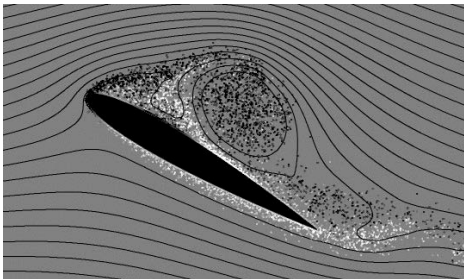
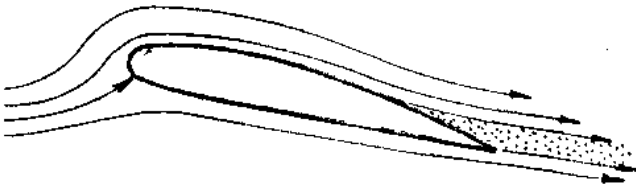


EXAMINATION SOLUTIONS

(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)		
i)	Valid explanation of wing theory - Mention: Velocity & therefore pressure differential – Bernoulli’s Principle Circulation – Starting vortex Deflects air – Newtons second law force applied to air equal/opposite on wing.	1 1 1
ii)	Leading edge stall: - Note sharp drop off in lift on lift curve  Trailing edge Stall – Gradual drop in lift on curve 	$\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$
iii)	End plates prevent pressure bleed around the wing tips Help maintain the maximum pressure differential between upper and lower surfaces. They push wing tip vortices further out effectively increasing efficiency at the outer edges of the span	1 1
b)	Mention separation is where boundary layer leaves aerodynamic surface. Separation occurs as kinetic energy is lost as heat due to viscous forces as	1



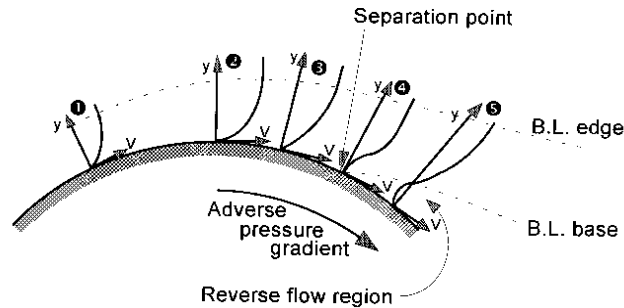
flow at surface is at velocity 0 (non slip condition) .

1

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.

1

As you move further into the positive pressure gradient back flow starts and hence boundary layer separates



Air dams:

c)

- Prevent stagnation pressure bleeding under vehicle (pushing air around and above)
- Rear vacuum can propagate forwards reducing pressure under vehicle and hence creating negative lift over underbody
- Reduction of flow under vehicle can lead to less turbulence caused by engine and transmission geometry and hence drag reduction

1

2

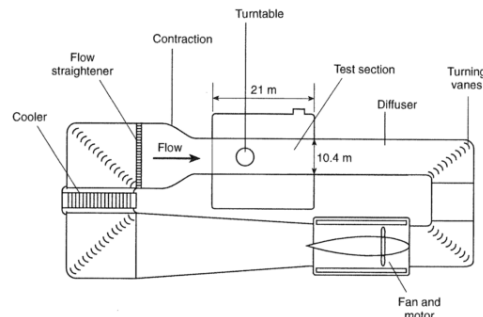
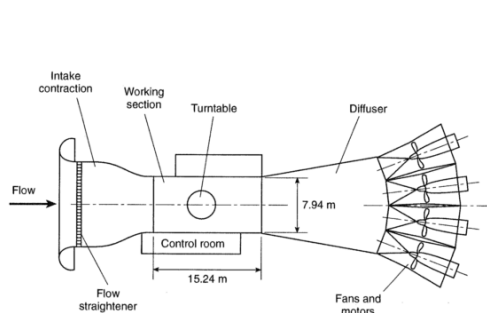
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d)

i)

1 Mark for Open and 1 Mark for Closed windtunnel sketch

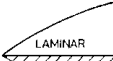
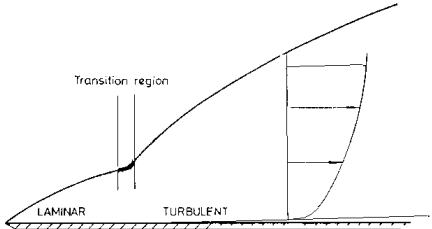
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1 Mark up to maximum of 3 for any of the following labelled

- Rolling Road
- Adaptive Walls
- Slotted Walls
- B.L Trip
- Tangential blowing/suction
- Sting
- Turn Table/balance
- Cooler

3

ii)	Drawings showing or explanation of development of boundary layer on full and scale models being the same and flow regimes therefore differing if Reynolds number not matched. SCALE MODEL :  FULL SIZE: 	2
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2.	a) How much energy is stored by the flywheel at the bottom of the hill? Potential energy = $m \cdot g \cdot h = 2000 \times 9.81 \times 30 = 588.6 \text{ KJ}$ Rolling resistance = $0.016 \times 2000 \times 9.81 = 313.9 \text{ N}$ Road speed 40kph = 11.111 m/s Aero resistance = $0.5 \times \text{density of air} \times C_d \times \text{frontal area} \times \text{velocity squared}$ $AR = 0.5 \times 1.2 \times 0.5 \times 3 \times 123.5 = 111.15 \text{ N}$ Total resistance force $RF = 313.9 + 111.15 = 425.1 \text{ N}$ Total resistive power $RP = RF \times \text{Velocity} = 425.1 \times 11.111 = 4723 \text{ watts}$ 400m at 11.11 m/s takes 36 secs 4723 watts over 36 secs uses $7774.9 \times 36 = 170 \text{ KJ}$ Available energy after decent = $PE - \text{used energy} = 588.6 - 170 = 419 \text{ KJ}$ b) If the vehicle turns left and continues at the same speed along level ground how far will it travel before the energy in the flywheel has been exhausted? Resistive power is 4723 watts Secs = $\text{joules/watts} = 419 \text{ KJ} / 4.723 \text{ Kw} = 89 \text{ secs}$ 89 secs @ 11.11m/s = 985m c) A similar vehicle is equipped with a similar KERS device. The flywheel has been specified to store 250KJ of energy.	8 4
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	The device has a maximum rotational speed of 10,000rpm Packaging dictates that the disc can be no larger than 0.3 m outer diameter Calculate the dimensions and mass for a suitable solid (plain section) flywheel? Density of steel = 7820 kg/m³ 10000 rpm = 166.67 rps = 1047 rads/sec KE = 0.5 Rot In x 1047 squared Rot In = 2 x KE / 1047 squared = 800000 / (1047 x 1047) = 0.73 kgm² Rot In = M.K² K = rad x 0.707 = 0.2 x 0.707 = 0.1414m M = 0.73/(0.1414 x 0.1414) = 36.5 Kg Flywheel mass = area x thickness x density Thickness = mass/ (area x density) = 36.5 / (Pi x 0.2 x 0.2 x 7820) = 0.037m = 37mm d) Discuss power transmission problems from the road wheels to a flywheel storage device. Suggest and analyse possible solutions to overcome these problems. Use diagram and example calculations to support your discussion. The student should identify the problem that as the vehicle slows down the flywheel must pick up speed. Therefore there is an energy transmission problem esp for a mechanical solution, which should be efficient. A graph would be expected. Ideally the student will assume a max vehicle speed and calc the speed ratio range that would be appropriate. The student should discuss the application of: ▪ IVT (Torotrak) ▪ CVT ▪ Fixed speeds with slipping clutches (Flybrid) ▪ The flywheel battery concept with an 'electrical transmission' and possible magnetic coupling within a permanent vacuum (Ricardo).	3
3		
3a	a) With an open rear differential what is the maximum initial acceleration that can be generated ? Each wheel loading 1600 x 0.6 kg (for rear axle) / 2 = 480kg (note weight transfer at initial launch is ignored) Mu=1 FL traction 480 x 9.81 = 4709N Mu=0.1 FR traction = 471N With an open diff TL=TR Total tractive effort = 471 x 2 = 942N F=Ma a= F/M = 942/1600 = 0.5886 m/s²	4
3b	What steering action would the driver have to take to ensure straight line acceleration?	1



	None, even drive torque on each wheel	
3c	If the vehicle was equipped with a locked differential what is the maximum initial acceleration that can be generated ? Mu=1 FL traction $480 \times 9.81 = 4709\text{N}$ Mu=0.1 FR traction =471N With a locked differential all available tractive grip may be utilised. $4709 + 471 = 5179\text{N}$ Acceleration = $5179/1600 = 3.24 \text{ m/s/s}$	4
3d	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.	1
3di)	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.	
3dii)	What handwheel angle must the driver apply to ensure that the vehicle launches in a straight line? Resulting moment $TL - TR = 4709 - 471 = 4238\text{N}$ applied about Centre of vehicle (half track) $0.9 \text{ m} = 3184\text{Nm}$ 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 = $3184\text{Nm}/2.8\text{m} = 1362\text{N}$ This is the total lateral force at the front wheels required to resist the differential drive torque. RF provides $1/10^{\text{th}}$ of LF grip $1362/11 = 124\text{N}$ from RF and hence 1240 from LF With 400N per degree slip angle. Slip angle required = $1240/400 = 3.1$ degs Total front wheel steer ± 45 degs = 90 degs Required $3.1 \text{ degs}/90 \text{ degs} = 0.0344$ of available travel Total handwheel travel = $3.5 \times 360 = 1260$ degs $1260 \times 0.0344 = 43.4$ degs handwheel travel.	
3e	a) The vehicle has a rotational inertia about the 'z' axis of 2200kg/m^2 The vehicle is going clockwise around a roundabout with a path radius of 15m at a constant speed of 10m/s	
3ei)	What is the yaw rate of the vehicle ?	



	Circumference = $\pi \times \text{dia} = 3.14 \times 30\text{m} = 94.2 \text{ m}$ At 10 m/s it takes 9.42 secs for a lap $(2 \times \pi) / 9.42 = 0.667 \text{ rads/sec}$ or $360/9.42 = 38.22 \text{ degs/sec}$	2
3eii)	The vehicle yaw rate begins to change, one second later the on board yaw rate sensors measures a yaw rate of 0.917 rads/sec/sec. What is happening to the vehicle? The vehicle is turning faster than predicted, therefore it is oversteering	1/2
3eiii)	What is the yaw rate acceleration? $0.917 - 0.667 = 0.25 \text{ rads/sec}^2$	1/2
3eiv)	The brake based vehicle stability controller wishes to correct the vehicle and regain the original vehicle yaw rate within one second. Which front wheel should brake force be applied Left front to correct the oversteer.	1
3ev)	How much braking force is required? Rotational torque = Inertia x rotational acceleration $= 2200 \times 0.25 = 550\text{Nm}$ Force = Torque / radius = Torque / track/2 = $550\text{Nm} / 0.9 = 611\text{N}$	2
4	A vehicle is equipped with a single driven plate (2 surfaces) drive clutch With the following specification: Inner effective diameter = 100mm Outer effective diameter = 180mm Dry plate friction material to cast iron. Coefficient of friction (μ) = 0.3 The clutch is actuated with a linear diaphragm spring with a rate of 961.5 N/mm The fitted load is 6410N.	
4a	How much torque can be transmitted? (assume uniform wear) Torque = Force x $\mu \times (R_{\text{outer}} + R_{\text{inner}}) / 2$ Torque = $6410 \times 0.3 \times (0.05 + 0.09) / 2 = 134.4 \text{ Nm}$ There are 2 friction surfaces. Therefore total torque capacity = $2 \times 134.4 = 270 \text{ Nm}$	3



4b	Each of the clutch plate surfaces wears by 1.5 mm. How much torque can now be transmitted? 3mm wear means a force reduction of $3 \times 961.5 \text{ N} = 2884.5$ Axial force = $6410 - 2884.5 = 3525.5 \text{ N}$ Torque = Force $\times \mu \times (R_{\text{outer}} + R_{\text{inner}}) / 2$ Torque = $3525.5 \times 0.3 \times (0.05 + 0.09) / 2 = 74 \text{ Nm}$ There are 2 friction surfaces. Therefore total torque capacity = $2 \times 74 = 148 \text{ Nm}$	3
4c	The clutch is fitted to a vehicle with the following specification Mass 1500kg 1st Gear ratio = 3.5 : 1 Final drive ratio = 3.5 : 1 Wheel rolling radius = 0.29m Transmission and drive efficiency = 96% The clutch has worn such that it slips at 100Nm max engine torque Assume the rotational inertia of the driveline components is insignificant. How long will it take for the vehicle to reach 10 m/s ? Torque at clutch = 100 Nm Torque at gearbox secondary shaft = $100 \times 3.5 = 350 \text{ Nm}$ Torque at differential = $350 \times 3.5 = 1225 \text{ Nm}$ Allow for 96% efficiency. Torque at the wheels = $1225 \times 0.96 = 1176 \text{ Nm}$ Tractive force = Drive torque / rolling radius = $1176 / 0.29 = 4055 \text{ N}$ Acceleration = tractive force / vehicle mass = 2.7 m/s/s Time to reach 10m/s = speed / acceleration = $10 / 2.7 = 3.7 \text{ secs}$	4



4d	A vehicle is equipped with an air-conditioning system. The air conditioning pump pulley is driven at one half engine speed. The air conditioning pump has a rotational inertia of $0.015 = \text{kg} \cdot \text{m}^2$ The pumping resistance can be considered constant at 0.9 Nm The engine is on tick-over at 800 rpm There is a single surface cone clutch between the pulley and the pump with the following dimensions : - o Outer diameter = 80 mm - o Inner diameter = 70 mm - o Effective face width = 20 mm - o The coefficient of friction (μ) = 0.25 An electric solenoid provides a force of 15 N to actuate the cone clutch. What is the torque transfer generated by the cone clutch? Cone angle = $\tan^{-1}$ of $5/20 = 14 \text{ degs}$ Torque = force $\times \mu \times (R_{\text{outer}} + R_{\text{inner}}) / 2 \times \sin \alpha$ Torque = $15 \times 0.25 \times (0.04 + 0.035) / 2 \times \sin 14 = 0.580 \text{ Nm}$	3
4e	At tickover how long will it take to accelerate the pump from standstill to the engine's tickover speed? Total resistive torque = pumping torque + torque to accelerate the pump Torque to accelerate pump = Full clutch torque – pumping torque Torque to accelerate pump = $0.58 \text{ Nm} - 0.9 \text{ Nm} = -0.32 \text{ Nm}$ Therefore there is insufficient torque to overcome the friction Other related calcs Engine speed = 800 rpm Pump drive speed = $400 \text{ rpm} = 400 \times 2 \times \pi / 60 \text{ rad/s} = 41.89 \text{ rad/s}$ Torque = Inertia $\times$ rotational acceleration Rotational acceleration = Torque / inertia	4
4f	Explain the advantages and disadvantages of reducing the cone angle? The student should discuss. (and may use example calcs). Advantages: Possible reduced actuation force (solenoid) required Possible reduced package outer diameter. Disadvantages The tighter the cone angle the more likely that the cone will, wedge-in and not release. May require a release spring which will increase the actuation force required.	3