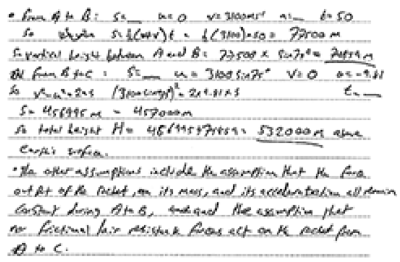
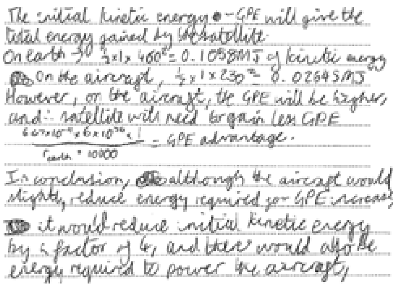
Mark scheme

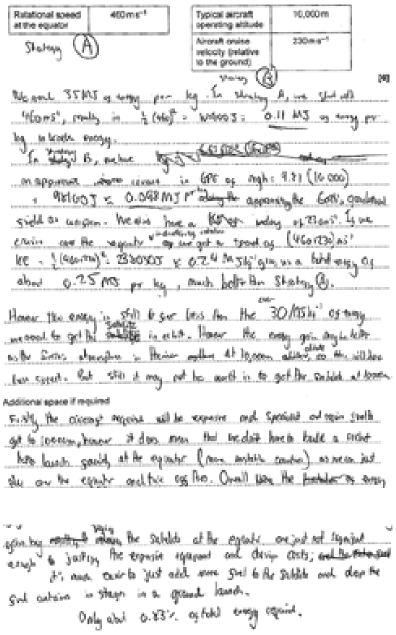
Question			Answer/Indicative content	Marks	Guidance
1			**Level 3 (5–6 marks)** Expect a correct calculation of *H* with correct assumptions **and** a clear evaluation supported with a calculation *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Expect **Either** a correct calculation of *H* but no evaluation **or** Some calculation **and** some evaluation **or** Incorrect calculations but a clear evaluation *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Expect **Either** Limited calculation (e.g. 3100 sin 75° seen, *AB* **or** *BC* calculated but not *H*, use of suvat but with wrong *v*) **or** Limited assumptions stated (note that 'g is always 9.81' is in stem) **or** Limited evaluation (e.g. *g* would be smaller at **C** than **A**) *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 mark**	B1 x 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Calculation** vertical component of velocity at **B** = 3100 sin 75° (= 2994 ms^{-1}) <u>AB</u> • Assume (force and mass constant so) constant acceleration • Use of suvat, *u* = 0, *v* = 2994, *t* = 50 • *s* = 74.9 km <u>BC</u> • Assume no air resistance • Use of suvat, *u* = 2994, *v* = 0, *a* = -9.81 • *s* = 457 km Total *H* = 457 + 74.9 ≈ 530 km **Evaluation** • $g \propto \frac{1}{r^2}$ • $\frac{g_C}{g_A} = \frac{r_A^2}{r_C^2} = \frac{6400^2}{(6400+530)^2} = 0.85$ • 15% drop in g from **A** to **C** (or 17% increase from C to A) but use ECF for *H* • therefore constant *g* is a poor assumption • g_c ≈ 8.3 or 8.4 if g_A= 9.81 but use ECF for *H* • If g is smaller, then H would increase **<u>Examiner's Comments</u>** Level 3 candidates set out a correct calculation of *H*, together with the assumptions required at each stage,

			No response or no response worthy of credit.		plus an evaluation of the assumption that *g* remains constant at 9.81 ms^{-2} throughout. Level 2 candidates missed out one or more of these three parts, usually the evaluation at the end, which they found quite difficult. Level 1 candidates were often unable to calculate *H*, or the value of g at height *H*, correctly **Common problems in 3 (b)** • omission of sin 75° (or using cos 75°) when calculating velocity • not converting from m to km correctly • not squaring the r term in the calculation for *g* **Exemplar 1**  Exemplar 1 demonstrates good practice in answering a LoR question. The candidate has made sure they have answered each part of the question by using bullet points. Their calculations are clearly set out and so easy to follow, and their handwriting is legible. Instead of just calculating a value for *g* at height *H*, they have also given an explicit evaluation: 'The assumption that *g* remains constant is not reasonable'. Other candidates went on to say that this means that the rocket would reach an even greater height. **OCR support**

					OCR has a Guide to Level of Response Questions. This includes guidance on communication and the use of bullet points (page 5).
			Total	**6**	
2	a	i	$\frac{GMm}{r^2} = \frac{mv^2}{r}$ $\frac{1}{2}mv^2 = \frac{1}{2}\frac{GMm}{r}$	M1 A1	Allow omission of 'm' on both sides of equation (gravitational field strength = centripetal acceleration) Cancelling/rearrangement/identification of GMm/r as GPE **<u>Examiner's Comments</u>** Many candidates made a good start by equating the formula for gravitational force with the expression for centripetal motion. Others that assumed that g of 9.81 m s^{-2} did not score any marks. The simplest way to arrive at the correct expression was to identify GM/r in the gravitational force formula, to rearrange and then multiply both sides by ½. Approximately ½ of all candidates that responded got as far as this gaining both marks.
		ii	(Increase in) GPE = (−56 − −63 MJ =) 7(MJ) or (Increase in) KE = 0.5 × 56 = 28 (MJ) Sensible reasoning, e.g. 7+28 > 30	M1 A1	Allow **evaluation of total energy** of 35 (MJ) **<u>Examiner's Comments</u>** Many candidates correctly determined how much GPE the satellite needed to gain i.e. 7 MJ in order to reach orbit from -63 MJ to -56 MJ. To find the KE when in orbit, candidates needed to use the result from the previous part of the question. This explains why the in orbit, the KE required is ½ of 56 MJ i.e. 28 MJ. A small fraction of candidates successfully accomplished this step. This means the total energy gain is the sum of 28 MJ and 7 MJ i.e. 35 MJ.

	b		**Level 3 (5–6 marks)** Correct calculations, and advantages and limitations discussed. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Correct calculations and an advantages discussed or Correct calculations and a limitation discussed. *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Attempted calculations or a single correct calculation or incomplete explanations of advantages and/or limitations. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 mark** *No response or no response worthy of credit.*	B1 × 6	Use level of response annotations in RM Assessor Ignore general knowledge answers e.g. accidents, cost, politics Allow references to energy, energy per unit mass or potential as interchangeable Allow ecf from candidate's value for total energy per unit mass in orbit from (i.e. 35 MJ) 22bii or use of 30 (MJ) **Indicative scientific points may include:** **Calculations** • (Minimum) additional KE from aircraft=26 kJ • Additional GPE from aircraft = 100 kJ • Additional KE from equatorial launch=110 kJ • GPE calculated by mgh as an acceptable approximation • (Without taking Earth's rotation into account,)KE at equator is about 4x aircraft KE • GPE calculated from vg = (−)GM/r • Total energy = 0.5GM/r **Advantages** • Aircraft launch provides KE and GPE • Aircraft velocity will be higher than 230 depending on where the aircraft takes off. • Less (rocket) fuel required • Aircraft launch has similar/slightly larger energy to equatorial • Equatorial launches can only happen in limited locations/aircraft launches can take place almost anywhere **Limitations** • Aircraft launches only suitable for small satellites.

					• Effects (for either) only significant for near earth orbits/low altitudes • Either launch provides very small fraction (less than 1%) of the energy required **<u>Examiner's Comments</u>** Many candidates found this difficult to access. A solely qualitative evaluation was limited to level 1 (2 marks). Exemplar 2  The initial kinetic energy – GPE will give the total energy gained by the satellite. On earth → ½×1×460² = 0.1058MJ of kinetic energy On the aircraft, ½×1×230² = 0.02645MJ However, on the aircraft, the GPE will be higher, and ∴ satellite will need to gain less GPE 6.67×10⁻¹¹×6×10²⁴×1 / r_earth + 10000 = GPE advantage. In conclusion, although the aircraft would slightly reduce energy required for GPE increase, it would reduce initial kinetic energy by a factor of 4, and there would also be energy required to power the aircraft, In Exemplar 2, the candidate has completed a small number of calculations comparing the KE the two methods would raise. There is also a statement that these differ by a factor of 4 along with an attempt at calculating the GPE advantage by launching from the aircraft rather than from the ground. Crucially, there is very little mention of limitation and no supporting calculations. Holistically speaking, therefore, there was not enough evidence to award this candidate Level 3, yet sufficient for a Level 2. Exemplar 3

					 Rotational speed at the equator: 460 m s⁻¹ · Typical aircraft operating altitude: 10,000 m · Aircraft cruise velocity (relative to the ground): 230 m s⁻¹ In Exemplar 3, this candidate makes an excellent attempt at every portion of the question. They have taken great effort to make themselves clear with technical language. They have also performed numerous calculations to compare the GPE and KE in the two different scenarios. A further figure appears right at the bottom of the response. The candidate has correctly calculated the percentage of the overall energy required that is supplied by either method. In conclusion, the candidate has used their many correct calculations to weigh up evidence effectively in terms of the advantages and limitations.
	c	i	Period equal to one day/24 hours/rotational period of Earth Or Rotation in same direction as the rotation of the Earth (on its axis) Or Equatorial orbit Or radius of orbit is approx 42 000 km Or height of orbit above Earth's surface is approx 36 000 km Or zero velocity relative to Earth's surface	B1	NOT 'is in the same place in the sky' **<u>Examiner's Comments</u>** In previous series, candidates needed to explain at least three conditions for a geostationary orbit for complete credit. This item, though, is considerably simpler: most candidates scored a mark here. There was some confusion about terminology with those candidates that did not score the mark. Often this was muddling up the time of orbit, the time

					of rotation of the Earth and the time of an orbit of the Earth around the Sun.
		ii	Use of T=3600×24 (or 86,400 from data book) Substitution into $T^2 = \frac{4\pi^2}{GM}r^3$ i.e. $(86400)^2 = (4\pi^2/(G \times 6.0 \times 1024))r^3$ $r = 4.2 \times 10^7$ (m)	C1 C1 A1	**<u>Examiner's Comments</u>** Most candidates correctly used the equation representing Kepler's Third Law to find the orbital radius. Common errors included mis-converting or mis-remembering the time for one complete orbit.
			Total	**14**	
3			**C**	1	**<u>Examiner's Comments</u>** By considering the GPE at the planet's surface of -GMm / r and the KE of ½ m v^2, the condition for 'escape' is that the total energy is zero at infinity. This gives the condition GMm / r = ½ mv^2. The gravitational field strength at the surface of the planet is GMm / r^2 i.e. gr, giving gr = ½ mv^2. When rearranged this gives answer C.
			Total	**1**	
4	a	i	**X** marked on orbit at closest point to Mars	B1	Horizontal line through centre of X must pass through or touch the label 'Mars' **Allow** a single dot/circle marked on the orbit **<u>Examiner's Comments</u>** Most candidates put their cross in the correct place. The most common wrong response was to place a cross placed at the furthest point from Mars.
		ii	orbits in an <u>ellipse</u> / orbit is <u>elliptical</u> with (COG of) Mars at one focus	B1 B1	**Allow** a general statement even if not applied to MAVEN eg (all) orbits are elliptical **Ignore** references to Sun or other planets **Not** the Sun at one focus **<u>Examiner's Comments</u>** The main difficulty here was remembering which was Kepler's 1st Law. Many candidates described how a line between Mars and MAVEN

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>would sweep out equal areas in equal times.

Sometimes valuable time was spent describing planetary orbits before restating the salient points for MAVEN.</td></tr>
<tr><td></td><td>b</td><td>i</td><td>$T^2 \propto r^3$

Correct calculations involving at least two sets of data which lead to a (reasonably) constant value</td><td>C1
A1</td><td>Not $T^2 = r^3$
Allow T^2 / r^3 = (any) constant or T^2 = (any) constant × r^3
Allow $T_1{}^2 / T_2{}^2 = r_1{}^3 / r_2{}^3$
May be inferred from a subsequent calculation

For example, T^2/r^3 (or r^3/T^2) calculated correctly at least twice:
Allow a constant value calculated for one set of data and then applied to at least one other object
Calculations do not need corresponding names of objects
Ignore number of sf;
ignore any incorrect calculations
Ignore statements about whether or not Kepler's 3rd Law applies

Values below are for benefit of markers, POTs removed

<table>
<tr><th>Object</th><th>T^2 / r^3 T(hr)</th><th>T^2 / r^3 T(s)</th><th>r^3 / T^2 T(hr)</th><th>r^3 / T^2 T(s)</th></tr>
<tr><td>MAVEN</td><td>7.4</td><td>9.6</td><td>1.4</td><td>10.5</td></tr>
<tr><td>Phobos</td><td>7.1</td><td>9.3</td><td>1.4</td><td>10.8</td></tr>
<tr><td>Deimos</td><td>7.4</td><td>9.6</td><td>1.4</td><td>10.4</td></tr>
<tr><td>Areostationary</td><td>7.8</td><td>10.1</td><td>1.3</td><td>9.9</td></tr>
</table>

<u>Examiner's Comments</u>

The majority of candidates remembered Kepler's 3rd Law correctly.

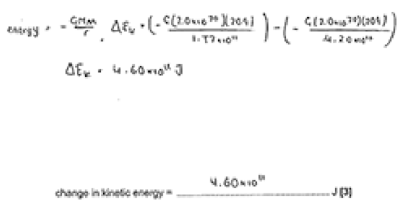
There were a number of different approaches which could gain credit here. The main one used was to find the ratio of T^2/r^3 for corresponding pairs of values, showing that this ratio was approximately constant. Another common approach was calculating the constant k in $T^2= kr^3$ using the data for</td></tr>
</table>

					MAVEN and then applying it to the distance of Phobos, for example, to show that it gave the correct value for the time period. The best responses were those where candidates thought carefully about how they were going to set out their calculations, naming the orbits under consideration or tabulating their values, whereas other responses were characterised by a sprawl of figures leaving the examiner to hunt for appropriate values.
		ii	(MAVEN needs) to see the whole planet / atmosphere **or** not just part of the planet / atmosphere (MAVEN needs) to be in / near to the atmosphere	B1 B1	**Ignore** comments about potential collisions / mass / orbital period / speed / direction **Allow** (if placed in an areostationary orbit, then) MAVEN would always orbit above the same place / it could only see one location / it could not see multiple locations / it could not see (atmosphere at) the poles / it could only see part of the (atmosphere of) Mars **Allow** (if placed in an areostationary orbit, MAVEN's orbital radius would be large that) it would not pass through the atmosphere / it could not analyse the atmosphere **Not** MAVEN is too close to see the atmosphere properly Note: Atmosphere does not need to be seen to award first BI Atmosphere must be mentioned somewhere in the response to award second B1 **Examiner's Comments** The strongest responses were given in terms of the function of MAVEN, which was to study the upper atmosphere of Mars. An areostationary orbit would be too far from Mars for this purpose, plus it would only allow MAVEN to sample one small part of its atmosphere. A common approach was to make

					partial statements such as 'MAVEN would be too far away...' and such responses were often too vague to be creditworthy. A few candidates misread the question and were obviously attempting to answer the question. 'H ow do we know that MAVEN is not in an areostationary orbit?'.
			Total	**7**	
5		i	Use of KE_{mean}= 3/2 kT = 3/2 x *k* x 4.0 x 10^6 $= \frac{3}{2}\times 1.38\times 10^{-23}\times 4\times 10^{6}$ $=8.3\times 10^{-17}$ J.	C1 A1	Allow k Unrounded answer is 8.28… x 10^{-17} **<u>Examiner's Comments</u>** Candidates answered Question 23 (b) (i) well, provided that they used the correct temperature i.e. that of the stellar atmosphere and not the surface temperature.
		ii	$= -2.3\times 10^{-16} + 8.3\times 10^{-17}$ $= -1.5\times 10^{-16}$ J.	B1	Allow use of 10^{-16} J from stem to give -1.3×10^{-16} J Reject response without negative sign **<u>Examiner's Comments</u>** The helium nucleus in parts (b) (ii) and (b) (iii) has a KE of 10^{-16} J and a GPE of -2.3×10^{-16} J. This helium nucleus cannot therefore escape and so the GPE at the further possible point of the helium nucleus must be negative. The GPE at this furthest possible point is where the KE is zero and there has been a gain of 10^{-16} J of GPE, giving the GPE = -1.3×10^{-16} J, using the values in the question. Of course, we used the exact value calculated in part (b) (i) instead of 10^{-16} J, giving *U* = -1.5×10^{-16} J as the 'correct' answer.
		iii	selection of GMm/r Substitution of values for M,m and energy and rearrangement 3.2×10^{10}m e.g.	C1 C1 A1	Allow ECF from (b)(ii) NB Use of values in stem gives 3.7 $\times 10^{10}$ **<u>Examiner's Comments</u>**

			$(-)\frac{GMm}{r} = (-)1.5\times10^{-16}$ $r = \frac{6.67\times10^{-11}\times1.1\times10^{31}\times6.6\times10^{-27}}{1.5\times10^{-16}}$ $= 3.2\times10^{10}$m		The helium nucleus in parts (b) (ii) and (b) (iii) has a KE of 10^{-16} J and a GPE of -2.3×10^{-16} J. This helium nucleus cannot therefore escape and so the GPE at the further possible point of the helium nucleus must be negative. The GPE at this furthest possible point is where the KE is zero and there has been a gain of 10^{-16} J of GPE, giving the GPE = -1.3×10^{-16} J, using the values in the question. Of course, we used the exact value calculated in part (b) (i) instead of 10^{-16} J, giving $U = -1.5\times10^{-16}$ J as the 'correct' answer.
		iv	Reference to Boltzmann distribution / AW OR Some particles will have greater kinetic energies /lower masses	B1	**<u>Examiner's Comments</u>** Question 23 (b) (iv) has several acceptable responses yet the predominant correct candidate answers were that the solar wind particles might be lighter (i.e. hydrogen) or that the Maxwell-Boltzmann distribution of KE values in a gas of particles would mean that some particles would have greater than average KE. **Assessment for learning** Usually in physics calculations, we use the calculator value all the way through the calculation. Any rounding should take place at the very end of the calculation.
			Total	**7**	
6			B	1	
			Total	**1**	
7			D	1	**<u>Examiner's Comments</u>** The question is asking for the candidate to calculate the speed of an object in a circular orbit with radius 42 400 km, i.e. 42.4×10^{6} m. To do this, the candidate equates the gravitational force, FG = GMm/r^2 with the centripetal force required for that orbit, FC = mv^2/r, where M is the mass

					of the Earth and *m* is the mass of the satellite. Rearranging gives $v = \sqrt{GM/r}$. Substituting the correct values for *G, M* and *r* will give answer D.
			Total	**1**	
8			$g = GM/r^2$ $g = \frac{6.67 \times 10^{-11} \times 4.87 \times 10^{24}}{(6\,050 \times 10^3)^2}$ g = 8.87 (N kg^{-1})	C1 C1 A1	**Allow** *m* for *M* **Allow** *d* or *D* or *x* or *X* or *R* for *r* Full substitution needed **Allow** *r* = 6 050 for this C1 mark **Allow** a negative answer Answer must be to exactly 3sf for the A1 mark. Do not use the **SF** penalty for the paper here **<u>Examiner's Comments</u>** This was a gentle start to the paper, with the formula *g* = *GM*/*r*2 being provided in the data, formulae and relationships booklet. **Common problems in 1(a)** • omitting to convert *r* from km to m and so incurring a power of ten (POT) error • using a value of *G* from a calculator or from memory rather than copying the 3 significant figure (3sf) value given in the formula sheet • writing the answer to more (or less) than the 3sf specified in the question
•			**Total**	**3**	
9	a		$G\frac{Mm}{r^2} = \frac{mv^2}{r}$ or $G\frac{Mm}{r^2} = mr\omega^2$ $v = \frac{2\pi r}{T}$ or $\omega = \frac{2\pi}{T}$ Substitution **and** manipulation to give $T^2 = \frac{4\pi^2}{GM}r^3$ (with $\frac{4\pi^2}{GM}$ is constant)	M1 M1 A1	**Allow** any subject **<u>Examiner's Comments</u>** The demonstration of Kepler's 3rd Law was well-remembered by the vast majority of candidates.

	b	i	$\left(\frac{168}{365}\right)^2 = \left(\frac{r}{1.50 \times 10^{11}}\right)^3$ distance = 8.9×10^{10} (m)	C1 A1	**Ignore** calculation of arithmetic mean of data in question **Allow** substitution into $T^2 = \frac{4\pi^2}{GM} r^3$ **Ignore** units for subs into Kepler's law **NOT** 8.95 or 9(.0) × 10^{10} (m) (mean calculated) **<u>Examiner's Comments</u>** Fortunately, most candidates saw the reference to Kepler's third law in bold and used it successfully. Only a small fraction found the mean orbital distance by finding the mean of the maximum and minimum distance. While this is mathematically sound, it does not use Kepler's third law and so was not deemed an acceptable answer to the question.
		ii	(ΔGPE = ΔKE) $GMm\left(\frac{1}{4.20 \times 10^{10}}\right)$ or $GMm\left(\frac{1}{1.37 \times 10^{11}}\right)$ (change in KE =) $6.67 \times 10^{-11} \times 2.0 \times 10^{30} \times m\left(\frac{1}{4.20 \times 10^{10}} - \frac{1}{1.37 \times 10^{11}}\right)$ change in kinetic energy = 4.6×10^{11} (J)	C1 C1 A1	**Allow** this mark without the *m* **Allow** this mark without the *m* **Allow** 2 marks for 2.2×10^9; ΔV calculated **Ignore** sign **<u>Examiner's Comments</u>** Previous examiner's reports have stated the importance of understanding how gravitational potential energy differences are calculated using the appropriate formula. More candidates got this idea right in this series, which was excellent.  This candidate has understood that the gravitational potential energy at both extremes of the orbit should be calculated and then the difference calculated.

		iii	Description of reasonable effect of Earth has been ignored / work done by fuel (during lift off) / idea that atmosphere has been ignored previously	B1	**Examiner's Comments** This question provides one of the 'stretch and challenge' marks in this paper. The idea is that the satellite needs first to climb out of the Earth's gravitational well before it can be a satellite of the Sun.
			Total	**9**	
10			**C**	1	**Examiner's Comments** Most candidates suggested that angular frequency and angular velocity do not have the same or equivalent units. The correct answer is C, because gravitational potential is measured in J kg^{-1} and kinetic energy is measured in J.
			Total	**1**	