at the indicated positions in the Arena.
- ☐ Each STACK has three levels. Placing a CRATE in the lowest region scores 2 points; in the middle region, 3 points; and in the top region, 5 points.
- ☐ The CRATEs are square lightweight 3D-printed polymer blocks approximately 50 cm in side length and 38 g in weight
- ☐ A sample drawing of a CRATE is shown in Figure 4.
- ☐ The CRATEs have embedded magnets on all six faces to assist with grabbing and placing. The magnets on the top and bottom faces have a stronger magnetic force compared to those on the four side faces

Table 1: STACK IR Beacon Frequencies

Beacon	Frequency (Hz)	Period (μS)
STACK G	3333	300
STACK B	1427	700
STACK R	909	1100
STACK L	2000	500

The CARRYER:

- ☐ Each CARRYER must be a stand-alone entity, capable of meeting all specifications described in this document. Only SPDL-supplied battery power is permitted. No more than two batteries may be used to drive motors that transfer force to the surface of the Arena.
- ☐ Each CARRYER must be able to automatically determine which side of the arena it has been placed on.
- ☐ Each CARRYER must include an electro-mechanical indicator that changes based on which region it is in at the start of a game round.
- ☐ CARRYERs must be autonomous (no tele-operation) and untethered (battery power only).

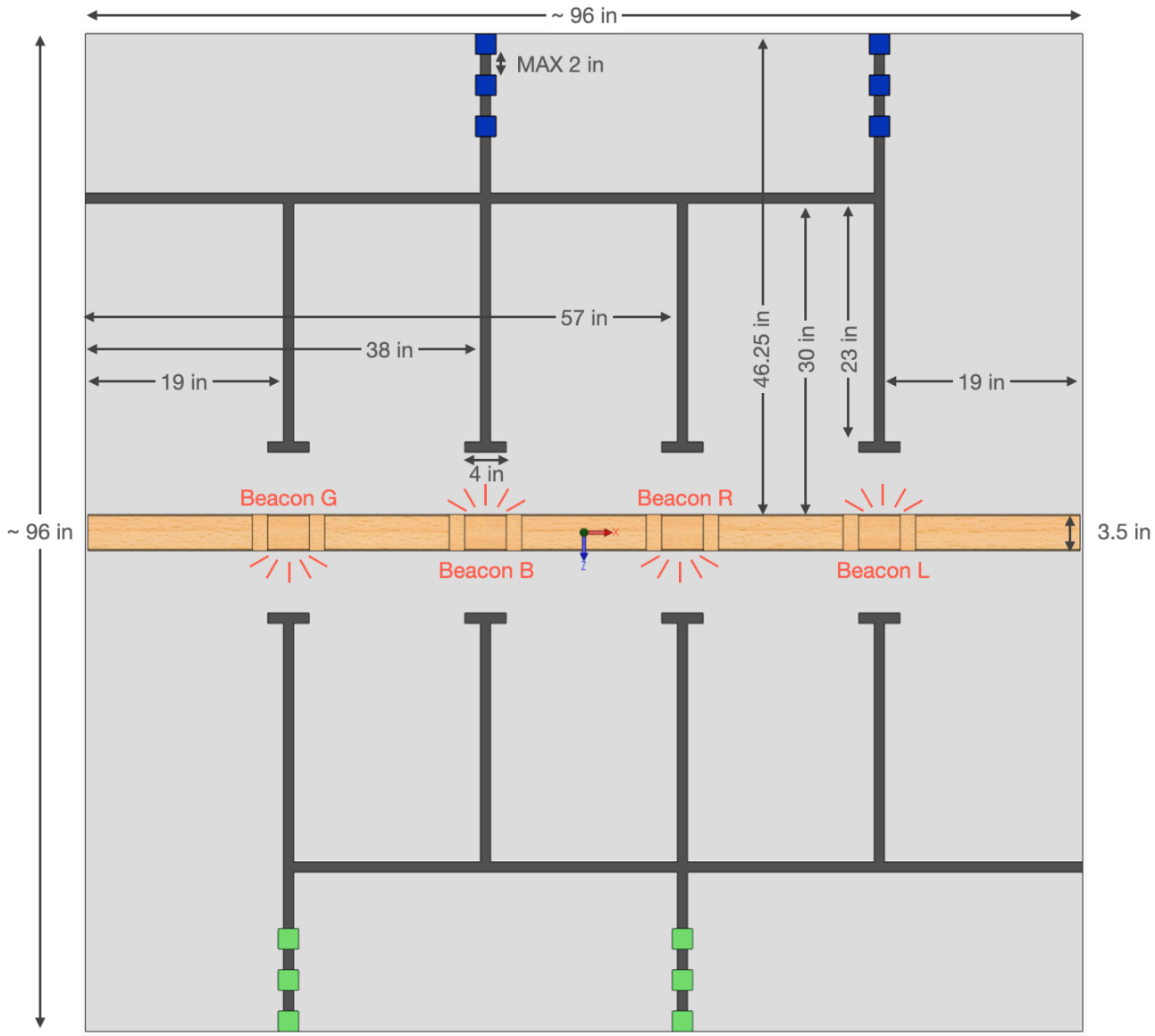

Figure 1: The playing Arena. Beacons B and L point towards the top side, while Beacons G and L point towards the bottom half. All dimensions are ± 2 cm.

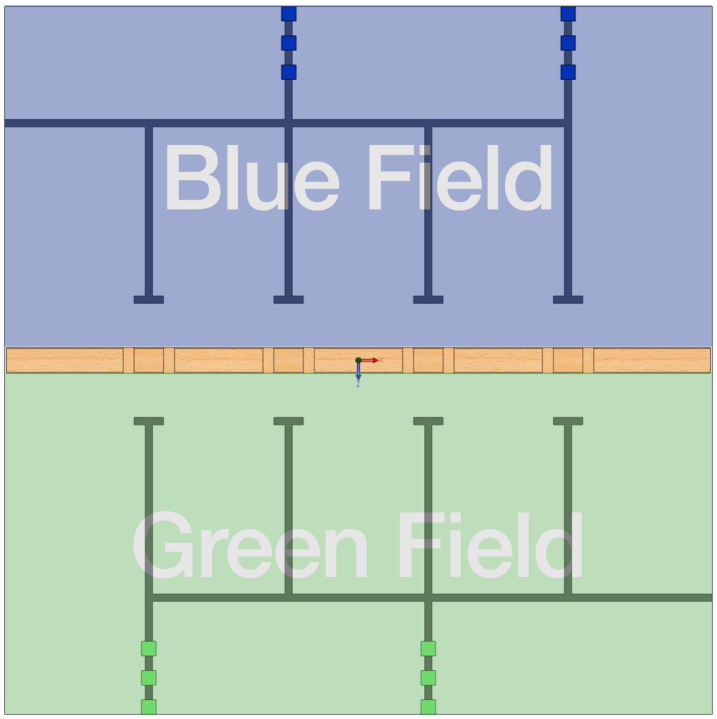

Figure 2: Field Definition.

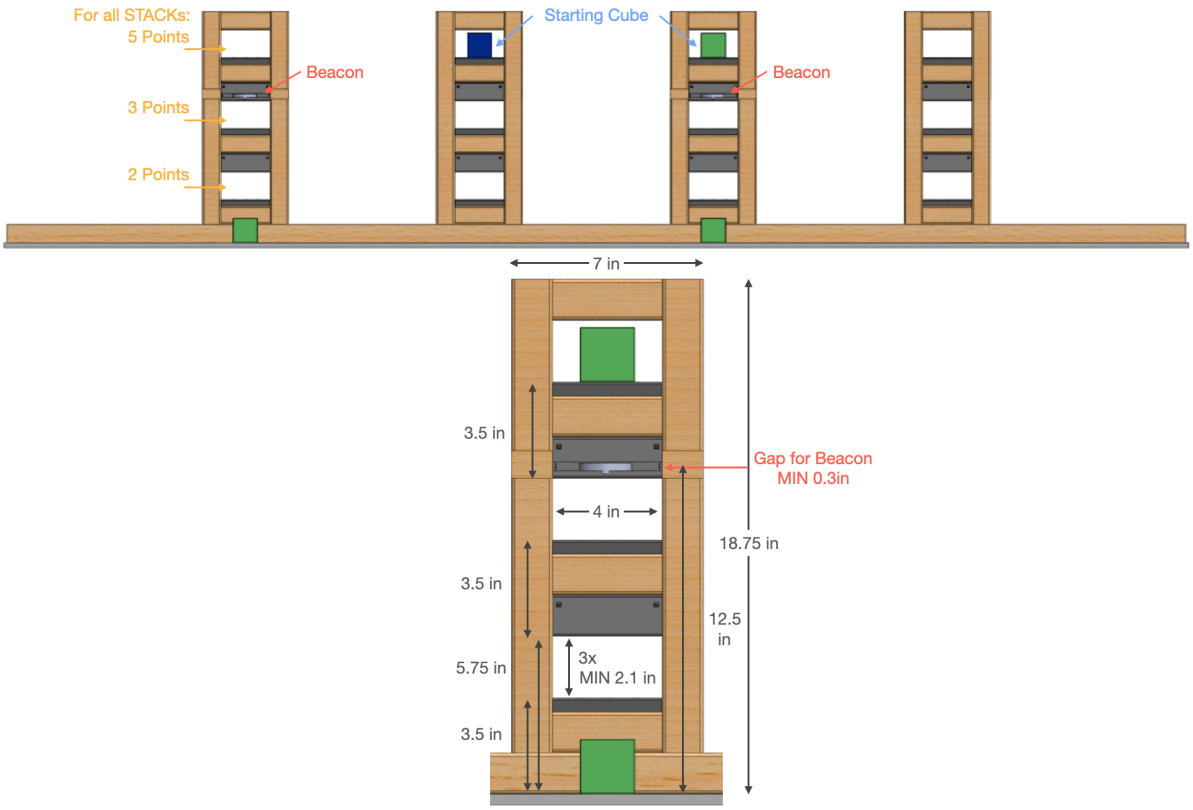

Figure 3: Front view of a STACK. All dimensions are ± 0.5 cm.

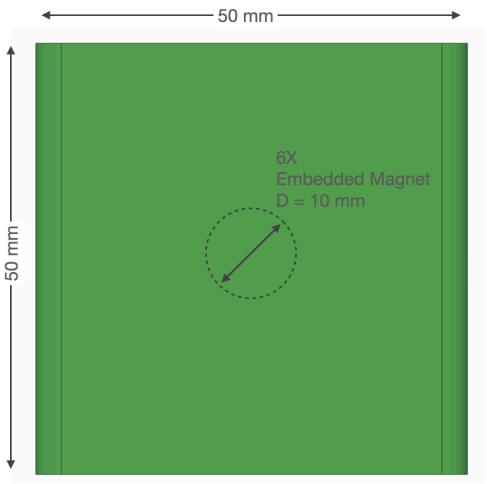

Figure 4: CAD Drawing of an CRATE. Dimensions are in cm. All dimensions are ± 0.2 cm.

- ☐ Parts of a CARRYER that touch the Arena floor must roll or slide, and **must be non-marking/non-marring**.
- ☐ Only the SPDL-provided motors may be used to drive anything that transfers force to the surface of the arena.
- ☐ At the beginning of a game round, your CARRYER must fit within a cube measuring 32 cm per side.
- ☐ After a game round starts, a CARRYER may expand to occupy a cube measuring 48 cm, but not part of the robot may extrude into opponent's field during any point of the game.
- ☐ Each CARRYER shall contain a network of processors consisting of, at a minimum, one PIC32 SPI leader and one PIC32 SPI follower device. How the necessary functionality is partitioned among the networked processors is up to each team to design. More PIC32's are acceptable, though not other microcontroller platforms.
- ☐ Each CARRYER must carry an easily accessible switch which shall cut power to the CARRYER completely. This switch is for safety, in case of software or hardware malfunction.
- ☐ The motor power supply for the CARRYER must be fused for protection in case of a hardware malfunction.
- ☐ Each CARRYER must be constructed as part of ME218b. It may not be based on a pre-existing or commercial off-the-shelf platform.
- ☐ Pharryl Dilbin has limited you to a total expenditure of **$200.00/team** for all materials and parts used in the construction of your project. Materials supplied to each team by SPDL or from the lab kit do not count against the limit. All other items count at their fair market value.
- ☐ Each CARRYER must provide an indication of when it thinks that a game round is in progress that is clearly visible from 7 m away. This indicator should be activated when the CARRYER determines that the game round has started, and be deactivated when the CARRYER thinks that the game round has ended.

Basic Game Play:

- ☐ The game is a head-to-head competition between two CARRYERs to move CRATEs into their STACKs.
- ☐ CRATEs may be moved by any mechanism that otherwise does not violate the rules, however, CRATEs must never become ballistic, unless it is falling off the tower.
- ☐ Before the start of each game round, each competing team will place their CARRYER in the marked

starting area in their region, centered on the black tape line. The teaching staff will choose the starting orientation of the CARRYERs.

- ☐ After the starting orientation of a CARRYER is chosen, the team responsible for the CARRYER may place one, and only one, CRATE directly adjacent or into the CARRYER of their choosing.
- ☐ The game round begins when a member of the teaching staff announces the start. At this time, a member of each team is expected to press a button on their CARRYER to commence gameplay. Any further interaction with the CARRYERs is prohibited until the game round ends.
- ☐ Prior to the start of the game, a single CRATE is placed at the top level of each CARRYER's closest STACK (meaning each team starts the game with a score of 5).
- ☐ Each game round lasts for 2 minutes, 18 seconds.
- ☐ During the game, each CARRYER scores by acquiring CRATEs and placing them in its STACKs. A CARRYER can also improve its relative score by pushing the opposing CARRYER's CRATEs out of the other STACKs. **Note that, for full credit in the Grading Session, a CARRYER need only place a single additional CRATE in one of its STACKs**.
- ☐ When a CARRYER detects that the round time has elapsed, the CARRYER must cease movement and deactivate its game-in-progress indicator.
- ☐ At the end of a game round, the CARRYER with the highest total score, as calculated by multiplying the number of CRATEs in each of its STACK by the point value of that STACK's level, and taking the sum, is declared the winner.
- ☐ If both teams have an equal score at the end of a game round, then a Sudden Death round is played. In Sudden Death, the first CARRYER to cause a score change in their favor (by either gaining a point or by making the opponent lose a point) wins.

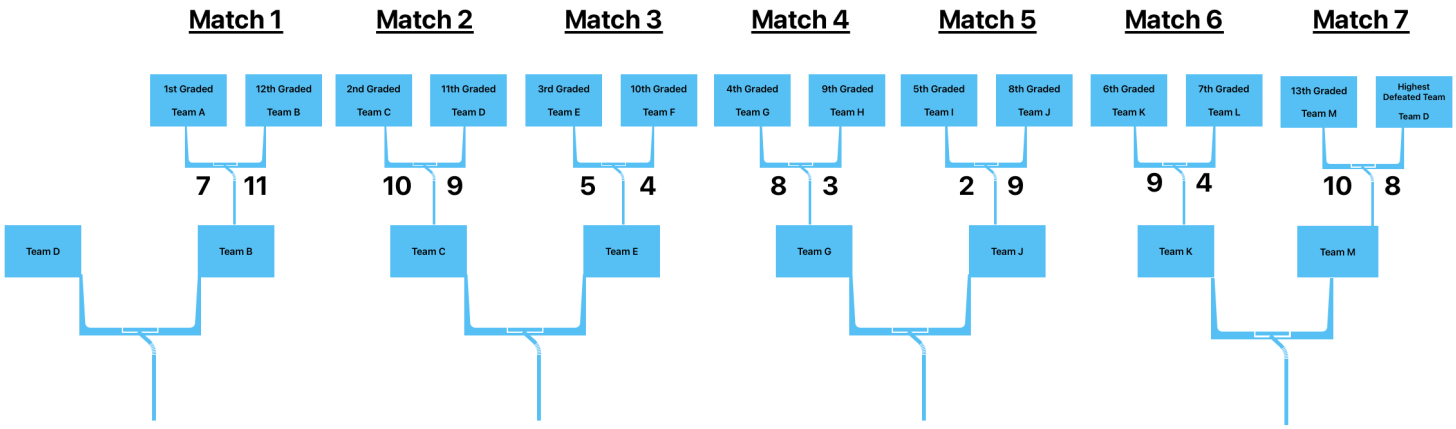

Figure 5: Example Progression from First Round. The initial seeding of the teams will be determined by the order in which each team completes the Grading Session. For example, this image uses "1st Graded" refers to the first team to complete the Grading Session. The scores that each team achieved in this example are listed below each team (ex. Team A earned a score of "7", while Team B earned a score of "11").

Making it Past the First Round:

- ☐ Since there are an odd number of teams, the following procedure will be used to determine which teams advance to the Second Round (an example is shown in Figure 5).
- ☐ The initial seeding of the teams (i.e. each team's opponent in the first round) will be determined by the order in which each team completes the Grading Session.

- ☐ In Matches 1-6, the 1st Graded Team (i.e. the first team to complete the Grading Session) through the 12th Graded Team will face off, with the 6 winners advancing to the second round. Of the teams that are defeated, the Highest Defeated Team and Second Highest Defeated Team (in this example, it would be Teams D and A respectively, as these two teams had the top two scores of the teams that lost) still have a chance of making it to the Second Round.
- ☐ In Match 7, the 13th Graded Team will face off against the Highest Defeated Team, with the winner of this match being the seventh team to advance to the Second Round (in this example, Team M won).
- ☐ To determine the final team to advance to the Second Round, the score of the loser of Match 7 (Team D in this example) will be compared to the score of the Second Highest Defeated Team (Team A, as previously established), with the highest scoring team taking the final slot in the Second Round (in this example, Team D still outscored Team A, so Team D made it to the Second Round, but if Team D had scored less than 7 points in their match with Team M, then Team A would have advanced instead).
- ☐ If there is a tie for Highest/Second Highest Defeated Team or between the loser of Match 7 and the Second Highest Defeated Team, Match Differential (i.e. how much the teams in question lost their match by; in this example, Team A lost by 4 points in their match against Team B, so they have a Match Differential of 4) will be used to break the tie, with the team achieving the lower Match Differential claiming the position (in the extremely unlikely event that two teams have identical losing scores and identical Match Differentials, a Sudden Death Match will be used to break the tie; in the uber-extremely unlikely event that more than two teams have identical losing scores and identical Match Differentials, the two teams that completed their Grading Sessions the earliest will face off in Sudden Death).
- ☐ This style of advancement promotes playing the game well (whereas the obvious alternative of First Round Byes promotes not playing in the First Round; Pharryl Dilbin only wants to see CARRYERs that sort CRATEs well advance to the Second Round) and keeps the First Round interesting for teams that lost.

General Rules and Requirements:

- ☐ No solderless breadboards are permitted in your CARRYER.
- ☐ Intentional interference with the operation of another team's CARRYER is prohibited.
- ☐ Each CARRYER must start and remain in one piece during a Game. Any locomotion of the CARRYER should cause all parts of the CARRYER to move.
- ☐ Your CARRYER may not, **IN ANY WAY**, alter the condition (e.g. mar the walls, or floor) of the playing field.
- ☐ Your CARRYER may not, **IN ANY WAY**, damage, including, but not limited to, jamming or toppling, the STACKs.
- ☐ The use of gases or liquids to impart force on any object is prohibited.
- ☐ Intentional jamming of your opponent's sensors is prohibited.
- ☐ There is no class-imposed upper limit on the number of processors employed; however, you must use only the PIC32MX170F256B. Tivas, Arduinos, Raspberry Pis, Teensys, Jetsons, and other microcontrollers are not permitted.
- ☐ You are limited to an expenditure of **$150.00/team** for all materials and parts used in the construction of your project. Materials supplied to each team by SPDL, from the lab kit, or the Cabinet Of Freedom do not count against the limit. All other items count at their fair market value. **If it's an issue with something from the kit, we will provide a replacement for free, but we can't guarantee latency. Be careful with your components.**
- ☐ A project logbook must be maintained for each group. A blog is appropriate to meet this requirement as long as it is made available to the teaching staff for review. This log should reflect the current state of

the project, planning for the future, results of meetings, designs as they evolve, etc. The project logbook will be reviewed at irregular intervals for evaluation.

- ☐ A report describing the technical details of the system will be required. The report should be of sufficient detail that a person skilled at the level of ME218c could understand, reproduce, and modify the design. The report must be in website format, and be suitable for posting on the SPDL site.
- ☐ CARRYERs based substantially on purchased platforms are not allowed.
- ☐ All projects must respect the spirit of the rules. If your team is considering anything that may violate the spirit of the rules, you must consult a member of the teaching staff.

Safety:

- ☐ Your CARRYER should be safe, both to users and to spectators. The teaching staff reserves the right to disqualify any CARRYER considered unsafe. This also applies during testing, so keep your CARRYER speeds low enough so as to not cause problems.
- ☐ You should make a stand to support your CARRYER on a benchtop for testing. The purpose of the stand is to prevent an errant CARRYER from driving itself toward rapid unscheduled disassembly.
- ☐ CARRYERs must be stable in the presence of a 15 m/s wind.
- ☐ No part of any CARRYER may become ballistic.
- ☐ All liquids, gels, and aerosols must be in three-ounce or smaller containers. All liquids, gels, and aerosols must be placed in a single, quart-size, zip-top, clear plastic bag. Each CARRYER can use only one quart-size, zip-top, clear plastic bag.
- ☐ Red, Green, and *especially* Blue shells are prohibited. Any banana peels must stay within the confines of your CARRYER at all times.
- ☐ Any early celebrations will be penalized.
- ☐ Your CARRYER is not permitted to steal talent from any other CARRYERs.
- ☐ CARRYERs may alter the space-time continuum only during the public presentations, but must have their flux-capacitor registration available for inspection at all times.

Checkpoints

Design Review:

During the day on **2/11/25** we will conduct design reviews. Sign-ups for 1-hour time slots of three teams each will take place on a Google sheet. Each team should prepare a few **simple** presentation slides (scans of sketches are OK). **No code, no state diagrams, no circuits.** The focus should be on the overall design and how you are tackling what you think are the critical subsystems, as well as how you will partition responsibility between team members. You will present to members of the teaching team as well as to your classmates, so that all may hear about your ideas and provide feedback and advice.

"I like to stack crates! Stacking crates."

Michael Falk, The Onion News (2011)

First Checkpoint:

By **2/14/25**, your team must submit a system block diagram, a set of KiCad schematics, textual descriptions, and software design documentation (including a state chart) that describes the state of the design *at that point in time*. The designs need not be tested, but they must be comprehensive, addressing all major subsystems. For your submission to Gradescope, create a single PDF document that includes the system block diagram, KiCad schematic(s), your state charts, and a document describing, in words, your strategy for meeting the project requirements and identifying your robot's core functionality. Only one team member needs to submit your checkpoint documentation.

"Man, I work in the warehouse! I'm cool, I'm hip and I'm jive."

Michael Scott, The Office

Second Checkpoint:

By **2/19/25**, you must demonstrate communications between at least two PICs. Between them, these PICs must demonstrate the ability to control the motors of the locomotion system and the ability to detect an IR beacon. This demonstration may be a tabletop demonstration and may be done while tethered to a deveopment computer.

"[stacking sounds]"

Stakataka, Pokémon Ultra Sun and Ultra Moon

Third Checkpoint:

By **2/22/25**, you must demonstrate an instance of your (possibly) tethered, motorized platform moving, though not necessarily with integrated software. Your platform must be able to, starting from the start position on the field, locate an IR beacon and move towards it under coordinated control from multiple PICs.

Fourth Checkpoint:

By **2/27/25**, each team's CARRYER must demonstrate, untethered and in an integrated physical form, under autonomous software control:

1. The ability to move around the field.
2. The ability to locate the IR beacons and to identify your side.
3. The ability to find/pick up the CRATE initially placed by your team.

This will be tested by following the normal starting procedure for a Game, followed by your CARRYER performing the required actions.

"Stacks are a Last-In-First-Out Buffer."

Karl Gumerlock, ME218

Grading Session:

Teams must successfully complete a Grading Round by **3/4/24**. Unlike last quarter, the Grading Session this quarter is unscheduled - simply ask a TA/Karl at any point to be graded.

During a grading round, each team will be required to demonstrate that their CARRYER can complete a single round of the Game.

During the Game, your CARRYER must demonstrate, in a completely integrated form, all abilities detailed in Checkpoint 4, plus the ability to place a CRATE in a STACK and to cease all motion after 2 minutes and 18 seconds.

Evaluation for grading purposes will only occur during these rounds. If your CARRYER fails at its first attempt to demonstrate the required functionality, it must demonstrate that functionality twice in succession at its next attempt. This increase continues after repeated failed attempts up to a maximum of four required successive demonstrations.

"I feel like the deck is stacked against me."

Phrase people say when they're stressed about a situation

Public Presentation:

This will take place on **3/5/25** starting at 7:00 pm in the Building 550 Atrium. (Building 550 is where our classroom is located.)

At this event, members of the public will be encouraged to watch your CARRYERs battle for the title of Most Efficient CARRYER (and for your team to escape this alien planet)!

Report:

Draft due on **3/10/25** by 4:00 pm. The final version (with revisions incorporated) is due by 5:00 pm on **3/14/25**.

"Thank you Ed Carryer for making ME218!"

(Most) ME218 Students

Evaluation

Performance Testing Procedures:

One or more team members will operate the CARRYER during the performance evaluation. A competition among the class CARRYERs will take place after the final performance evaluation.

Performance Evaluation:

Performance evaluation will take place twice during the project, the first time at the Project Preview and the second time at the Grading Session. These are the only functional evaluations that impact your grade.

Competition:

On the night of the public presentation, a tournament will be held. **Performance during the tournament and has no impact on your grade.**

Grading Criteria:

- ☐ **Concept (10 %)** This will be based on the technical merit of the design and the implementation of all technical aspecs of your machine. Included in this grade will be the evaluation of the appropriateness of the solution, as well as innovative use of hardware, software, and physical principles.
- ☐ **Implementation (15 %)** This will be based on the prototype displayed at the evaluation session. Included in this grade will be an assessment of the physical appearance of the prototype and the quality of its construction. Particular focus is placed on craftsmanship and finished appearance.
- ☐ **Checkpoint Performance (10 %)** Based on demonstrating required functionality at **Checkpoints 1-3**.
- ☐ **Preliminary Performance (10 %)** Based on the results of the performance demonstrated during **Checkpoint 4**.
- ☐ **Performance (20 %)** Based on the results of the performance testing during the **Grading Session**.
- ☐ **Coaches' Evaluation (5 %)** Evaluation by your coach: whether you made use of their input before the design review, and during the course of the project.
- ☐ **Report (20 %)** This will be based on an evaluation of your written report. It will be judged on clarity of explanations, completeness and appropriateness of the documentation. Your report should be in the form of a stand-alone website and must include schematics, pseudo-code, state charts, header and code listings, dimensioned sketches/drawings showing relative scale, a complete Bill Of Materials (BOM) for the project, as well as a 1-page description of function and a "Gems of Wisdom for future generations of 218ers" page.

  To submit your report, you must **enter the URL to your site into a Google sheet that will be made available for that purspose**. The only file types in your final report should be HTML/CSS, JPEG/PNG or other viewable bitmap image files, and PDF files. Schematics should be vector PDF fils, not bitmaps. A reasonable resolution bitmap place-holder witha link to a PDF is the best solution to readability. **Do not simply place a link to the PDF of the schematic without a viewable preview on the web page.** Do not include .doc, .docx, .xls, .xlsx, or other files that require opening an application other than a web browser. Your site should be fully functional on both desktop and tablet web browsers. **Do not embed video files directly** into your site. If you want to include video, provide a link to a video-sharing site.

  It is critical that the URL of your report be entered in the Google sheet on time, so that the peer reviewing team has adequate opportunity to review it before class. Final versions of the reports, incorporating the review comments, are due by 5:00 pm on 3/14/25. Make sure to test all of your links prior to submitting your report. If the teaching team cannot open and browse your report website, then they cannot grade it!
- ☐ **Report Review (5 %)** Based on the thoroughness of your review of your partner team's report. Read the explanations, do they make sense? Review the circuits, do they look like they should work? Could this CARRYER realistically be built for 150? If, during grading, we find things that don't make sense,

or circuits that don't work, we will consult your review. If your review caught them, then the partner team will lose points on their report. If the review missed it, then the reviewing team will lose points for their review. The Report Review should be submitted in the form of a text document submitted to Gradescope.

- ☐ **Housekeeping (5 %)** Based on the timely return of SPDL components, cleanliness of group workstations as well as the overall cleanliness of the lab. No grades will be recorded for teams who have not returned all loaned materials.
- ☐ **Peer Reviews** Completing a peer review on CATME is a **required** component of the project. These reviews are not optional, and project work will be considered incomplete unless reviews are completed by the due dates.

Team Organization

While each member of your team has principal design responsibility for a specific functional area, the experience of the teaching team is that turning team members into dedicated specialists will be a mistake in the long run. Many 218 alumni from such silo-ed teams report that they regret not sharing in all of the technical aspects of the project, feeling that they have lost out on some of the experience. The teaching team encourages you to remember that, first and foremost, *the purpose of the project is to enhance your learning of the material*. An organization that deeply involves all of the team members in all details of the design, implementation, and debugging of all subsystems will not only provide a better learning experience, it will also prevent hangups during the integration and testing phase when the team "expert" on a specific subsystem is not available.

Mechanical Design and Robustness

Your machine must be rugged enough to survive your testing.

While the emphasis in lectures has been on electronics and software, don't forget the mechanical aspect. Historically, project failures are often due to poor mechanical design or implementation. Pay attention to craftsmanship, and put thought into how your design supports all of the loads that your robot will be subjected to–not just when it's operating as intended, but also when it receives bumps from other robots or humans that may also be testing on the field.

While in-class work sessions have focused largely on software implementation, keep in mind that, although computers are deterministic, the real world is not. Make sure that your software is built not just to handle what you hope will happen, but also to deal with everything that might happen that could cause problems.

When integrating several subsystems, although it may seem (and feel) slower, it is absolutely worth your time to make sure that each subsystem is as bug-free as you can get it prior to integration. Fast is slow and slow is fast.

Preventing Disaster

It is unlikely, even given the advice in the section above, that your CARRYER will be robust to a fall from tabletop height to the floor. To avoid the possibility of that happening, your team should create a stand/platform for your CARRYER that raises its wheels above the surface. With this stand in place, and your CARRYER perched upon it, if your electronics or software go haywire and your CARRYER spins its wheels uncontrollably, it will not drive itself off of a cliff edge.

Resources

Websites:

SparkFun	Seeed Studio	Jameco	Mouser
Newark	Ponoko	Adafruit	Hackaday
DigiKey	McMaster-Carr	HobbyKing	ServoCity

You may also find PlantUML and PlantText helpful for creating message sequence diagrams. WaveDrom can be used for timing diagrams.

Local Stores (Not applicable while quarantine is in effect):

Anchor Electronics in Santa Clara J&M Hobby House in San Carlos
Jameco in Belmont
TAP Plastics in various locations

Gems of Wisdom:

Be sure to check out The ME218 Archive for guidance from past generations.

Team Names:

Team names are a tradition in ME218b. Get inspired by your favorite duels, either real or fictional!

Revision History

Revision 0: Initial, figures still being worked on (2/7/24)
Revision 1: Figures and tables added (2/8/24)
Revision 2: Added diagram callouts, dimension tolerances, date fixes and minor edits (2/5/25)
Revision 3: Add CRATE weight. (2/5/25)