# Test Yourself Solutions

# Test yourself - Payloads

1. What qualifies an instrument as an "active" sensor?
   a) It has moving parts
   b) It probes the subject using the instrument's own energy
   c) It manufactures data
   d) It can be activated on command
   e) It actively measures existing light

2. How many arcsec does a penny subtend if it is located 2 km away? Tip: assume a penny is 1cm across.

$$\theta \approx \frac{s}{d} \approx \frac{1\ \cancel{\text{cm}}}{2\ \cancel{\text{km}}} \times \frac{1\ \cancel{\text{km}}}{1000\ \cancel{\text{m}}} \times \frac{1\ \cancel{\text{m}}}{100\ \cancel{\text{cm}}} = \frac{1}{2} \times 10^{-5}\ \text{ra}\cancel{\text{dians}} \times \frac{1\ \mu\text{rad}}{10^{-6}\ \cancel{\text{rad}}} = 5\ \mu\text{rad} = 1\ \text{arc sec}$$

3. What physical properties determine spatial resolution?

   Orbit altitude, aperture and wavelength

4. Hyperspectral scanners produce a scan of multiple narrow bandwidth spectrum channels. What would be the advantages and disadvantages of using them for Earth Observation?

Fine differentiation, but large volume of data.

# Test yourself – Orbits 1

1. Which scientist is credited with the collection of the data necessary to support the elliptical motion of planets? Brahe

2. Define the term ‘apohelion’. Furthest point in an orbit around the Sun

3. Explain why a solar day is longer than a sidereal day. Draw the diagram!

4. If the apogee of a satellite’s orbit is 68000km, what is the altitude of the satellite at this point? Assume the radius of the Earth=6378km. Apogee = $r_{a\,,}$ radius of Earth=$R_e$

$$r_a - R_e = h_a = 68000.10^3 - 6378.10^3 = 60622.10^3 m$$

5. A satellite in earth orbit has a semi-major axis of 6,700 km and an eccentricity of 0.01. Calculate the satellite's altitude ‘h’ at both perigee and apogee. See video Orbits1 Q5.

# Test Yourself – Orbits 2

1. 'The ascending node can be defined as where an orbiting spacecraft crosses the semi-major axis going north.' True or False? False

2. 'A sun-synchronous orbit is never a precessing orbit'. True or False? False

3. What is the angle between the equator and the ecliptic? 23.5º

4. Does inclination change with increase in altitude? No

5. How is RAAN measured? Vernal equinox to ascending node

6. Is argument of perigee measured clockwise or anti-clockwise? Anti-clockwise

7. What is the approximate inclination of Molniya orbits from the ground track on slide 34? Approx 65º

# Test Yourself – Orbits 3

1. If the Moon-Earth distance were to shrink, what would happen to the Moon's Period? Increase/decrease/stay the same? Decrease, think about K3.
2. Which planet has the lowest escape velocity?

| | Mercury | Venus | Earth | Mars | Jupiter | Saturn | Uranus | Neptune |
|---|---|---|---|---|---|---|---|---|
| diameter (Earth=1) | 0.382 | 0.949 | 1 | 0.532 | 11.209 | 9.44 | 4.007 | 3.883 |
| diameter (km) | 4,878 | 12,104 | 12,756 | 6,787 | 142,800 | 120,000 | 51,118 | 49,528 |
| mass (Earth=1) | 0.055 | 0.815 | 1 | 0.107 | 318 | 95 | 15 | 17 |

$$v_{esc} = \sqrt{\frac{2GM}{r}}$$

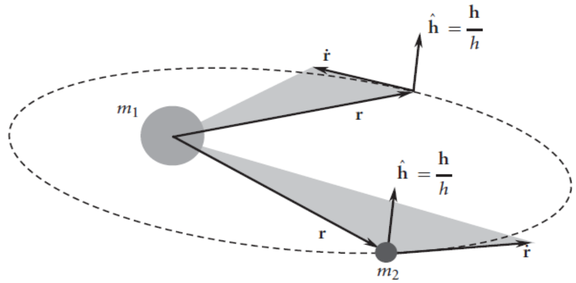
Mercury has lowest mass to diameter ratio.

3. In the Phoebe example, does it make sense that the resultant acceleration is along –r axis? Phoebe is orbiting Saturn so we would expect there to be a negative acceleration (ie: towards Saturn).
4. Where will a spacecraft go if it has exactly the escape velocity of the planet? It will be in the same orbit around the sun as the planet, at 0km/s relative to it, but distant. It will need another boost to go anywhere.

# Test Yourself – Orbits 4

1. Is a 'barycentre' exactly the same as the centre of mass? Barycentre is the center of mass of two or more bodies, usually bodies orbiting around each other.
2. What assumption allows us to use 1 body central force model for the motion of Mercury wrt the Sun? M>>m, so centre of massive body can be treated as fixed.
3. Why do we use polar coordinates for planetary motion? Since the motion is planar and the force radial.
4. Use a diagram and simple equation to show which vectors determine the plane of an orbit.

$L = \mathbf{r} \times m\mathbf{v}$



# Test Yourself! Orbits 5

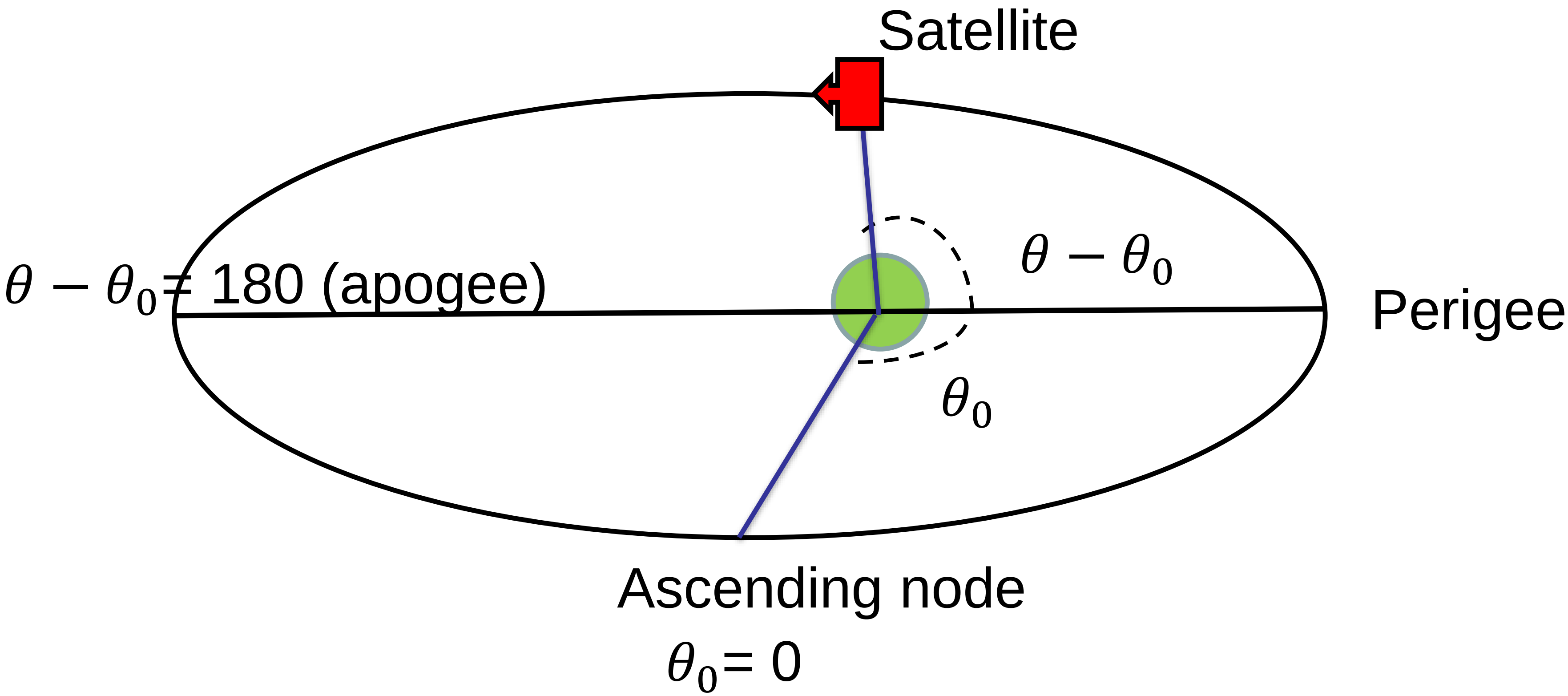
1. What does $\theta - \theta_0$ in the orbit equation represent? The true anomaly.
2. What is the value of true anomaly for the apogee point? 180º or π.
3. If the argument of periapsis is 150, what value of $\theta - \theta_0$ would you use to find the ascending or descending node? 0-150=-150 and 180-150=30
4. For a satellite with semimajor axis 7500000m, e=0.1, argument of perigee=45 degrees, calculate the length of its position vector at the descending node.

   $r = a \times (1 - e^2) / (1 + e\cos\theta)$

   $r = 7{,}500{,}000 \times (1 - 0.1^2) / (1 + 0.1 \times \cos 135)$

   $r = 7989977$ m

# Test Yourself!



# Test Yourself! Orbits 6

1. Video solution
2. An artificial Earth satellite is in an elliptical orbit which has an altitude of 250 km at perigee and an altitude of 500 km at apogee. Use the above result to find the perigee velocity.

Given: $r_p = (6{,}378 + 250) \times 1{,}000 = 6628000$ m

$r_a = (6{,}378 + 500) \times 1{,}000 = 6878000$ m

$$v_p^2 = 2\mu\left(\frac{r_a}{r_p(r_a+r_p)}\right) = 2\,x\,3.986005 \times 10^{14}\left(\frac{6878000}{6628000(6878000+6628000)}\right)$$

$$v_p = 7826\text{m/s}$$

3. Video solution
4. Video solution

# Test Yourself! Orbits 7

1. After launch, what is the first step for a supply ship to rendezvous with a space station? Match inclination at the nodes.
2. Describe how a chaser supply ship catches up with a target space station which is trailing it? What is this manoeuvre called? The chaser burns prograde to raise the orbit (increase the ‘a’) this will slow it down and then it can end up just behind the target. This is called co-orbital rendezvous
3. Where do you do an inclination burn in an elliptical orbit? Why? At apoapsis as this is where the spacecraft is going slowest, so it minimises the delta V used.

# Test Yourself! Space Envt

1. What are the six major effects of the space environment? Vacuum, photon radiation, microgravity, charged particles, atomic oxygen, meteoroids and space debris.
2. How would you mitigate against the effect of eg: atomic oxygen? C*oatings* of inorganic oxides, such as $SiO_2$
3. What kinds of testing would you suggest for investigating the effects of the space environment? See slides.
4. Describe a Whipple shield. When do you think it is worth using Whipple shields to protect against micrometeoroids/debris? A thin sheet of material which acts as a bumper to disperse the energy of an impactor into many small pieces. Worthwhile for crewed spacecraft.

# Test Yourself! Rockets

1. What conditions are required for maximum thrust? C and Ve must be the same (nozzle is perfectly expanded) where Pe-Pa=0 ie: Pe=Pa.
2. A spacecraft's engine ejects mass at a rate of 30 kg/s with an exhaust velocity of 3.1 km/s. The pressure at the nozzle exit is 5 kPa and the exit diameter is 0.95 m. What is the thrust of the engine in a vacuum?

   $\dot{m}$ = 30 kg/s

   Ve = 3100 m/s; Ae = π x $(0.95/2)^2$ =0.71$m^2$

   Pe = 5 kPa = 5000 $N/m^2$; Pa = 0

   $$F = \dot{m}V_e + A_e(P_e - P_a)$$

   F = 30×3100 + 0.71×(5000-0)=96,544 N

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# Test Yourself! Rockets

3. Find the Characteristic Exhaust Velocity (C*) for perfect expansion if:

Throat diameter= 0.16 m    Nozzle exit diameter= 0.23 m

Constant Thrust= 18450N    Chamber pressure = $8 \times 10^5$ Pa

Time of burn = 80 sec    Mass of solid propellant = 400 kg

Throat and exit Areas using $\pi(d/2)^2$ :

$A_t$=0.0201m2, $A_e$=0.0415$m^2$

$\dot{m}$= 400 kg / 80 s = 5 kg/s

As expansion is perfect we can assume $V_e$ = C,

$C^* = P_c . A_t / \dot{m}$ = 800000 x 0.0201 / 5 =3216 m/s

# Test Yourself! Launchers

1. Which is the propellant with the highest specific impulse? Liquid Oxygen/Liquid Hydrogen or Fluorine/Hydrogen
2. Why is a hybrid so called? It has liquid and solid elements.
3. How much delta V does a rocket need to reach LEO? 9.3km/s
4. How much delta V does the $N_2O_4$/UDMH multistage rocket in slide 72 produce for each of its 2 stages?

$$\Delta V_1 = 3200 \ln\left[\frac{33.3+2.99+5.10+0.46+1.0}{33.3+2.99+5.10+0.46+1.0-33.20}\right] = 4770\text{m/s}$$

$$\Delta V_2 = 3200 \ln\left[\frac{5.10+0.46+1.0}{5.10+0.46+1.0-5.10}\right] = 4808\text{m/s}$$

$$\Delta V = \Delta V_1 + \Delta V_2 = 9578\text{m/s}$$

# Test Yourself! Structures

1. What is the definition of the configuration of a spacecraft? The arrangement or architecture given by a GA drawing.
2. What might drive the configuration of a spacecraft going to Mars, Mercury, a comet? [Think about mission characteristics including temps, payload, trajectory, comms]
3. What are quasistatics? a dynamic load, launch acceleration, which varies slowly enough to be treated as static
4. What model philosophies can be used for spacecraft? Structural test model, protoflight, qualify by similarity

# Test Yourself! Structures 2

5. How would you test a spacecraft structure? Types of testing include: structural, vibration, acoustic, thermal vacuum, life, deployment.
6. Name types of continuous and one-shot mechanisms. Continuous: antenna steering mechanism, solar array drive mechanism. One shot: boom or solar array deployment.

# Test Yourself! Thermal

1. What is the function of the thermal subsystem on a spacecraft?
   Keep the temperatures within limits
2. Calculate the heat transfer through an aluminium (k=201W/mK) spacecraft wall which is 1mx1m wide and 1cm thick, if the surface temps are 20°C and -100°C.

$$Q_x = -k.A.\frac{dT}{dx} = -201x1x1x\frac{(20 - -100)}{0.01} = -2.412x10^6\mathrm{W}$$

3. If you double the temperature of an object, how much more radiation will it emit? 16x
4. The star Betelgeuse has a surface temperature of 3250 K, what is the peak wavelength and what colour would it be?
   Using Wien's Law:
   $\lambda_{max}$ = 2897/3250 = 0.891μm, it is a red giant

# Test Yourself! Thermal 2

5. Neglecting albedo and IR inputs, for a temperature of 300K, wha would the size of a LEO spacecraft radiator (e=0.8 and a=0.15) be to reject 100W? Assume the Sun points directly at it. What difference will it makes if it faces deep space?

$$\varepsilon\sigma A_s T^4 = Q_w + P + \alpha . A_{proj} \mathrm{G_s} . cos\theta + \alpha A_s \mathrm{G_s} a F_{sc-p} + \ q_{ir} \varepsilon A_s F_{sc-p}$$

$$\varepsilon\sigma T^4 = \frac{Q_w}{A_s} + \alpha . \mathrm{G_s}$$

$$0.8x5.67x10^{-8}x300^4 = \frac{100}{A_s} + 0.15x1370$$

$$A_s = 0.618m^2$$

$$Deep\ space:\ we\ neglect\ direct\ solar\ term:\ A_s = 0.273m^2$$

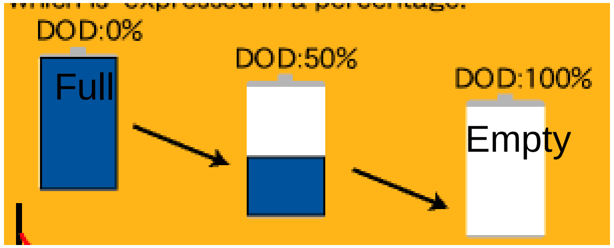
# Test Yourself! Power

1. How many solar cells and strings are needed for a bus voltage of 28V and power of 112W, if each cell is 0.5V and 0.05A? (Assume no losses). No. cells in a string=28/0.5=56 and current=112W/28V=4A, so no. of strings required is 4/0.05=80 strings.
2. Explain how a fuel cell works. (see slide 11 of notes)
3. What is the Seebeck effect? Current is produced when junctions of two dissimilar conducting materials are maintained at different temps.

# Test Yourself! Power 2

4. What are the disadvantages of RTGs? And solar dynamic generators? RTGs – expensive, no Pu238 left, efficiency 7%, huge heat losses, once started it keeps going, radio-activity. SDGs – if Pu238 involved all the same apart from efficiency which is better. If solar used at hot end, then mechanically complex and expensive but no other disadvantages.
5. How can we improve the specific efficiency of photovoltaics? Gallium Arsenide, Multijunction cells, thin films, solar concentrators, tracking the Sun with solar array deployment mechanism.
6. Is 80% DoD better/worse than 50%?

   Better, as it will last for longer.



# Test Yourself! Geosats

1. Could you have a geostationary satellite in a polar orbit for worldwide weather monitoring? No, this would not be a geostationary orbit as geostationary satellites are at an inclination=0 deg (not polar orbit where inclination=90deg)
2. Why is geostationary orbit so popular and who regulates the slots? You can provide continuous monitoring of a certain area of the Earth. The ITU (international telecoms Union) regulates the slots.
3. How do perturbations affect the ground track of a geostationary satellite? The Sun, Moon gravity will pull the spacecraft out of plane. This is called North-South drift. East-West drift occurs due to noncircular shape of the earth's equator.

# Test Yourself! Geosats 2

4. What kind of propulsion would you use for stationkeeping of a geosat and why? Electric propulsion is excellent as it is low mass and high sp.impulse and stationkeeping requires low thrust.
5. Why is an apogee boost motor (slide 15) needed on a geostationary satellite? To circularise the orbit after the GTO.
6. Why do you think that geosats have been getting larger and with longer lifetimes recently? It is costly and fuel intensive to get to GEO, so it is more efficient to send more payloads on one mission of long duration, than to have multiple launches. This places great emphasis on reliability.