ME22007 Design, Materials and Manufacturing 2 - 2024/2025

Machine Design Exercise:

Automated Battery Module Assembly for Hovercrafts

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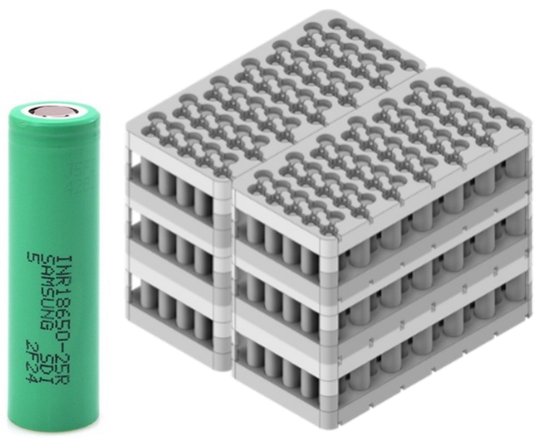

Contents

1. Project Context

Transport represents 28% of the UK's greenhouse gas emissions, with road traffic being by far the largest contributor within this category[1]. As part of the legislative commitment by the UK government to reach net-zero emissions by 2050[2], the sale of new petrol and diesel road vehicles will be phased out by the year 2030[3]. There is ongoing and fierce debate regarding the overall sustainability benefits of vehicle electrification and especially personal transportation.

Decarbonizing the power that is used to produce electric vehicles (**EVs**) and their batteries is likely to result in electric vehicles and emerging personal transportation means that have less overall environmental impact than their petrol and diesel counterparts. As such, we are likely to see significant growth in the electric vehicle arena, including **hovercraft vehicles**[4] and the batteries that are used to power them.

2. Project Scope

You will work in teams to design a machine that automatically assembles battery modules for electric hovercrafts

In the not-too-distant future electric hovercrafts will be powered by large battery packs, otherwise referred to as accumulators. The accumulator supplies power to an electric motor to propel the hovercraft. **The task at hand is to design a machine capable of automatically assembling the battery modules,** which are crucial components of accumulators with precision and efficiency as the market demand is expected to grow exponentially.

The anatomy of an EV accumulator is as follows:

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[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/862887/2018_Final_greenhouse_gas_emissions_statistical_release.pdf

[2] https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law

[3] https://www.gov.uk/government/news/government-takes-historic-step-towards-net-zero-with-end-of-sale-of-new-petrol-and-diesel-cars-by-2030#:~:text=Step%202%20will%20see%20all,will%20be%20defined%20through%20consultation.

[4] https://tech-pr0n.gadgethacks.com/news/real-life-star-wars-hover-bike-could-be-future-personal-transportation-0138851/

i. Individual ***cells*** perform the basic function of a rechargeable battery, converting chemical energy into electrical energy and vice versa. These are the fundamental building blocks of the accumulator.

ii. Multiple cells are connected to create a battery ***module.*** Within a module, cells are connected in both series and parallel to deliver the required voltage and capacity (amount of energy) to suit the application. The module also provides structural support and a thermal management scheme for the cells.

iii. Finally, multiple modules are connected to form a battery pack or ***accumulator.*** The accumulator contains sensors and a control system referred to as the battery management system (BMS). The number of modules in the accumulator dictates the supply voltage and the total available energy. This in turn governs the vehicle range, impacts the available space for packaging other vehicle subsystems, and contributes a significant proportion of the hovercraft's mass.

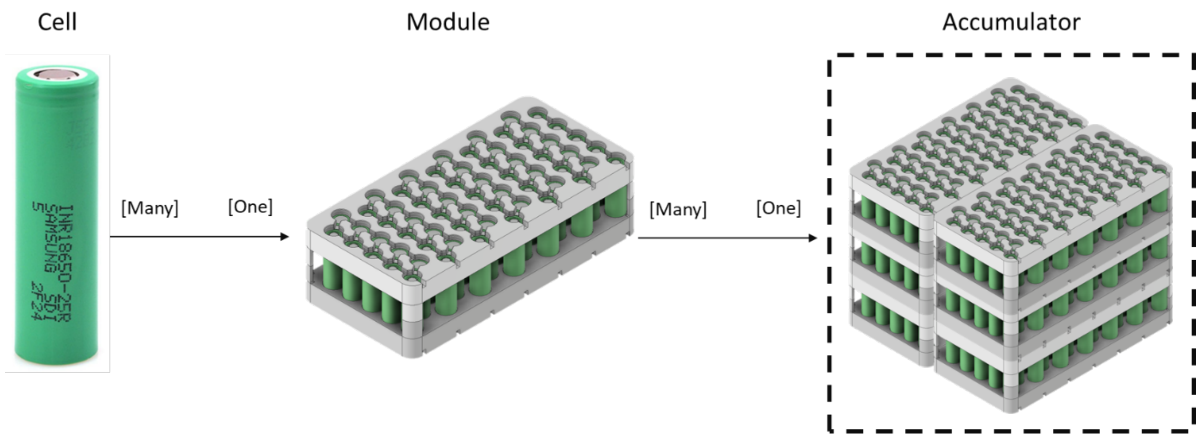

Figure 1: Diagrammatic representation of how cells and modules make up an accumulator. This is not exactly what they look like, but it is topologically accurate.

3. Machine Design

Depending on your group size, you will have to follow slightly different design briefs. Make sure you are following the correct brief before you begin. The brief for 3-person teams outlines a design problem with a smaller scope to match the team size. The overall machine process flows are given below. Please note that while processes may appear sequential, your machine does not need to follow the same sequence.

Stage	3-Person Team	4-Person Team
1	Automatically remove cells from their cardboard box. Cells are packed with the positive electrode pointing towards the top opening of the box. Each box contains 65 cells, packed tightly in a 5 x 13 rectangular array. The box is exactly as deep as the battery cells and the cardboard walls are 3mm thick on the four sides and the bottom of the box. You can assume that there are no flaps preventing access to the box and that boxes are loaded into the machine manually by an operator.	Automatically remove cells from their cardboard box. Cells are packed with the positive electrode pointing towards the top opening of the box. Each box contains 65 cells, packed tightly in a 5 x 13 rectangular array. The box is exactly as deep as the battery cells and the cardboard walls are 3mm thick on the four sides and the bottom of the box. You can assume that there are no flaps preventing access to the box and that boxes are loaded into the machine manually by an operator.
2	Retrieve Lower Carrier from a buffer (stack of Lower Carriers) and have it ready to receive cells.	Retrieve Lower Carrier from a buffer (stack of Lower Carriers) and have it ready to receive cells.
3	Insert cells into Lower Carrier, making sure you get the correct polarity. Each cell requires 10N to be pressed into the Lower Carrier.	Insert cells into Lower Carrier, making sure you get the correct polarity. Each cell requires 10N to be pressed into the Lower Carrier.
4	Retrieve Upper Carrier from a buffer (stack of Upper Carriers).	Retrieve Upper Carrier from a buffer (stack of Upper Carriers).

5	Align upper carrier above cells (and Lower Carrier) and force it down onto the cells that are standing in the Lower Carrier. To ensure all cells are pressed into the upper carrier correctly, the same per-cell force as above must be applied.	Align upper carrier above cells (and Lower Carrier) and force it down onto the cells that are standing in the Lower Carrier. To ensure all cells are pressed into the upper carrier correctly, the same per-cell force as above must be applied.
6	Eject the completed Battery Module in a conveyor of width 500mm.	Create the current path within your modules by applying self-adhesive copper strips to the designated pathways to connect the cells. Each side of the module requires coverage of 6 double rows and 1 single row. The copper strips are provided in 100-meter rolls of double rows - similar to duct tape, but pre-shaped to the required pathways shape. Each roll has an inner core diameter of 300 mm, with a copper thickness of 0.2 mm.
7	N/A	Eject the completed Battery Module in a conveyor of width 500mm.

Table 1: The general process flow that the machine must deliver

The following figures give key technical information and a visual representation of the cells, carriers and module. In addition, some more specific information is given for the conveyor and camera system.

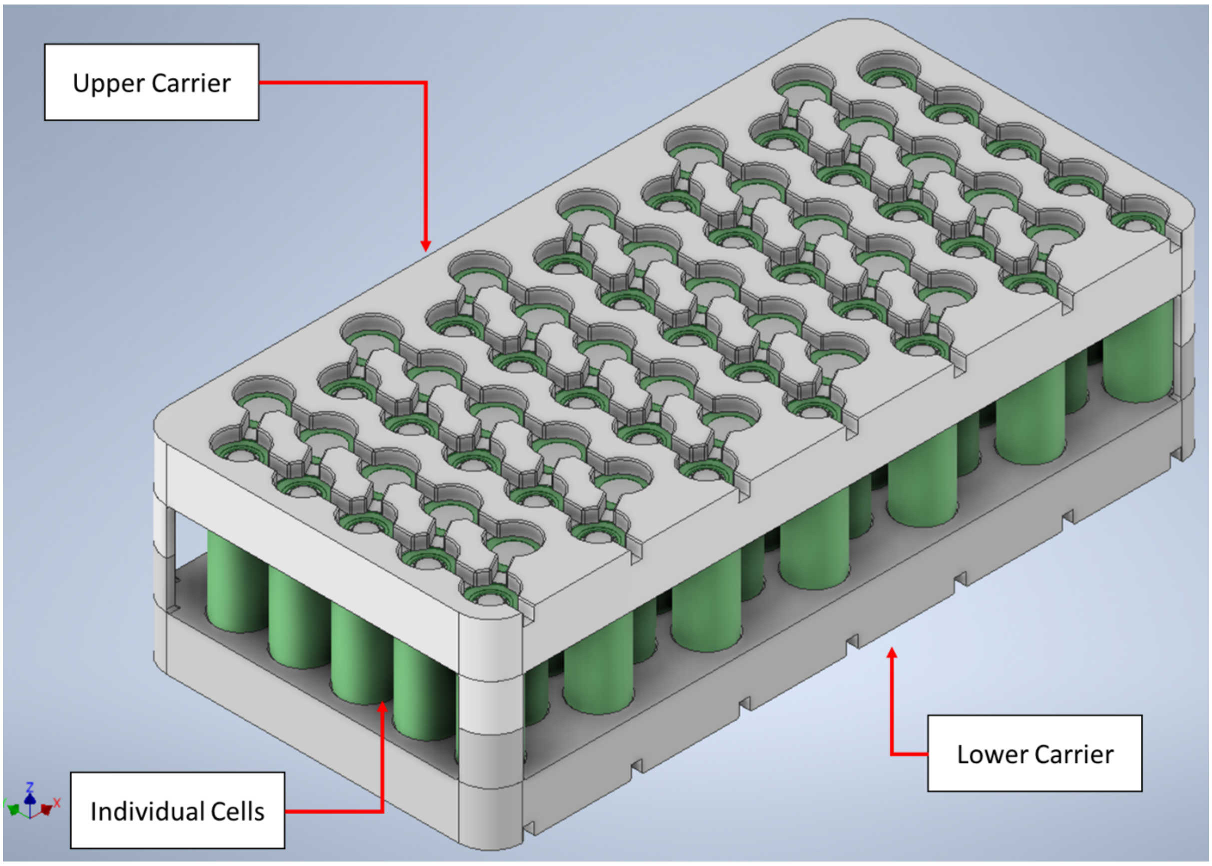

Figure 2: A single EV battery module. The individual cylindrical cells are pressed into a lower carrier and then an upper carrier is pressed down on top of the cells. Please note that the copper strips are not visible in this figure.

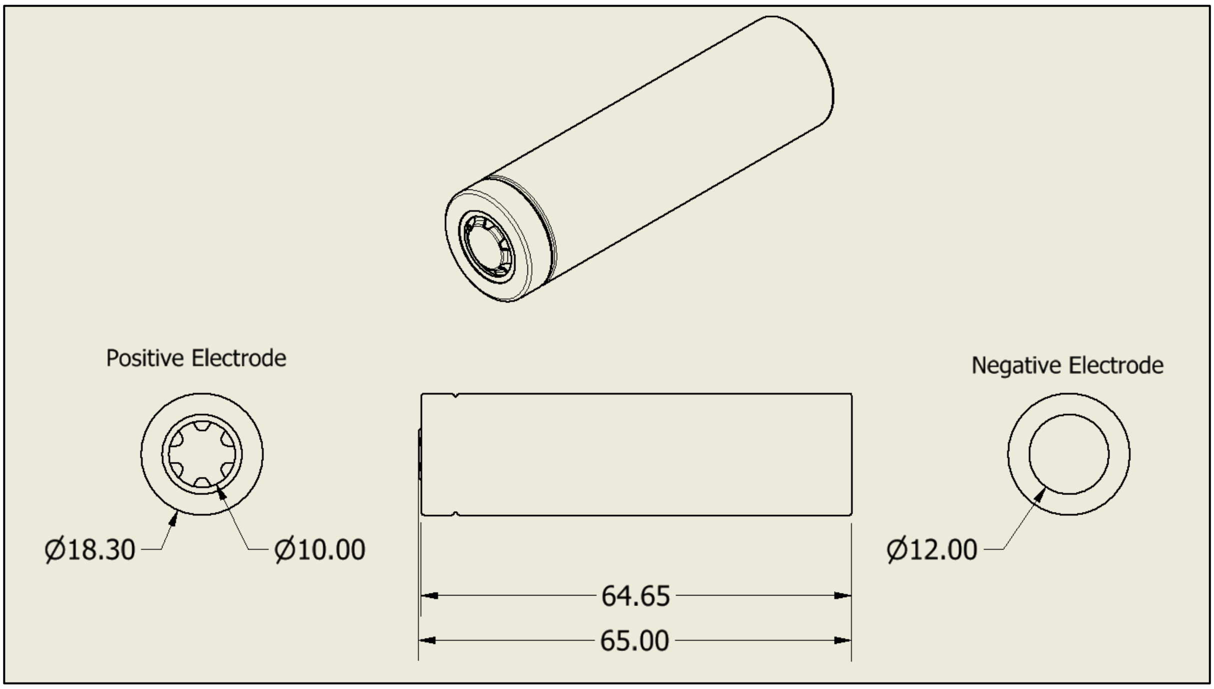

Figure 3: Panasonic NCR-18650B battery cell general dimensions [all units reported in millimetres]

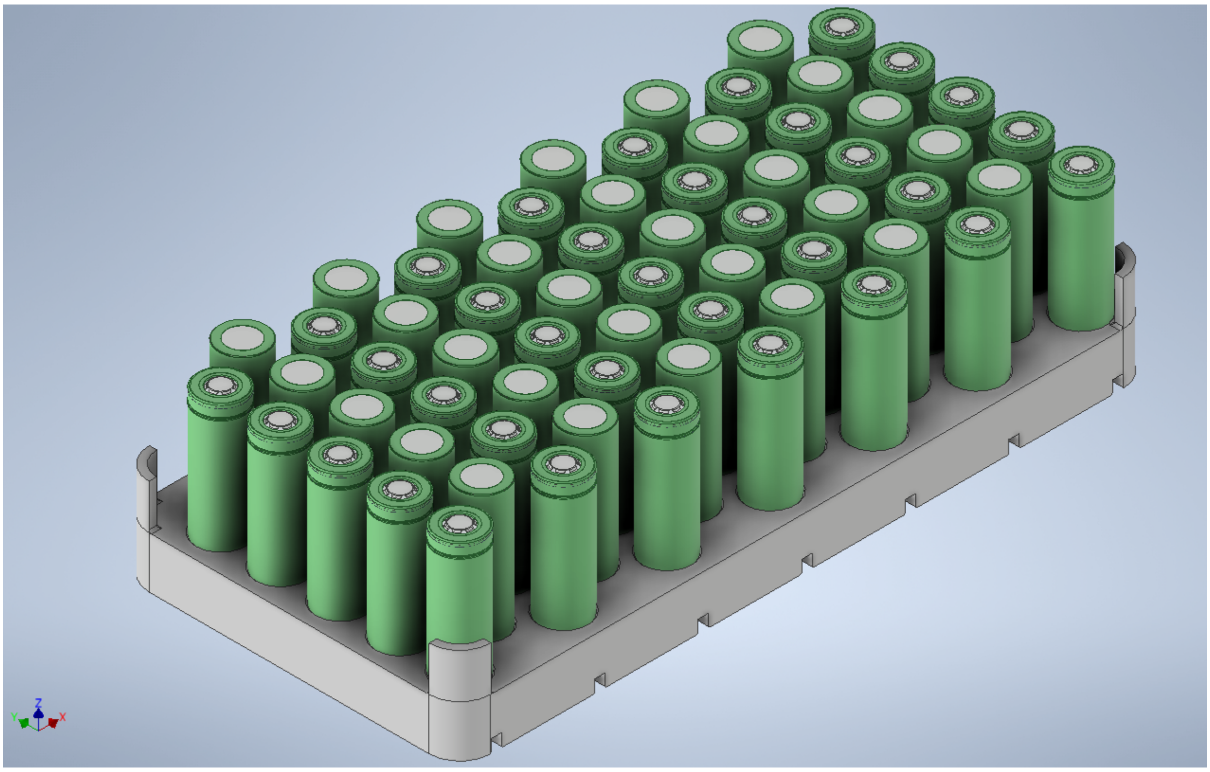

Figure 4: 65 cells inserted into the bottom carrier resulting in a 48V output and increased capacity. Note the polarity of the cells in each position.

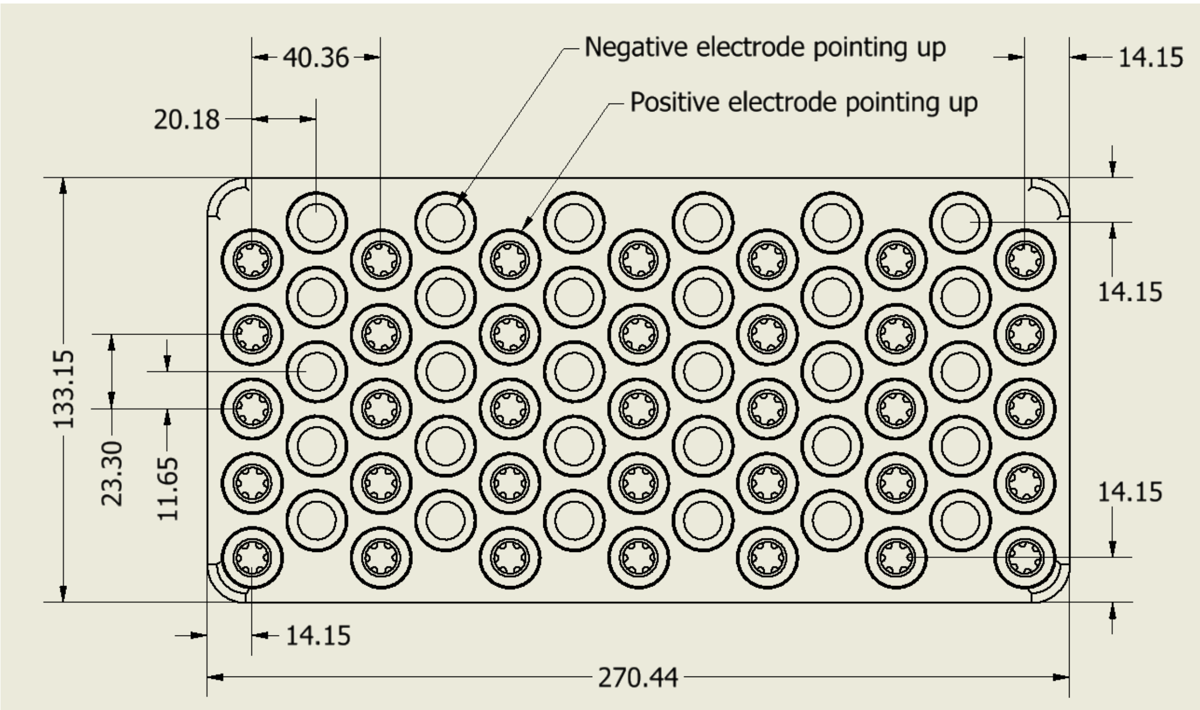

Figure 5: Plan view of cells stacked within the lower carrier, clearly showing the polarity arrangements of each cell and some of the key dimensions of the module [all units in millimetres]

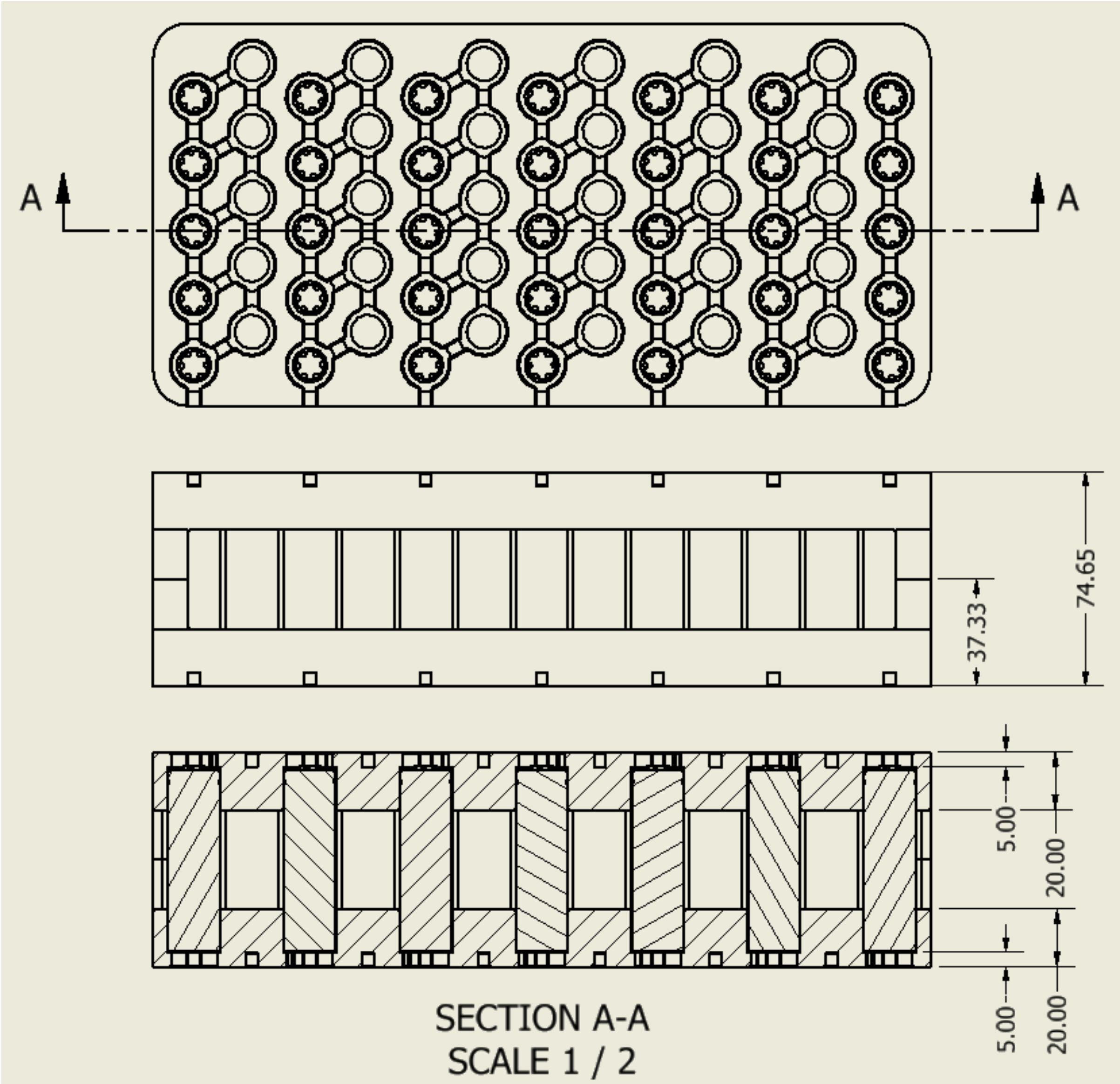

Figure 6: From top-to-bottom: plan, front and section view of the battery module. The plan view shows the upper carrier, and the section view shows how the cells are pressed into pockets in the upper and lower carrier to locate them.

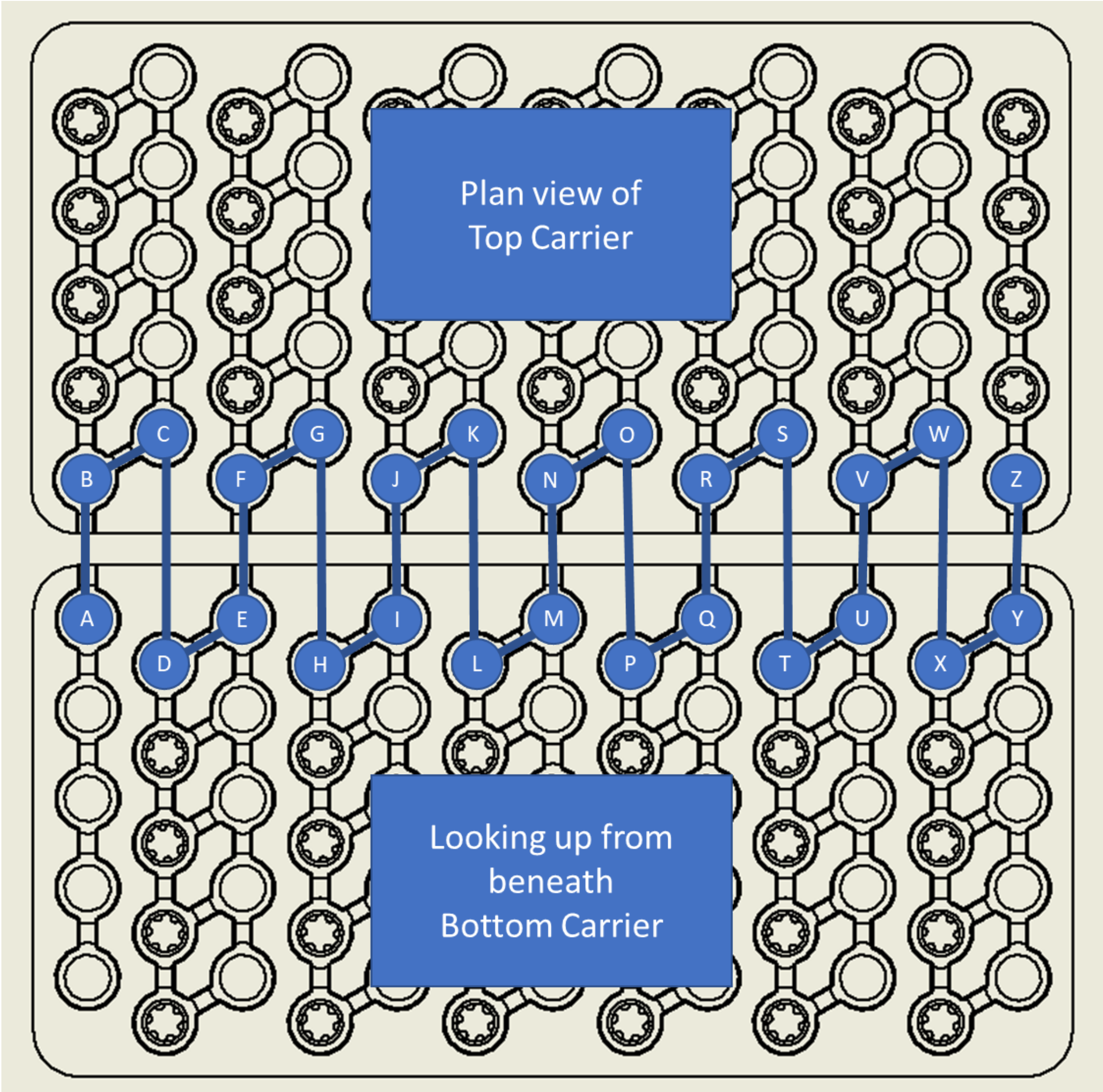

Figure 7: Diagram of the current path for a single set of series connections in the module. The current path of these series connections is taken in alphabetical order. The module has five such series arrangements that are connected in parallel to increase the capacity (life of the module). The copper strips enable the current path.

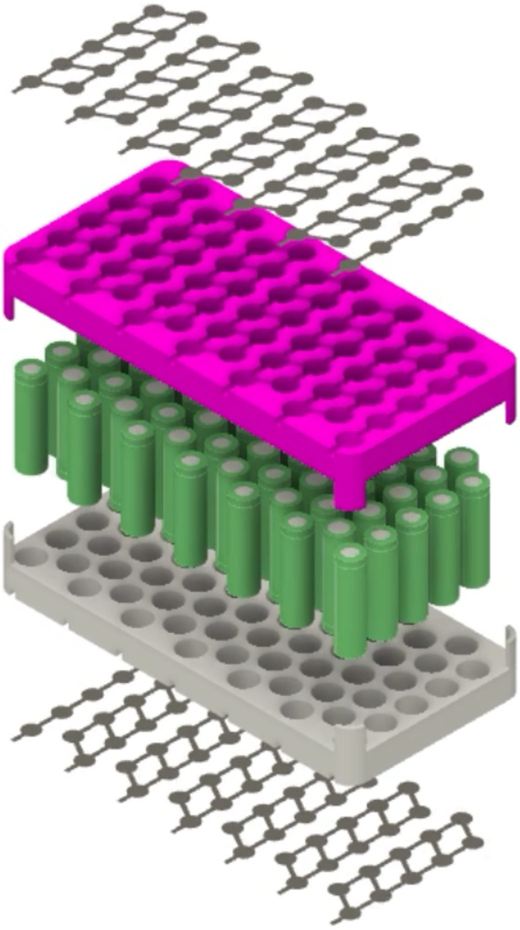

Figure 8: Exploded view of an assembled module

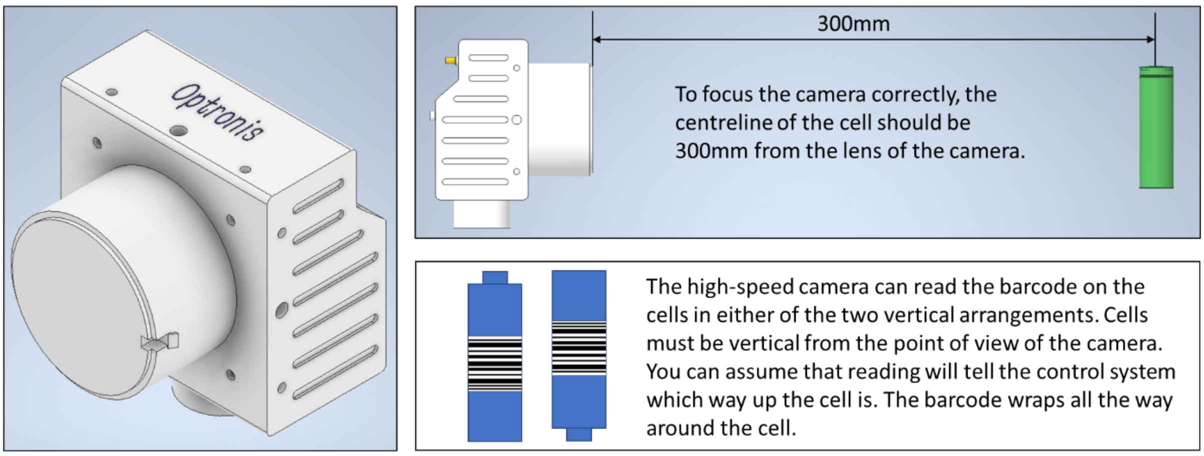

Figure 9: A high-speed camera can be used to read a barcode which is printed on each cell. Having read the barcode, the machine's control system will know which way up the cell is orientated with respect to the camera's field of view

Please see below for some useful pointers and system requirements:

- Although the process flow of the machine is given in stages, you should consider whether processes can happen in parallel – concurrent engineering is generally considered more efficient in principle. Also your machine does not need to look like a production line.
- Your machine needs to take less than 200 seconds to assemble one module. It can take less, but not more.
- The upper and lower carriers have the same design. They come to you in a stack. They are made of PEEK and are slightly chamfered to guide the battery cells in. Tolerance of H7 / k6. Between the cells and the axis of the holes, +/0.5 degrees is a suitable tolerance to avoid misalignment-related issues.
- The batteries being handled are recycled. It is essential to prioritize health and safety measures when dealing with them.
- You should consider how to store subassemblies or components in-between the process stages to create a production flow.
- Manual operators are generally available in the shop floor where your machine will operate and can restock the materials required to operate your machine a couple of times per shift. They can monitor stock levels periodically, but they cannot remain stationed in the machine during their shifts.
- The cost of the materials for your machine must not exceed £20,000. This is the cost of the parts to build your machine, it does not include manufacturing manhours. Your budget does not include the high-speed camera (1,000fps, cost £1,000), which is optional to use in your design.
- The majority of parts should be bought. If you need to design custom components or parts, consider alternative approaches to simplify or reduce cost. You will also need to evaluate material selection, manufacturing feasibility and manufacturing costs.
- Maximum allowable floor area for your machine is 15 m², with the flexibility to be any shape.

- The machine should work on a standard UK single-phase (220V) or three-phase (415V) electricity supply. A 6-bar shop air supply for pneumatic systems is also available.
- You are strongly discouraged from presenting a robot arm as your main concept.

4. Manufacturing Operations

In this section, you will consider the plant layout and manufacturing strategy for a new facility where the overall assembly of the hovercrafts takes place. You can assume this is a rectangular space with dimensions 30 m by 60 m.

1. Plant Layout: Provide a one-page concept diagram indicating the plant layout. The diagram should include clearly labelled departments of your choosing, reflecting the needs of the overall product. The departments need to be arranged logically, consistent with one of the types of layouts discussed in lecture. Entrance and exit points should also be labelled. Finally, label the location of the machine you designed within the facility. Relevant assumptions and justifications should be given on the following page (up to 400 words).
2. Material Flow: Calculations for the material flow associated with the battery module assembly machine within the facility should be included. Further calculations can be included if they support the chosen placement of departments. Figures for useful quantities can be assumed, as long as they consistent with the brief and your design.
3. Capacity & Inventory: With reference to the plant layout and an assumed annual increase in demand for battery modules of 20%, explain your production capacity strategy. A visualisation of the planned capacity and expected demand with respect to time in an appropriate plot is encouraged. List the types of inventory that the operation requires (up to 400 words).
4. Quality Management Plan: Produce a quality plan for the battery assembly operation. Within this, ensure you suggest one or more technologies for quality inspections, explain at which stage of assembly the inspection will take

place, and state whether SPC or acceptance sampling is the best quality control approach (up to 400 words).

5. Meeting the Needs of the Client

The brief provided in the previous sections **is not a complete specification**. You will need to collaborate with a team of engineers, including academics and PhD students, to refine the brief and develop a comprehensive Product Design Specification (PDS). Your team **must attend the Q&A session (week 21)** to ask targeted questions that will **help clarify and define the requirements** more precisely.

Some of this work can be done independently by applying sound engineering principles, using common sense, and conducting research. For instance, you should account for basic safety protocols when handling batteries in industrial environments, as well as physical constraints. Budgetary limitations must also be taken into consideration throughout the design process.

1. A **live Q&A session** will be hosted in the first week in which you can ask any clarifying questions and **help you form your PDS**.
2. After the Q&A, all clarification questions must be asked through **the Moodle forums** or in the **studio sessions**. You might want to delegate to one member of your team to track information in the Moodle Forum to ensure your team is on track with any additional information.

6. Machine Design Weekly Schedule

Week 21		Tuesday 18 February	Wednesday 19 February		
Lecture		10:15 – 11:05 Machine Design Intro	9:15 – 10:05 Q&A		
Studio		11:15 – 13:05			
Week 22	**Monday 24 February**	**Tuesday 25 February**		**Thursday 27 February**	
Lecture		10:15 – 11:05 From Idea to Blueprint		15:15 – 16:05 Plant Layout & Production Planning and Control	
Studio	9:15 – 10:05	11:15 – 13:05			
Week 23	**Monday 3 March**	**Tuesday 4 March**		**Thursday 6 March**	
Lecture		10:15 – 11:05 Actuators and Mechanisms		15:15 – 16:05 Capacity and Inventory	
Studio	9:15 – 10:05	11:15 – 13:05			
Deadline		**16:00 Stage Gate Deadline (Individual Formative Submission) 16:00 - Moodle**			
Week 24		**Tuesday 11 March**			
Guidance		12:15 – 13:05 Submission Guidance			
Studio		13:15 – 15:05			
Week 25	**Monday 17 March**	**Tuesday 18 March**		**Thursday 20 March**	
Lecture		10:15 – 11:05 Sensors and Control		15:15 – 16:05 Operating Sequencing and Activity Diagrams	
Studio	9:15 – 10:05	11:15 – 13:05			
Week 26	**Monday 24 March**	**Tuesday 25 March**		**Thursday 27 March**	**Friday 28 March**
Lecture		10:15 – 11:05 Design for Reliability		15:15 – 16:05 Quality management and Maintenance	
Studio	9:15 – 10:05	11:15 – 13:05			
Deadline					**16:00 Deadline Design Freeze CAD Drawings Submission, Moodle**
Week 27	**Monday 31 March**	**Tuesday 1 April**		**Thursday 3 April**	
Lecture		10:15 – 11:05 Q&A			
Studio	9:15 – 10:05	11:15 – 13:05			
Deadline				**16:00 Deadline Documentation Submission, Moodle**	

7. Deadlines and Description of the Submissions

The table, below, lists the three deadlines for the Machine Design assignment. Please note that weightings are for the assignment and not the entire unit.

Title	**Deadline**	**Weighting**
Stage Gate Formative Submission (Individual) Teamwork Feedback Fruits Submission	Tuesday 4 March, 4pm	
Drawing Hand-in	Friday 28 March, 4pm	50%
Documentation Hand-in Teamwork Feedback Fruits Submission	Thursday 3 April, 4pm	50%

7.1 Stage Gate Check-point Submission

This submission check-point is designed to ensure your work is on track and you are not getting left behind within your team. The majority of this work will be completed within your team, however you need to submit individually what you and your team have worked on through Moodle. **Your work is <u>not going to be marked</u> at this stage**, but will be re-submitted as part of your final documentation submission (week 27). You can update this work using feedback from the studio discussions before your final team documentation submission. This stage is to ensure that everything is on track with your team and you have a plan for completing the project as a team going forward. What you need to submit:

- Product Design Specification Table – Completed as a group.
- Morphological Chart – Completed as a group.
- Full-Machine Concept Sketch – This is your individual sketch.

You will also submit a **reflection on team performance** through Feedback Fruits as part of this process.

If a student fails to complete the individual stage gate submission a member of the unit team will get directly in contact with their student group to ensure this member still contributes to activities.

7.2 CAD Drawing Hand-in

In the past, students have become fixated on their CAD work and ultimately damaged their mark by not completing the accompanying documentation. For this reason, we ask for the technical drawings of the machine to be handed in the week before the final documentation. This is similar to a 'design freeze' in industry.

This hand-in requires you to produce:

1. At least one General Assembly drawing of the entire machine. You might choose to produce two drawings, one without the machine's covers/guards/casing.

2. A subassembly drawing for each machine subsystem. You might find that these relate to the morphological functions you created earlier, but this is not a requirement.

7.3 Documentation Hand-in

Documentation includes some specific elements which are outlined below. You may also include **an executive summary** to outline your work as an introduction. Please keep the titles of the documentation elements in **sections consistent with the numbering below** (3.1 PDS, 3.2 Morphological Chart etc.) and start a new page for each new section.

You will also be asked to submit a second individual and **team reflection in Feedback Fruits.**

Table 2: Description of each section of the documentation submission

Documentation Element	**Description**
3.1 Product Design Specification (PDS)	• A table of machine specs that are specific and measurable • Items broken down into themed subsections within the table • Items identified as either wish/must • Wish items given an importance weighting • Clear evidence of research or early analysis • An indication of how each metric would be assessed
3.2 Morphological Chart	• A table containing no more than 10 morphological functions that describe the essential behaviours/ capabilities/ functionalities of the machine • Each morphological function should have at least three concepts

Documentation Element	Description
	• Each concept is described with a photograph, small sketch or other visual representation
3.3 Three or Four Initial Concept Sketches (depending on group size – one per each team member)	• Combine different concepts from within each morphological function to generate ideas for full-machine concepts • Produce 1 x A3 sheet for each full-machine concept you worked in your team • Include a 3D sketch of the entire machine • Include additional 2D sketches around the edge to show key features/principles • Add useful annotations to describe how the machine works, introduce any key engineering features and explain the machine flow
3.4 Concept Selection and Evolution, and Final Machine Sketch	• Using a recognised concept evaluation technique (Pugh matrix, MCDA, pairwise comparison, etc.), systematically score your concepts You might want to consider which evaluation technique provides better justification in your case • Based on the scoring and any further design evolution, produce a final A3 sheet, which describes your final concept • Follow the same guidance given for the initial full-machine concept sketches (above)

Documentation Element	Description
3.5 Component Selection Method/Calculations	• The aim in this assignment is to buy as much components as possible, rather than designing and manufacturing it yourself. • Selecting and sizing the machine components requires calculations or the use of selection guidelines set out by suppliers. • For the major machine components (actuators, rotary tables, conveyors, grippers. Etc.), document your engineering calculations and selection process in a word document as you make your decisions • Avoid calculations that are for low-risk items or elements that do not relate to the major functions of the machine. • Avoid the temptation to reproduce work from previous assignments. We do not want to see 68 versions of the shaft design again!
3.6 Method of Operation Storyboard	• This is a storyboard that shows how your machine works from the point of view of the user • Each stage of the machine's operation should be shown with one or two well-selected screenshots or renders from your CAD work • Each stage should also be accompanied by bullet point notes that describe what is happening • Added value in the form of arrows, changes of colour to highlight key machine

Documentation Element	Description
	components, or even models of the battery cell/modules are greatly appreciated
3.7 UML Activity Diagram	• This is a diagram, similar to a flowchart, that you should use to describe the way the machine works from the point of view of the control system. • This diagram will communicate timing, synchronisations, logical decisions, the way sensors and control is used, and more • This is a formal diagram with a specific syntax, so pay attention to this
3.8 FMECA Table and Fault Tree Diagram	• Produce a FMECA table for one of your machine's subsystems • Produce a fault tree diagram for a different machine subsystem • Avoid choosing trivial subsystems that would lead to boring tables/diagrams • Try to be forensic and detailed in your analysis of where failures/faults might occur • Use specific engineering language rather than "shaft breaks"
3.9 Solution Specification	• A bullet point list that highlights the key features of the machine (much like what you would see listed within a tech-spec of a laptop on the Amazon website) that might be used in a brochure to buy this machine • This is NOT an opportunity to reflect on your PDS, please do not do this.

Documentation Element	Description
	• Try to focus on points that would be interesting to a prospective customer. For example, how long does it take to produce each battery module? How much floorspace is required? What sort of power/air supply is needed?
3.10 Manufacturing Operations	• Plant Layout: Provide a one-page concept diagram indicating the plant layout. The diagram should include clearly labelled departments of your choosing, reflecting the needs of the overall product. The departments need to be arranged logically, consistent with one of the types of layouts discussed in lecture. Entrance and exit points should also be labelled. Finally, label the location of the machine you designed within the facility. Relevant assumptions and justifications should be given on the following page (up to 400 words). • Material Flow: Calculations for the material flow associated with the battery module assembly machine within the facility should be included. Further calculations can be included if they support the chosen placement of departments. Figures for useful quantities can be assumed, as long as they consistent with the brief and your design. • Capacity & Inventory: With reference to the plant layout and an assumed annual increase in demand for battery modules of

Documentation Element	Description
	20%, explain your production capacity strategy. A visualisation of the planned capacity and expected demand with respect to time in an appropriate plot is encouraged. List the types of inventory that the operation requires (up to 400 words). • Quality Management Plan: Produce a quality plan for the battery assembly operation. Within this, ensure you suggest one or more technologies for quality inspections, explain at which stage of assembly the inspection will take place, and state whether SPC or acceptance sampling is the best quality control approach (up to 400 words).

7.4 Use of GenAI

The Machine Design Activity has been designated as a Type B assignment in terms of the use of GenAI i.e. it is permitted (but not mandated) as an assistive tool, to check spelling, language and grammar, and to help as a starting point for ideation.

8. Submission Format

The CAD and documentation will be submitted to a dedicated submission portal on Moodle. Your submission will comprise several PDF documents and these should be placed within a .ZIP archive folder (or MAC OS equivalent).

DO NOT TRY TO MERGE PDF DOCUMENTS

The final documentation will be submitted to a different submission portal on Moodle. You will have a mixture of text documents, diagrams, tables etc. Please bring these together into a single text document and then save this document as a PDF. You should change the size of individual pages within this document to A3 where appropriate. Once all elements are within the same text document, save it as a PDF using text document software.

DO NOT TRY TO MERGE PDF DOCUMENTS

For the final submission, your PDF document should take the following naming format where ‘XX’ is replaced by your group number.

GroupXX_ProjectDocumentation.pdf