UNIVERSITY OF GREATER MANCHESTER

OFF CAMPUS DIVISION

WESTERN INTERNATIONAL COLLEGE, RAS AL KHAIMAH

BENG (HONS) MECHANICAL ENGINEERING

SEMESTER 1 EXAMINATION 2025/2026

ENGINEERING MODELLING AND ANALYSIS

MODULE NO: AME5014

Date: Thursday, 15th January 2026 **Time: 1:00pm – 3:00pm**

INSTRUCTIONS TO CANDIDATES:

There are FIVE (5) questions on this paper.

Answer ANY FOUR (4) questions only.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Electronic calculators may be used provided that data and program storage memory is cleaned prior to the examination.

CANDIDATES REQUIRE: **Formula Sheet (attached)**

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Q1

a) Consider a system with the potential energy function:

$$f(x, y) = x^4 - 4x^2y + y^4$$

(i) Find the stationary points of the potential energy surface $f(x, y)$, by solving for the points where the gradient of $f(x, y)$vanishes.

(ii) Determine the stability of each stationary point using the second derivative test. State whether the points are stable (local minima), unstable (local maxima), or saddle points.

(10 marks)

b) A production supervisor wants to investigate whether the type of machine used (Machine A, Machine B, Machine C) is related to the quality of the output (Acceptable, Defective). A random sample of 240 products was taken, and the results are summarized below:

Machine Type	**Acceptable**	**Defective**	**Total**
Machine A	60	20	80
Machine B	50	30	80
Machine C	40	40	80
Total	150	90	240

Use a Chi-squared test (χ^2) at the 5% level of significance to determine whether the type of machine and the quality of the output are associated.

(15 marks)

Total 25 marks

Q2.

a) Find (i) $L^{-1}\left\{\frac{4s}{s^2-16}\right\}$ (ii) $L^{-1}\left\{\frac{2s+5}{s^2+4s-5}\right\}$

(10 marks)

Q2. Continues over the page

Q2 continued…..

b) In a vibration damping analysis, the displacement response of a system is modelled by the function:

$$x(t) = e^{-3t} cos(4t)$$

To analyse the system in the Laplace domain (for control system design or dynamic simulation), determine the Laplace transform of the response.

Using the standard second-order step response formulas, calculate the displacement $x(t)$ at t = 0.1 s, 0.2 s, 0.3 s, and 0.4 s. Present the results in a table, and briefly comment on the damping effect observed in the motion.

(15 marks)

Total 25 marks

Q3.

a) A robotic arm used in an automated manufacturing system consists of three interconnected joints, each contributing to the overall flexibility and response of the arm. The dynamic behaviour of the arm under small oscillations is modelled using the following stiffness matrix [K], which accounts for the joint flexibility and coupling effects

$$[K] = [1\ -4\ -2\ 0\ 3\ 1\ 1\ 2\ 4\ ]$$

To evaluate the natural frequencies and mode shapes of the system, determine the eigenvalues and eigenvectors of the stiffness matrix $[K]$.

(25 marks)

Q4.

a) In a structural component subjected to a combined mechanical and thermal load, the stress potential function z (in MPa) at any point within the component is described by the following equation:

$$z = 4x^2y^3 - 2x^3 + 7y^2$$

where x and y represent the local coordinates (in cm) measured along the length and height of the component, respectively. Determine the following second-order partial derivatives of (i) $\frac{\partial^2 z}{\partial x^2}$ (ii) $\frac{\partial^2 z}{\partial y^2}$ (iii) $\frac{\partial^2 z}{\partial x \partial y}$ (iv) $\frac{\partial^2 z}{\partial y \partial x}$

(15 marks)

b) The radius of a right cylinder is increasing at a rate of 8 mm/s and the height is decreasing at a rate of 15 mm/s. Find the rate at which the volume is changing in cm^3/s when the radius is 40 mm and the height is 150 mm.

(10 marks)

Total 25 marks

Q5.

An engineer is studying the displacement of a mechanical component governed by the equation:

$$3x^2 - 10x + 7 = 0$$

Using Newton's method, determine the positive root of this quadratic equation, correct to 3 significant figures, which represents the point of maximum displacement.

(Hint: Newton's method is given by the iteration formula:

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

where $f(x) = 3x^2 - 10x + 7$and $f'(x) = 6x - 10$.)

After finding the root using Newton's method, verify the result by solving the equation using the quadratic formula.

Total 25 marks

End of Questions

Please turn the page for formula sheet

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Laplace transforms table

$f(t)$	$F(s)$		$f(t)$	$F(s)$
1	$\frac{1}{s}$		$u_c(t)$	$\frac{e^{-cs}}{s}$
t	$\frac{1}{s^2}$		$\delta(t)$	1
t^n	$\frac{n!}{s^{n+1}}$		$\delta(t-c)$	e^{-cs}
e^{at}	$\frac{1}{s-a}$		$f'(t)$	$sF(s)-f(0)$
$t^n e^{at}$	$\frac{n!}{(s-a)^{n+1}}$		$f''(t)$	$s^2F(s)-sf(0)-f'(0)$
$\cos bt$	$\frac{s}{s^2+b^2}$		$(-t)^n f(t)$	$F^{(n)}(s)$
$\sin bt$	$\frac{b}{s^2+b^2}$		$u_c(t)f(t-c)$	$e^{-cs}F(s)$
$e^{at}\cos bt$	$\frac{s-a}{(s-a)^2+b^2}$		$e^{ct}f(t)$	$F(s-c)$
$e^{at}\sin bt$	$\frac{b}{(s-a)^2+b^2}$		$\delta(t-c)f(t)$	$e^{-cs}f(c)$

Inverse Laplace transforms table

	$F(s) = \mathcal{L}\{f(t)\}$	$\mathcal{L}^{-1}\{F(s)\} = f(t)$
(i)	$\frac{1}{s}$	1
(ii)	$\frac{k}{s}$	k
(iii)	$\frac{1}{s-a}$	e^{at}
(iv)	$\frac{a}{s^2+a^2}$	$\sin at$
(v)	$\frac{s}{s^2+a^2}$	$\cos at$
(vi)	$\frac{1}{s^2}$	t
(vii)	$\frac{2!}{s^3}$	t^2
(viii)	$\frac{n!}{s^{n+1}}$	t^n
(ix)	$\frac{a}{s^2-a^2}$	$\sinh at$
(x)	$\frac{s}{s^2-a^2}$	$\cosh at$
(xi)	$\frac{n!}{(s-a)^{n+1}}$	$e^{at} t^n$
(xii)	$\frac{\omega}{(s-a)^2+\omega^2}$	$e^{at} \sin \omega t$
(xiii)	$\frac{s-a}{(s-a)^2+\omega^2}$	$e^{at} \cos \omega t$
(xiv)	$\frac{\omega}{(s-a)^2-\omega^2}$	$e^{at} \sinh \omega t$
(xv)	$\frac{s-a}{(s-a)^2-\omega^2}$	$e^{at} \cosh \omega t$

Maxima / Minima

$$z = f(x, y)$$

Stationary Points

$$\frac{\partial z}{\partial x} = 0, \quad \frac{\partial z}{\partial y} = 0$$

$$\Delta = \left(\frac{\partial^2 z}{\partial x \partial y}\right)^2 - \left(\frac{\partial^2 z}{\partial x^2}\right)\left(\frac{\partial^2 z}{\partial y^2}\right)$$

if $\boldsymbol{\Delta > 0}$ then the stationary point is a **saddle point.**

if $\boldsymbol{\Delta < 0}$ and $\boldsymbol{\frac{\partial^2 z}{\partial x^2} < 0}$, then the stationary point is a **maximum point**,

if $\boldsymbol{\Delta < 0}$ and $\boldsymbol{\frac{\partial^2 z}{\partial x^2} > 0}$, then the stationary point is a **minimum point**.

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Partial Fractions

$$\frac{f(x)}{(x+a)(x-b)(x+c)} = \frac{A}{(x+a)} + \frac{B}{(x-b)} + \frac{C}{(x+c)}$$

$$\frac{f(x)}{(x+a)^3} = \frac{A}{(x+a)} + \frac{B}{(x+a)^2} + \frac{C}{(x+a)^3}$$

$$\frac{f(x)}{(ax^2+bx+c)(x+d)} = \frac{Ax+B}{(ax^2+bx+c)} + \frac{C}{x+d}$$

Eigenvalues

$$|A - \lambda I| = 0$$

Eigenvectors

$$(A - \lambda_r I)x_r = 0$$

Total differential, rates of change and small changes

$$dz = \frac{\partial z}{\partial u}du + \frac{\partial z}{\partial v}dv + \frac{\partial z}{\partial w}dw + \cdots$$

$$\frac{dz}{dt} = \frac{\partial z}{\partial u}\frac{du}{dt} + \frac{\partial z}{\partial v}\frac{dv}{dt} + \frac{\partial z}{\partial w}\frac{dw}{dt} + \cdots$$

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Newton–Raphson Iterations Method

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

Approximate Relative Error

$$\varepsilon_a = \left| \frac{x_{n+1} - x_n}{x_{n+1}} \right| \times 100\%$$

Quadratic Formula

For $ax^2 + bx + c = 0$:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Common Derivatives

$$\frac{d}{dx}(x^n) = nx^{n-1}, \frac{d}{dx}(kx) = k, \frac{d}{dx}(c) = 0$$

Volumes of solids.

About X axis

$$V = \int_a^b \pi y^2 \, dx$$

About Y axis.

$$V = \int_c^d \pi x^2 \, dy$$

<u>Statistics</u>

Chi-square distribution

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

$$Degrees\ of\ freedom = (rows - 1) * (columns - 1)$$

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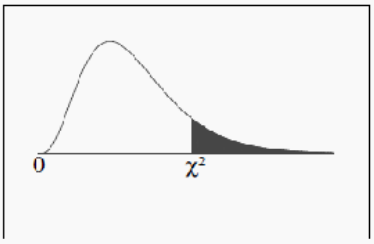
Chi-Square Distribution Table



The shaded area is equal to α for $\chi^2 = \chi^2_\alpha$.

df	$\chi^2_{.995}$	$\chi^2_{.990}$	$\chi^2_{.975}$	$\chi^2_{.950}$	$\chi^2_{.900}$	$\chi^2_{.100}$	$\chi^2_{.050}$	$\chi^2_{.025}$	$\chi^2_{.010}$	$\chi^2_{.005}$
1	0.000	0.000	0.001	0.004	0.016	2.706	3.841	5.024	6.635	7.879
2	0.010	0.020	0.051	0.103	0.211	4.605	5.991	7.378	9.210	10.597
3	0.072	0.115	0.216	0.352	0.584	6.251	7.815	9.348	11.345	12.838
4	0.207	0.297	0.484	0.711	1.064	7.779	9.488	11.143	13.277	14.860
5	0.412	0.554	0.831	1.145	1.610	9.236	11.070	12.833	15.086	16.750
6	0.676	0.872	1.237	1.635	2.204	10.645	12.592	14.449	16.812	18.548
7	0.989	1.239	1.690	2.167	2.833	12.017	14.067	16.013	18.475	20.278
8	1.344	1.646	2.180	2.733	3.490	13.362	15.507	17.535	20.090	21.955
9	1.735	2.088	2.700	3.325	4.168	14.684	16.919	19.023	21.666	23.589
10	2.156	2.558	3.247	3.940	4.865	15.987	18.307	20.483	23.209	25.188
11	2.603	3.053	3.816	4.575	5.578	17.275	19.675	21.920	24.725	26.757
12	3.074	3.571	4.404	5.226	6.304	18.549	21.026	23.337	26.217	28.300
13	3.565	4.107	5.009	5.892	7.042	19.812	22.362	24.736	27.688	29.819
14	4.075	4.660	5.629	6.571	7.790	21.064	23.685	26.119	29.141	31.319
15	4.601	5.229	6.262	7.261	8.547	22.307	24.996	27.488	30.578	32.801
16	5.142	5.812	6.908	7.962	9.312	23.542	26.296	28.845	32.000	34.267
17	5.697	6.408	7.564	8.672	10.085	24.769	27.587	30.191	33.409	35.718
18	6.265	7.015	8.231	9.390	10.865	25.989	28.869	31.526	34.805	37.156
19	6.844	7.633	8.907	10.117	11.651	27.204	30.144	32.852	36.191	38.582
20	7.434	8.260	9.591	10.851	12.443	28.412	31.410	34.170	37.566	39.997
21	8.034	8.897	10.283	11.591	13.240	29.615	32.671	35.479	38.932	41.401
22	8.643	9.542	10.982	12.338	14.041	30.813	33.924	36.781	40.289	42.796
23	9.260	10.196	11.689	13.091	14.848	32.007	35.172	38.076	41.638	44.181
24	9.886	10.856	12.401	13.848	15.659	33.196	36.415	39.364	42.980	45.559
25	10.520	11.524	13.120	14.611	16.473	34.382	37.652	40.646	44.314	46.928
26	11.160	12.198	13.844	15.379	17.292	35.563	38.885	41.923	45.642	48.290
27	11.808	12.879	14.573	16.151	18.114	36.741	40.113	43.195	46.963	49.645
28	12.461	13.565	15.308	16.928	18.939	37.916	41.337	44.461	48.278	50.993
29	13.121	14.256	16.047	17.708	19.768	39.087	42.557	45.722	49.588	52.336
30	13.787	14.953	16.791	18.493	20.599	40.256	43.773	46.979	50.892	53.672
40	20.707	22.164	24.433	26.509	29.051	51.805	55.758	59.342	63.691	66.766
50	27.991	29.707	32.357	34.764	37.689	63.167	67.505	71.420	76.154	79.490
60	35.534	37.485	40.482	43.188	46.459	74.397	79.082	83.298	88.379	91.952
70	43.275	45.442	48.758	51.739	55.329	85.527	90.531	95.023	100.425	104.215
80	51.172	53.540	57.153	60.391	64.278	96.578	101.879	106.629	112.329	116.321
90	59.196	61.754	65.647	69.126	73.291	107.565	113.145	118.136	124.116	128.299
100	67.328	70.065	74.222	77.929	82.358	118.498	124.342	129.561	135.807	140.169

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