M1.(a) The (total) angular momentum (of a system) remains constant provided no external torque acts (on the system) ✓

Do not accept 'force' in place of 'torque'

1

(b) I is the sum of the $m r^2$ products for point masses m at radius r ✓

Or WTTE

Not m is the mass and r the radius – must refer to point or small masses or distribution of mass

OR

$\Sigma m r^2$ with m and r defined

OR

I is a measure of the mass and the way the mass is distributed about an axis

1

More of the satellite's mass is at greater radius ✓

1

(Small change in r) gives large change in r^2, hence large change in I

OR even though m of panels is small, much of m is at a greater radius and radius is squared ✓

For 2nd mark must refer to effect of r^2.

1

(c) Angular momentum = 110 × 5.2 = 572 ✓

1

N m s **OR** kg m^2 s^{-1} ✓

accept

kg m^2 rad s^{-1}

1

(d) (Use of conservation of ang momtm) $572 = 230 \times \omega_2$ ✓

1

$\omega_2 = 572 / 230 = 2.49$ rad s^{-1} ✓

1

[8]

M2.(a) $\frac{3.5}{(2\pi \times 0.088)}$ = 6.3 rev

$6.3 \times 2\pi = 39.8$ rad or 40 rad ✓

OR

$\frac{3.5}{0.088}$ = 39.8 or 40 rad ✓

If correct working shown with answer 40 rad give the mark
Accept alternative route using equations of motion

1

(b) $\omega = v / r = 2.2 / 0.088 = 25$ rad s^{-1} ✓

1

(c) (i) $E = ½I\omega^2 + ½mv^2 + mgh$
$= (0.5 \times 7.4 \times 25^2)$
$+ (0.5 \times 85 \times 2.2^2)$
$+ (85 \times 9.81 \times 3.5)$
= 2310 ✓
+ 206 ✓
+ 2920 ✓
(= 5440 J or 5400 J)

CE from 1b
$½ I \omega^2 + ½mv^2 = 2310 + 210 = 2520$ J
$½ I \omega^2 + mgh = 2310 + 2920 = 5230$ J
$½mv^2 + mgh = 210 + 2920 = 3130$ J
Each of these is worth 2 marks

3

(ii) Work done against friction = $T\theta$
$= 5.2 \times 40 = 210$J ✓
Total work done = $\boldsymbol{W}$ = 5400 + 210
= 5600J ✓ 2 sig fig ✓

CE if used their answer to i rather than 5400J
Accept 5700 J (using 5440 J)
Sig fig mark is an independent mark

3

(d) Time of travel = distance / average speed = 3.5 / 1.1 = 3.2s ✓

$P_{ave} = \frac{5600}{3.2} = 1750$ W

$P_{max} = P_{ave} \times 2 = 3500$ W ✓

OR accelerating torque = $T = W / \theta$
= 5600 / 40 = 140 N m ✓
P = $T\,\omega_{max}$ = 140× 25 = 3500 W ✓

CE from ii

1780 W if 5650 J used

2

[10]

M3.(a) Use of $I = \Sigma mr^2$ or expressed in words ✓

With legs close to chest, more mass at smaller r, so I smaller ✓

2

(b) (i) Angular momentum is conserved / must remain constant **OR** no external torque acts √

WTTE

as I decreases, ω increases and vice versa to maintain $I\,\omega$ constant ✓
OR as I varies, ω must vary to maintain $I\,\omega$ constant

2

(ii) (Angular velocity increases initially then decreases (as he straightens up to enter the water)).

No mark for just ang. vel starts low then increases then decreases, i.e. for describing ω only at positions 1,2 and 3.

With one detail point e.g. ✓

- Angular velocity when entering water is greater than at time t = 0 s.

- Angular velocity increases, decreases, increases, decreases
- Maximum angular velocity at t = 0.4 s
- Greatest rate of change of ang. vel. is near the start
- Angular velocity will vary as inverse of M of I graph

1

(c) angular. momentum = 10.9 × 4.4 = 48 (N m s) ✓

(ω_{max} occurs at minimum I)

Allow 6.3 to 6.5. If out of tolerance e.g. 6.2 give AE for final answer

minimum I = 6.4 kg m^2 (at 0.4 s) ✓

6.4 × ω_{max} = 48 leading to

ω_{max} = 7.5 rad s^{-1} ✓

3

(Total 8 marks)