Version NJC/06

MET 3

MANUFACTURING ENGINEERING TRIPOS PART IIB

Tuesday 28 April 2026 9:00 to 12:10

Paper 1

Answer not more than ***four*** *questions.*

Answer each question in a separate booklet.

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Write your candidate number not your name on the cover sheet on each booklet.

STATIONERY REQUIREMENTS

8-page answer booklet x 4
Rough work pad

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM

CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

You may not remove any stationery from the Examination Room.

Question 1

A company is launching an inhaler for respiratory disease management with an estimated annual production volume of 2,000,000 units/year. It consists of:

- Housing & mouthpiece (polymer):
    - Must withstand repeated cleaning (mild detergents), 100,000 accidental drops and 2 years of use.
    - Aesthetic requirements: high gloss, low sink marks, consistent colour.
- Flow-control insert (precision part):
    - Made of ceramic, it contains a micro-nozzle array controlling aerosol flow.
    - Critical dimensions: nozzle diameters 120 - 200 µm; surface finish requirement in nozzle region: Ra < 0.2 µm.

The final product assembly includes the placement of an insert within the housing body, housing closure, sealing, and functional test. There are three product variants with different colour configurations and stock keeping units (SKUs). It is necessary for the assembly system to have fast changeover between SKUs of less than 30 minutes.

(a) An injection moulding route is chosen for the polymer housing and mouthpiece.

(i) For each component, which physical properties must the polymer possess?

(ii) State *three* moulding quality risks and describe how to mitigate these risks.

[20%]

(b) For the insert:

(i) Describe a suitable production technology that can be used to manufacture the insert (use sketches to support your answer).

(ii) Describe three expected constraints or risks in your approach and how to mitigate these risks.

[30%]

(c) For the assembly:

(i) Propose a suitable assembly system configuration for the inhaler (use sketches to support your answer).

(ii) Describe two potential challenges when assembling the inhaler and note how you would detect any assembly failures.

[30%]

(d) A manufacturing engineer is keen to incorporate additive manufacturing into the manufacturing process. Discuss the advantages and disadvantages of this approach.

[20%]

Question 2

(a) A structural adhesives manufacturing firm makes Methyl Methacrylate Adhesives (MMAs) to sell directly to the automotive industry. At the moment, eight ingredients are weighed out and added manually in the right order to a single heated, stirred vessel, where the product is made. The firm have decided to invest in automation. There will be an automated raw material feed, where the programmed masses of six ingredients will be pumped from the storage area, heated to 75 °C and then transferred to the main vessel. The remaining two ingredients will first go into a pre-mixing vessel for 30 minutes prior to being transferred to the main vessel.

(i) This chemical processing firm is described as a *secondary industry* rather than *a primary industry*. Explain each of these terms, compare and contrast their common characteristics, and note why this firm is a *secondary industry*.

[20%]

(ii) Describe the process design steps the firm should carry out prior to procurement and start-up of the new, automated processes.

[15%]

(iii) The fluid properties of the MMAs are very important throughout the process. With the changes in the process, the firm wants to check:

- the material that comes out of the pre-mixing vessel will be suitable for mixing within the main vessel;
- the final product exiting the main vessel can be extruded into containers for sale;
- the time taken to cure (*pot life*) is the same as when manufacturing with the original, manual technique.

Describe the tests you would carry out to check these requirements have been met.

[20%]

(iv) Describe any three other quality checks you would carry out to assess the product's quality.

[15%]

(b) Many semiconductor handling tools for inserting, positioning and holding wafers in their chip manufacturing steps are made from engineered, high-performance ceramics.

(i) Explain why ceramics may be the preferred materials for this application.

[10%]

(ii) Describe how an engineered, high-performance ceramic component is manufactured.

[20%]

Question 3

A manufacturing organisation is experiencing excessive lead times and frequent delays in delivering a customised product to its customers. Senior management has approved a process improvement project to address this issue. You are a consultant hired to manage the project.

(a) You have identified the project activities as detailed in Table 1. All costs are proportional to the activity duration. You are contractually obligated to complete the project in 25 weeks.

Activity	**Predecessors**	**Planned duration (weeks)**	**Planned cost (£'000)**	**Staff required**
A	–	3	30	2
B	A	5	75	3
C	A	4	60	2
D	B	6	90	3
E	B	4	60	2
F	C	5	75	3
G	D, E	3	45	2
H	F, G	4	80	4

Table 1

At the end of week 12, the following information is available:

- Activities A, B and C are complete.
- Activity D has not yet started.
- Activity E is 50% complete.
- Activity F is 30% complete.
- Activities G and H have not yet started.
- The actual cost incurred to date is £255,000.

Assuming that your plan was to start the activities as early as possible, carry out an earned value analysis, and comment on the progress of the project in terms of its schedule and cost performance.

[30%]

(b) Following a resource review at this 12 week point, you realise that no more than 6 staff can be assigned to the project at any time. Assuming activity durations remain unchanged and that partially completed activities continue without interruption, propose a revised activity schedule for the remainder of the project that respects the resource limit. Determine the impact of the resource constraint on the project completion time.

[25%]

(c) The project is subject to a contractual penalty of £40,000 per week for late completion beyond the original planned completion date. The crashing options available for the remaining activities are shown in Table 2.

Activity	**Maximum reduction (weeks)**	**Additional cost (£'000 per week)**
D	2	25
E	1	50
F	2	20
G	1	30
H	2	35

Table 2

(i) Determine which activities should be crashed, and by how much, in order to minimise the total cost of the project.

[15%]

(ii) Evaluate the final project duration and the total cost incurred.

[10%]

(iii) Discuss why you might consider crashing additional activities beyond those you have identified in (c)(i).

[20%]

Question 4

(a) In the context of machine learning, briefly describe how *K-Nearest Neighbours* (KNN) predicts the class label for a new data point.

[10%]

(b) Briefly discuss how an "optimal" value of K can be chosen in KNN.

[10%]

(c) A company wants to classify whether a high-speed milling machine is likely to Fail or Not Fail. The company develops a binary classifier which is evaluated on a test set using a confusion matrix.

(i) Explain the performance metrics that can be obtained from a confusion matrix.

[15%]

(ii) Briefly discuss the Precision-Recall trade-off in the context of predictive maintenance.

[15%]

(d) The life of a certain type of electric light bulb is assumed to be normally distributed with a mean of 1400 hours and a standard deviation of 300 hours. The characteristics of the standard normal distribution can be found in Table 3.

(i) If the manufacturer guarantees a life of 1000 hours, what percentage of bulbs can be expected to fail to meet the lifetime guarantee?

[10%]

(ii) At what length of life should the guarantee be set in order for 95 per cent of bulbs to be found satisfactory?

[10%]

(e) Answer the following questions:

(i) Explain what archiving is and its role in stochastic optimisation methods.

[10%]

(ii) Describe two different types of archiving and how they would be used.

[20%]

Standard Gaussian distribution

If X has a Gaussian (Normal) distribution with mean μ and variance σ^2 (i.e. standard deviation σ), denoted $X \sim N(\mu, \sigma^2)$, then $Y = (X - \mu)/\sigma$ has a Gaussian distribution with mean 0 and variance 1, denoted $Y \sim N(0, 1)$. $N(0, 1)$ is referred to as the *standard* Gaussian distribution.

A table of the cumulative probability function $\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{x=-\infty}^{z} \exp\left(-\frac{1}{2}x^2\right) dx$ for the standard Gaussian distribution appears below. If $Y \sim N(0, 1)$, then for $z > 0$, $P(|Y| > z) = 2(1 - \Phi(z))$.

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

z	1.282	1.645	1.960	2.326	2.576	3.090	3.291	3.891	4.417
$\Phi(z)$	.90	.95	.975	.99	.995	.999	.9995	.99995	.999995
$2(1-\Phi(z))$	.20	.10	.05	.02	.01	.002	.001	.0001	.00001

Table 3.

Question 5

(a) Answer the following questions:

(i) Describe the benefits that robot user frames can provide in developing an automated cell. Consider both the mechanical benefits in configuring the cell and robot programming benefits in the optimisation of robot control code. Use an example to illustrate your answer.

[20%]

(ii) Describe how *case statements* using structured text can be used to implement a control sequence on a PLC. Provide an example of two case statements that would be required in an automated cell and describe methods for communicating between them.

[20%]

(iii) Describe how flexibility and robustness can be incorporated into the design and development of an automated cell.

[10%]

(b) A small manufacturing company produces switch cluster modules for the automotive sector and wants to implement a robotic assembly cell to perform the core mechanical assembly process. Critical to the design of the robotic solution is flexibility, as future orders will require the switch cluster modules to be customised with different switches and button styles and assembled within different module locations. To achieve this, it is proposed that the cell will be controlled by a PLC and three robot arms will be used for the assembly tasks. Each robot arm will be fitted with a tool changer and be capable of selecting a specific end effector for each component type. Additional end effectors will be added to the assembly cell to accommodate future products. Fig. 1 Provides an exploded assembly view of the switch cluster module, with Operation 1 depicting a switch being fitted to the cluster module and operation 2, a button being fitted to a switch. Tables 4 and 5 describes the different inbound and outbound material formats for the cell.

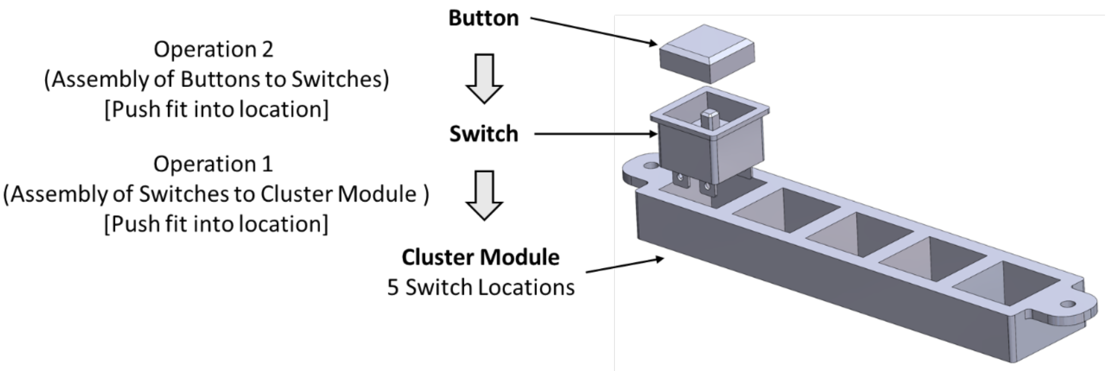

Fig.1 Exploded Assembly View of Switch Cluster Module

Components (Inbound)	**Containment / Format / Quantity**
Switch Cluster Modules - Common to all Products	Tote Bin / Loose, Jumbled Orientation / 100 items
Buttons (Type 1) - Current Product	Tote Bin / Loose, Jumbled Orientation / 500 items
Buttons (Type 2) - Future Product	Tote Bin / Loose, Jumbled Orientation / 500 items
Switches (Type 1) - Current Product	Kitting Tray / Grid 25 x 20, Fixed Orientation / 500 items
Switches (Type 2) - Future Product	Kitting Tray / Grid 25 x 20, Fixed Orientation / 500 items

Table 4

Components (Outbound)	**Containment / Format / Quantity**
Assembled Switch Cluster Modules - Common to all Products	Kitting Tray / Grid 25 x 4, Fixed Orientation / 100 items

Table 5

(i) Considering mixed production of both the current and future products, draw a floor layout showing all hardware components required for the operation of the robot assembly cell. This should include the handling of all parts, totes, kitting trays and end effectors. Also identify any control and sensory components required to enable fully automated operations.

[30%]

(ii) Draw a control architecture diagram, integrating all hardware components of the assembly cell. Provide details about the inter-connection methods used between components and any performance characteristics that make them suitable.

[20%]

Question 6

Two commonly used tools for evaluating the environmental impacts of a product, process, or change to a product or process are *Life Cycle Assessment* (LCA) and *Eco-audit*.

(a) Describe each of these tools, outlining how they are conducted. What information is needed? What form do the outputs take, and how should they be interpreted? Discuss the strengths and limitations of each of the tools.

[35%]

(b) Discuss which of the two tools would be the most appropriate to allow the environmental impact of food packaging to be assessed. What assumptions need to be made, and what additional information would be needed? Discuss how these assessments enable you to make recommendations for how the environmental impact could be reduced.

[25%]

(c) An eco-audit is conducted for a small domestic electric oven. Sketch the expected output from the analysis and explain why it takes this shape. How would you use this information to reduce the environmental impact of the oven?

[25%]

(d) A company uses an LCA to assess the relative environmental impact of two formulations of their product, one of which contains critical metals and the other which uses an alternative to the critical metal. What factors should be considered for this assessment?

[15%]

END OF PAPER

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