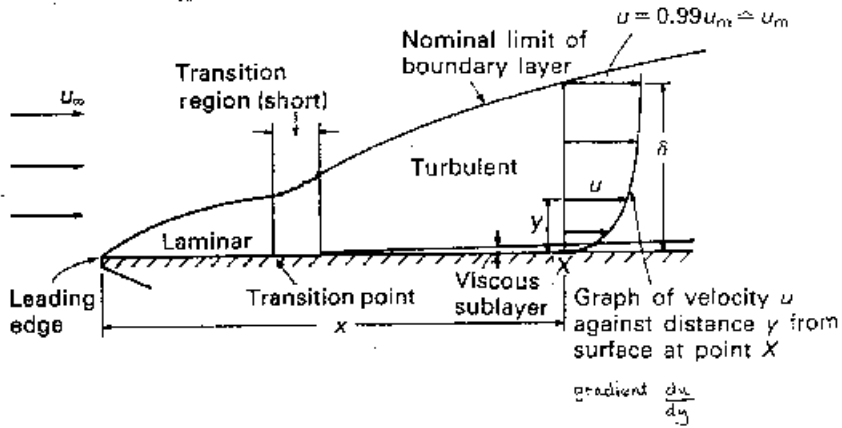
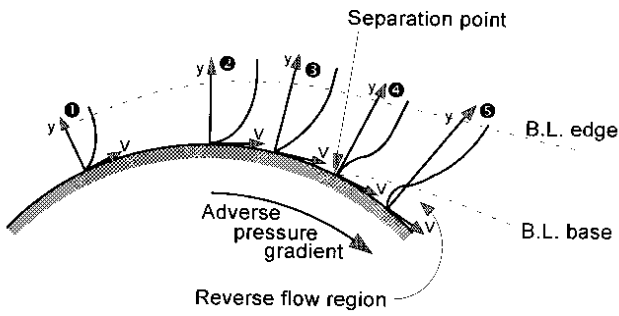


EXAMINATION SOLUTIONS

(to accompany the examination paper sent to the external examiner but NOT to be seen by students)

Programme:	BEng Motorsport Engineering and Design	Level:	5
Module:	Motorsport Structures and Aerodynamics & Vehicle Dynamics		
Author:	T. Tudor & M. Sandford	Page:	

Q 1	Question	Marks
a)	$P_{Total} = \frac{1}{2} \rho v^2 + P_{Static}$ Recognition of total pressure and static pressure from pitot tube diagram. $P_{Static} = P_{Total} - \frac{1}{2} \rho v^2$ $P_{Static} = 1.02 \times 10^5 - \frac{1}{2} \times 1.256 \times 35^2$ $P_{Static} = 101.2 \text{ Kpa}$	1 1/2 1/2
b) i)	BOUNDARY LAYER ON FLAT PLATE (y scale greatly enlarged)  1/2 mark for representative shape, 1/2 mark for turbulent, lamiar, transitional and sub-lamiar/viscous region labelled.	1

ii)	$R_e = \frac{\rho u l}{\mu}$ $x = \frac{R_e \mu}{\rho u}$ $x = \frac{600000 \times 1.8205 \times 10^{-5}}{1.223 \times 32}$ $x = 0.279m$	1
iii)	Mention separation is where boundary layer leaves aerodynamic surface. Separation occurs as kinetic energy is lost as heat due to viscous forces as flow at surface is at velocity 0 (non slip condition) . This means that the fluid doesn't have enough kinetic energy to push through the positive pressure gradient so flow near the surface is brought to rest. As you move further into the positive pressure gradient back flow starts and hence boundary layer separates 	1 1 1
c)	Mention: i) - Wings shape create circulation (differential of velocities above and below wing) - This in turn results in a pressure differential (Bernoulli's theorem) - Pressure differential creates resultant force, one component as drag, one as lift ii) - Splitters provide a horizontal surface for stagnation pressure to act upon yielding a vertical force - Also help reduce high pressure from propagating under vehicle and therefore low pressure under vehicle is maintained.	1 1 1 1 1



iii)	- Diffusers create an expansion rearward of the floor and this expansion helps draw air under the floor increasing underfloor velocity and hence reducing pressure in this area producing downforce. - As expansion increases as you move towards the rear of the diffuser, flow speed reduces and hence pressure is recovered limiting resulting drag.	1
d)	Mention: - Ground boundary layer –rolling road, ground board etc - Blockage effect – slotted walls, adaptive walls, open section - Rotating wheels - stings, rolling road, separated wheels - Mounting models and force measurement – stings, 6 component balance. Award 1 mark for each 'source of error' identified and 1 mark for features to mitigate these upto a maximum of 5 marks.	5

2		
2a	a) With an open rear differential what is the maximum initial acceleration that can be generated ? Each wheel loading $1800 \times 0.45 \text{ kg}$ (for rear axle) / 2 = 405kg (note no weight transfer at initial launch) $\mu=0.85$ FL traction $405 \times 9.81 = 3377\text{N}$ $\mu=0.1$ FR traction =397N With an open diff TL=TR Total tractive effort = $397 \times 2 = 794\text{N}$ $F=Ma \quad a= F/M = 794/1800 = 0.44 \text{ m/s/s}$	4



2b	What steering action would the driver have to take to ensure straight line acceleration? None, even drive torque on each wheel	1
2c	If the vehicle was equipped with a locked differential what is the maximum initial acceleration that can be generated ? Mu=0.85 FL traction $405 \times 9.81 = 3377\text{N}$ Mu-0.1 FR traction =397N With a locked differential all available tractive grip may be utilised. $3377 + 397 = 3774\text{N}$ Acceleration = $3774/1800 = 2.1 \text{ m/s/s}$	4
2d	Maximum wheel rotation ± 45 degrees Handwheel rotation 3.5 turns from 'lock to lock'. For the vehicle front wheel loading: on a road surface with a coefficient of friction $\mu = 0.1$ the tyres will generate a lateral force 500N per degree slip angle. Explain how the tractive forces in b) affect vehicle handling. The student will explain that the asymmetrical drive force will result in a moment applied to the vehicle that will cause the vehicle to drive toward the low μ track. What handwheel angle must the driver apply to ensure that the vehicle launches in a straight line? Resulting moment $TL - TR = 3377 - 397 = 4238\text{N}$ applied about Centre of vehicle (half track) $0.8 \text{ m} = 2384\text{Nm}$ To react this moment by the steering wheels forces are applied 2.8m ahead of the rear axle. Therefore leverage moment reacted by lateral force at front wheels = $2384\text{Nm}/1.3\text{m} = 1834\text{N}$ This is the total lateral force at the front wheels required to resist the differential drive torque. RF provides $2/17^{\text{th}}$ of LF grip $1834 \times 2/17 = 216\text{N}$ from RF and hence 1621 from LF With 400N per degree slip angle. Slip angle required = $1621/400 = 4$ degs Total front wheel steer ± 45 degs = 90 degs Required 4 degs/90 degs = 0.0444 of available travel Total handwheel travel = $3.5 \times 360 = 1260$ degs $1260 \times 0.0444 = 56$ degs handwheel travel.	5

[illegible]

3		
3 a	a) What is the total force required to accelerate the vehicle? Total vehicle mass = $11800\text{kg} + (67 \times 100\text{kg}) = 18500\text{kg}$ Rolling resistance = $18500\text{kg} \times 9.81 \times 0.01 = 1815 \text{ N}$ Acceleration resistance = $18500 \times 1.2 = 22,200 \text{ N}$ Total force = $1815 + 22,200 = 24,015 \text{ N}$	2

3 b	What is the distance covered during the acceleration phase? Final speed is 30kph = 8.33 m/s Acceleration is 1.2 m/s/s Time during accel = $8.33 / 1.2 = 6.94$ secs Distance travelled = $(8.33 / 2) \times 6.94 = 28.9\text{m}$	2
3 c	How much energy is required from the flywheel to accelerate the vehicle? Kinetic Energy = $0.5 \times \text{mass} \times \text{velocity}^2$ $= 0.5 \times 18,500 \times 8.33 \times 8.33 = 641,847$ Joules Rolling resistance energy = $1815\text{N} \times 28.9\text{m} = 52,454$ J Total tractive energy required = $641,847 + 52,454 = 694,300$ J Energy from flywheel = total tractive energy $\times$ efficiency = $694,300 \times (1/0.8) = 867,875$ J	2
3 d	What is the maximum tractive power required at the end of the acceleration at point B? Power = force $\times$ velocity = $24,015\text{N} \times 8.33\text{m/s} = 200.045\text{kw}$	1
3 e	How much energy is required from the flywheel during the constant speed phase? Aero dynamic resistance = $0.5 \times \text{area} \times \text{cd} \times \text{density of air} (1.2 \text{ kg/m}^3) \times \text{velocity}^2$ $= 0.5 \times (2.5 \times 4.4) \times 0.8 \times 1.2 \times 8.33 \times 8.33 = 366.4$ N Total resistance = Aero resistance + rolling resistance = $366.4 + 1814.9 = 2181.3\text{N}$ Traction energy required = $2181.3\text{N} \times 150\text{m} = 327,195$ J Energy from the flywheel = $327,195 \times (1/0.8) = 408,994$ J	3
3 f	How much energy can be recovered and stored to the flywheel during the deceleration phase? Kinetic energy of vehicle = 641,847 J Losses during decel = 52,454 J Kinetic energy available for recovery = $641,847 - 52,454 = 589,393$ J Energy into flywheel = Kinetic energy available for recovery $\times$ efficiency. $= 589,393 \text{ J} \times 0.6 = 353,636$ J	3
3 g	Assuming the ICE is not operational. What is the total energy reduction from the flywheel per cycle? Energy reduction = energy used A to B plus B to C minus energy recovered. $= 867,875 \text{ J} + 408,994 \text{ J} - 353,636 = 923,233$ J	2
3 h	How many cycles can the bus achieve before the ICE must be started to provide additional power?	

	Flywheel capacity = 30.6 MJ Number of cycles = useable capacity / energy per cycle = 30600000 / 923,233 = 33.144	2
3 i	a) What is the outer diameter? 8000 rpm = 8000 x 2 x 3.14 / 60 radians per sec = 838 Kinetic energy = $\frac{1}{2} I \omega^2$ Hence $I = 2KE / \omega^2$ Therefore as $I = M k^2$ $k = \sqrt[2]{KE / (\omega^2 M)}$ $K = \sqrt[2]{30600000 / (838^2 \cdot 200)} = 0.66\text{m}$ For a plain disc the radius = 0.66/0.707 = 0.934m So diameter = 1.87m	3

4		
4 a	(a) A competition car's transmission system incorporates a multiplate clutch unit with two plates, ie four contact surfaces. Each of the clutch plates has an external diameter of 200 mm and an internal diameter of 100 mm.	
4 a (i)	When the clutch is new and unused find the total spring force required to transmit 150 kw at 4000 rpm. Take the coefficient of friction (μ) between the friction surfaces to be 0.4. Power = Torque . rotational velocity $T = P / \omega$ 4000rpm = 4000 x 2 x 3.14/60 rads/sec = 419 rads/sec Torque = 150,000kw / 419 rads/sec = 358Nm New clutch use uniform pressure theory.. $T = \frac{2}{3} \mu \cdot F \cdot \frac{(r_0^3 - r_1^3)}{(r_0^2 - r_1^2)}$	1 2



	Therefore $F = \frac{3}{2} \cdot \frac{t}{\mu} \cdot (r_0^2 - r_1^2) / (r_0^3 - r_1^3)$ $F = 3/2 \cdot 358\text{Nm}/0.4 \cdot (0.1^2 - 0.05^2) / (0.01^3 - 0.05^3)$ $F = 3/2 \times 895 \times 8.571 = 11510 \text{ N (total force for one surface)}$ But there are 4 effective surfaces. $F = 11510\text{N} / 4 = 2877\text{N Clamp load.}$	4 1
4 a (i)	The clutch is now worn by 1 mm per surface. The original springs provided 3500 N of axial force. The spring rate is 100 kN/m. What torque can the clutch now transmit 1mm per surface would mean that the pack of 4 surfaces has reduced by 4mm in total. Spring rate 400,000 N/m x 0.004m = 400N (reduction in axial spring force). Axial force is now 3500N – 400N = 3100N Now that the clutch is worn one must apply the uniform wear theory $T = \frac{F \cdot \mu \cdot (r_0 + r_i)}{2}$ Torque = 3100 x 0.4 x (0.1 + 0.05) / 2 Torque = 93 Nm (per surface) So with 4 working surfaces Torque = 4 x 93 = 372 Nm	4
4 b	(a) Determine the time required to accelerate a fly wheel of mass 400 kg with a radius of gyration 0.3 m with a single plate cone clutch the following specification 2 acting surfaces Outer effective clutch diameter 200 mm Clutch length 10mm Cone angle 5° (included angle 10°) 0 – 2500 rpm Applied axial load 4000 N $\mu = 0.3$	



	Inertia = $m.k^2$ $= 400\text{Kg} \times 0.3^2 = 36 \text{ kg m}^2$	1
	Effective clutch inner diameter, Difference between outer and inner diameter. $\tan 5^\circ = \text{opp/adj}$ $\text{Opp} = \tan 5^\circ \times \text{adj} = \tan 5^\circ \times 10\text{mm}$ $\text{Opp} = 0.0875 \times 10 = 0.875\text{mm}$ Therefore inner radius = $100\text{mm} - 0.875\text{mm} = 99.125\text{mm} = 0.099125\text{m}$	2
	Torque available from the clutch. $T = \frac{F.\mu.(r_o+r_i)}{2.\sin\alpha}$	
	Torque = $4000\text{N} \times 0.3 \times (0.1 + 0.099125) / 2.\sin 5^\circ$. Torque = 1370 Nm	2
	Torque = Inertia x rotational acceleration Rotational accel = Torque / rotational inertia Rot acc = $1370\text{Nm} / 36 \text{ kg.m}^2 = 38 \text{ rads/sec/sec}$	
	Initial rotational speed = 0 Final rotational speed = $2500\text{rpm} \times 2\pi/60 = 261.8 \text{ rads/sec}$ $261.8 \text{ rads/sec} / 38 \text{ rads/sec/sec} = 6.9 \text{ secs}$	2
		1