MagSail CubeSat Flight Experiment

Revision 05 (1U CubeSats)
Jan 21, 2021
(Revised mass budget, smaller battery)

High-level requirements

- Design a CubeSat flight experiment to test the hypothesis that magsails can serve as a viable deorbit method for satellites in Low Earth orbits (700-1400 km).

- Design drivers:
  - low-cost
  - flexible and frequent launch options,
  - ability to conclusively detect the magsail drag effects
  - simple deployment mechanism,
  - possibly demonstrate deorbit (re-entry) in 100 days
  - use proven COTS parts with flight-heritage

Baseline mission concept

- The reference design consists of 2 "**1U**" cubesats to start with, with minimal capability
  - to see what can be done with 1U ("minimal" experiment)

- Cubesat #1 has magsail energized with 1.4 W.
  - 4 deployable booms 50 cm each creates current "square"
  - Magsail On during sunlight, off during eclipse
  - Other cubesat will not have magsail turned on.

- Both satellites should drift by several thousand kilometeres in about 3 weeks (to be checked at the end).

Key trades (1 of 2)

- Orbit altitude: **420 km**, 750 km, GTO
  - selected primarily due to ease of access and magsail effectiveness
- Form factor: **1U**, 1.5U, 2U, 3U
  - to see what can be done with 1U
- Number of satellites: 1, **2**
  - two identical satellites with one magsail energized will be able to conlusively detect the effect of magsail drag and cancel out aerodynamic drag, solar radiation pressure etc.
- Attitude control: **none,** passive (permanent magnet, gravity gradient, spin about max MoI axis), active (mag.torquer, reaction wheels)
  - no driving attitude requirements, passive for low cost
  - lightweight permanent magnets can align one axis with the Earth's field, and improve downlink, more reliable GPS lock.

Key trades (2 of 2)

- Solar panels: **fixed**, deployable, articulated
  - low cost, reliable
- Batteries: **Li-ion**, Li-Po,Ni-Cd, supercapacitors
  - low-cost, high Wh/kg, low vol/kg, high-discharge current, commercial, flight-heritage
- Telecom: **UHF** (ground station), L-band (Iridium).
  - low cost, less regulatory hurdles, no poiniting required
- Antenna: **deployable monopole**, patch.
  - flight-heritage
- Processor and data handling:
  - commericial off the shelf, need not be rad hard, redundancy with cross-strap architecture

Power (1 of 3) - power budget (revised)

TX on only 0.5 sec per minute, 0.2 W

Form factor	1U	2U	3U				
Orbit average power generated, W	2.44	4.89	7.33				
Orbit average power (conservative), W	1.90	4.00	6.00				
Power requirement (s)	**Power**	**Magsail mode duty cycle**	**Transmit mode duty cycle**	**Magsail off mode duty cycle**	**Idle mode duty cycle**	**Safe mode duty cycle**	
Nominal time, h		**0.95**	**0.00833**	**0.60**	**0.00**	**0.00**	
On Board Data Handling, W	**0.30**	1.00	1.00	1.00	1.00	1.00	
Telemetry, TX	**0.20**	0.00	1.00	0.00	0.00	0.00	
Telemetry, RX	**0.00**	1.00	1.00	1.00	1.00	1.00	
Attitude Control System	**0.00**	0.00	0.00	0.00	0.00	0.00	
Electrical Power System	**0.10**	1.00	1.00	1.00	1.00	1.00	
Magsail, W	**1.50**	1.00	0.00	0.00	0.00	0.00	AVG
Orbit average power req., W		1.90	0.60	0.40	0.40	0.40	**1.31**
Form factor	**1U**	**2U**	**3U**				
Orbit average power margin, W	0.59	2.69	4.69				
Energy requirement per orbit, Wh							
During eclipse		0.24					
Depth of discharge (eclipse)		0.30					
Min. energy required (eclipse), Wh		**0.54**					
Selected battery capacity, Wh		**3.70**					

Power (2 of 3) - Battery (revised)

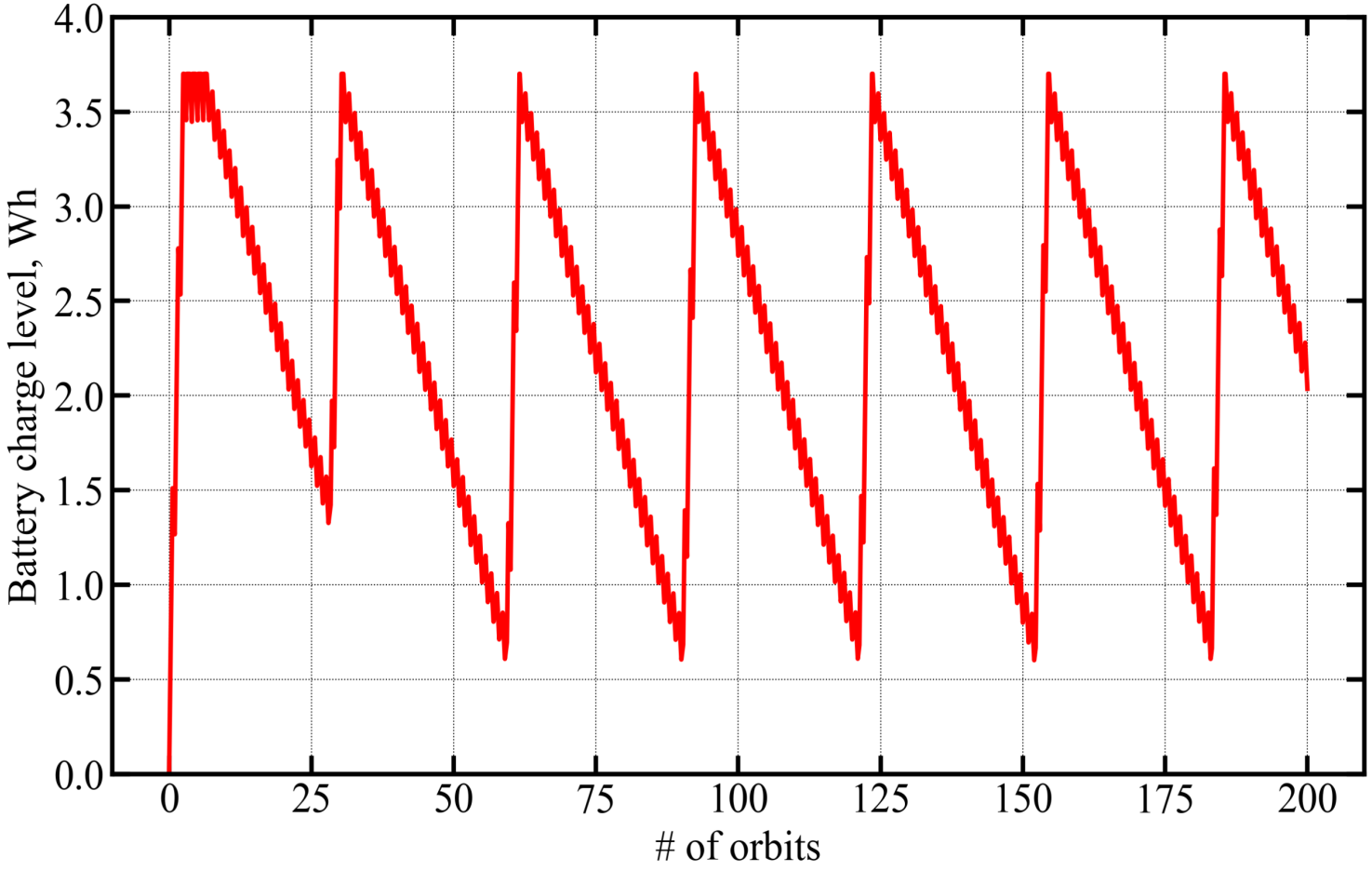
Lower Wh battery than before, 23 g instead of 100g

Recommend 2 in parallel for redundancy, and higher battery capacity

1 X LG LGIP-520B Li Ion
= 3.7 Wh, 23g, $9

see next slide for battery discharge during operation

Power (3 of 3) - Battery charge



Magsail ON during sunlight, P = 1.5W

Magsail turned off for 4 hours every 48 hours to replenish battery

Telecom (1 of 3)

- Reference: VHF/UHF, ground station
  - Nominal TX power: **0.2 W**
  - Duty cycle: 0.5 second beep every minute
  - Desired data rate: ~ 10 kbps, total data = **5 kb per beep**

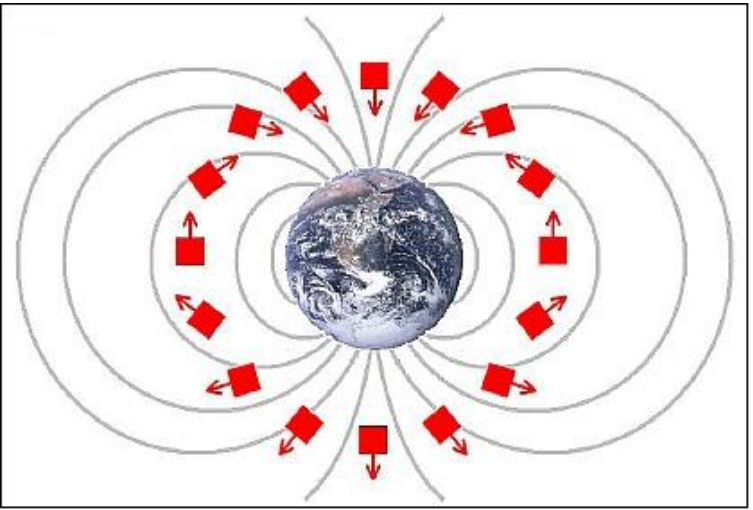
  - Link budget in next page
  - Link has to be closed (margin > few dB)

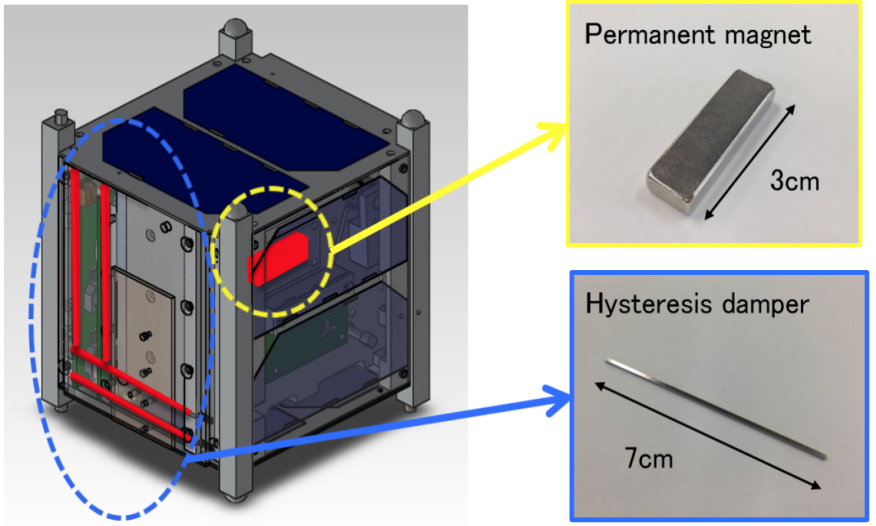
Telecom (2 of 3) - Link budget

	Uplink (to-ground)	Downlink (to-Cube)
Frequency, MHz	145	437
Range, m (slant @ 10 deg)	2.50E+06	2.50E+06
Transmit power, mW	**200**	1.00E+05
Transmit power, dBm	23.01	50.00
Transmit loss, dB	0.2	3.1
Transmit gain, dBi	0	15.5
Path loss, W	2.31E+14	2.09E+15
Path loss, dB	143.63	153.21
Other prop. loss, dB	4.1	4.1
Receive gain, dBi	12.34	0
Receiver noise temp Tr, K	870	1228
Antenna nosie temp, Tant, K	290	150
System noise temp, Ts, K	1160	1378
10 log 10 (Ts), dBK	30.64	31.39
Boltzmann's constant 10 log 10(k) + 30	-198.6	-198.6
Data rate, R, bps	**9600**	1.00E+06
10 log 10 (R), dBHz	39.82271	60
Received SNR	15.76	15.40
SNR required for 1E-5 BER, dB	9.5	9.5
Link margin, dB	**6.26**	**5.90**

Attitude control (1 of 2)

- No attitude control for reference 1U.
- Attitude control system not necessary, however more analysis is required. Need to detumble before deployment?
- It may help to have a few permanent magnets (< 50 g) along the magsail axis so it stabilizes the magsail axis along the ambient field. (or use magnetotorquers)





Attitude control (2 of 2)

- May help data download and GPS reception.
- Some addtional analysis is being done.

Tracking (1 of 2)

- A low mass, low power GPS receiver is added
  - Mass = 9 g, power = 0.15 W, time to first fix ~ 90s

Flight heritage since 2018

HIGHLIGHTS

- Multi-constellation receiver
- Active or passive antenna compatible
- Tracking rate: > 10 Hz
- Time to first fix: < 90 s
- TTL UART interface
- In-orbit position accuracy: < 8 m
- Low mass: 3 g
- Low power: < 150 mW peak
- Module dimensions: 20 x 15 x 3 mm

Tracking (2 of 2)

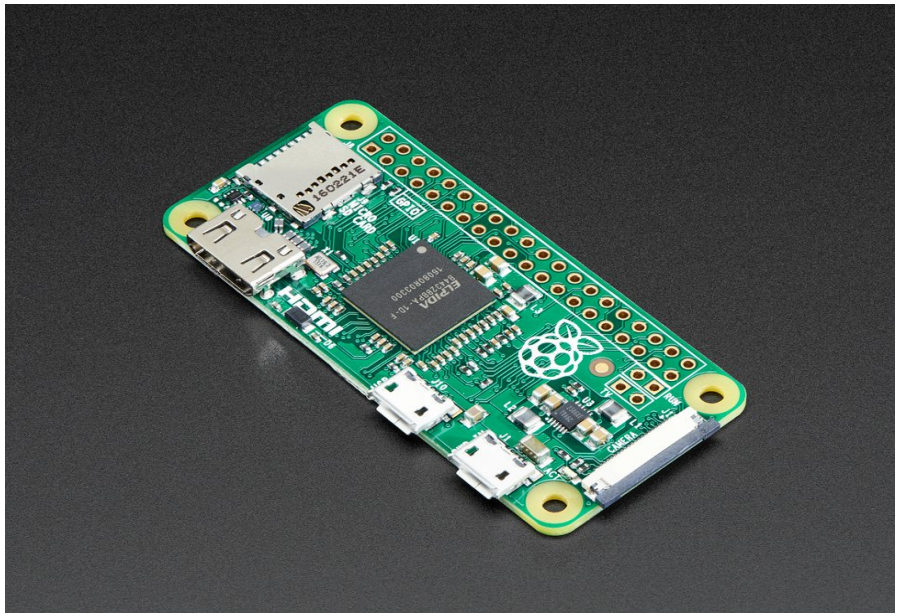
- Other options:
  - NORAD tracking data
- Commercial radar observations (LeoLabs)

Mass budget (Jan 21)

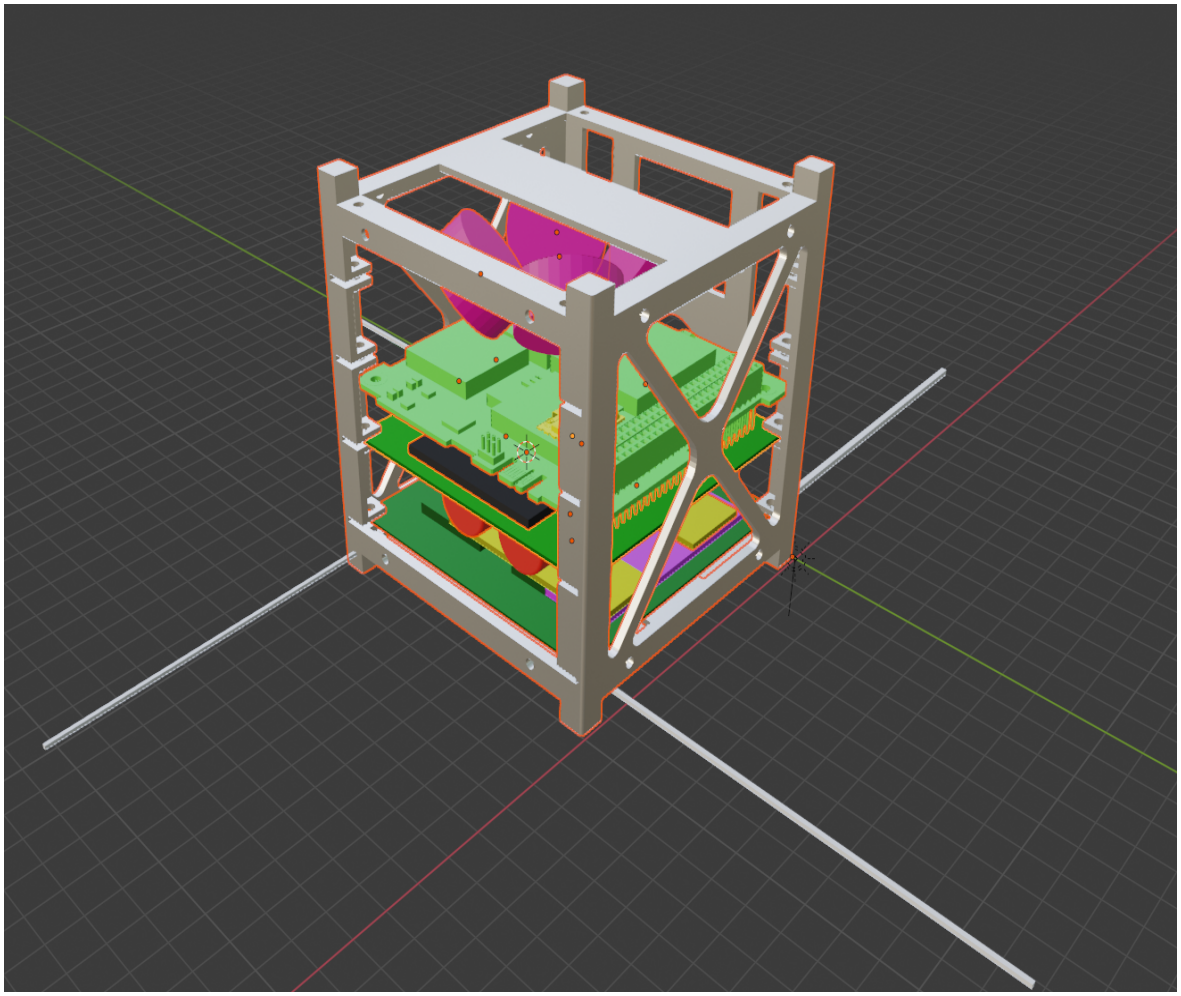
	Reference	**Mass, g**	mass goal	**Revised mass, g**
Structure, g	ISIS Space 1U	120	120	120
Battery, g	see link on right	100	10	23
Electrical Power System, g	Approximate	100	80	70
On Board Computer	EnduroSat	120	80	80
Transceiver	ISIS Space 1U	80	80	80
Harness, Screws etc	Approximate	50	50	50
Payload	Allocation	**400**	300	300
Solar panels	5 faces	250	300	300
UHF Antenna	Tape spring	50	50	50
GPS Antenna	Hyperion x 2	6	6	10
Margin	Allocation	50	200	247
Total		**1326**	**1276**	**1330**

Raspberry Pi as On Board computer?

- $20 computer
- 9g, 0.4W
- Can use 2 boards for redundancy



Drawing (Work in progress)



Deployment demo (in progress).

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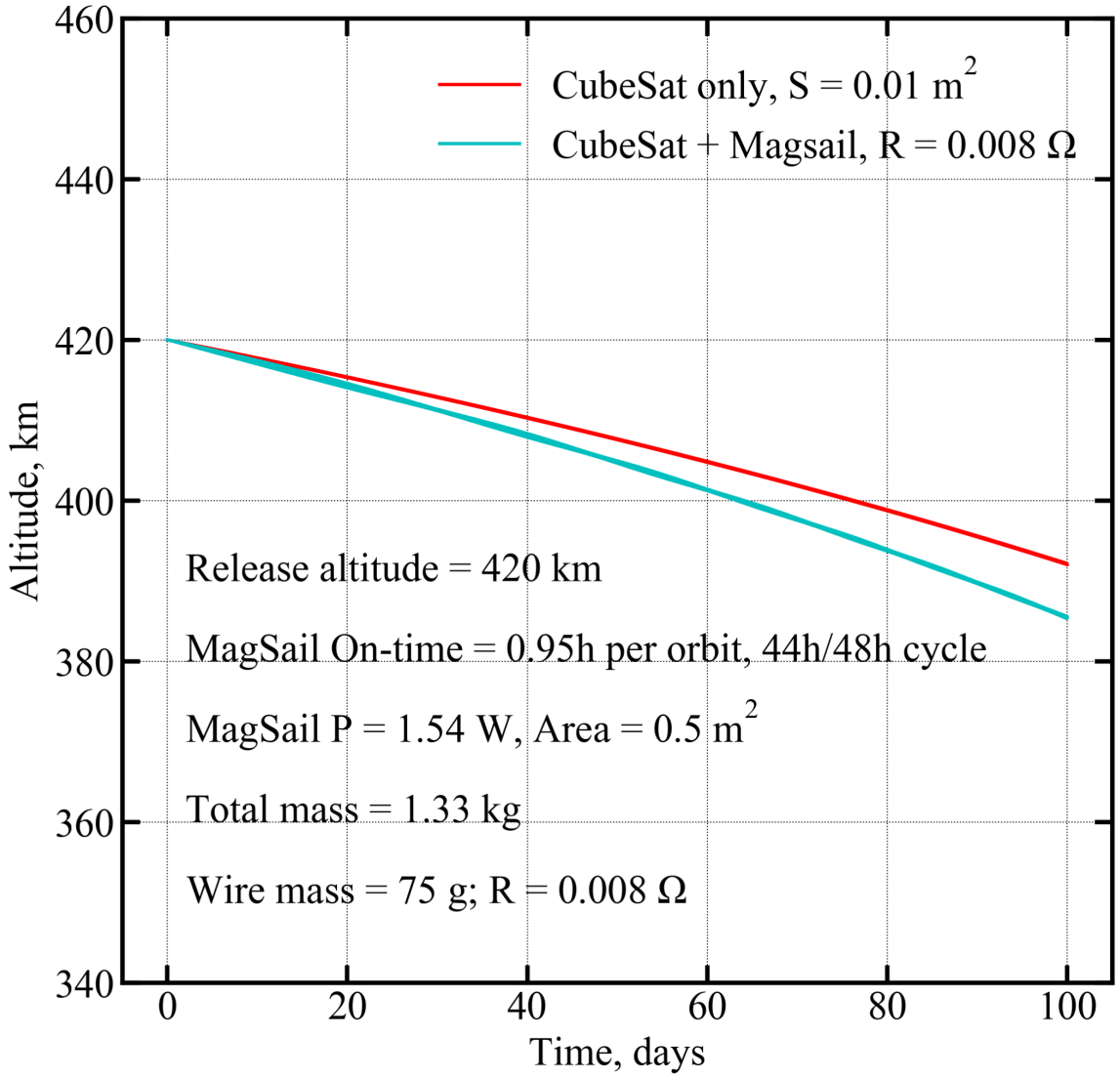
Deployment demo (in progress).

Deployment with rolled up tape spring is unstable, this problem is solved by composite tape springs which deploy much more predictably. However, these are not readily available for purchase. But if we move to a flight experiment, we should be able to get them.

However, we may be able to show some kind of demonstration with ordinary tape spring.

Will try again tomorrow.

Orbit decay


460
440
420
400
380
360
340
Altitude, km
0
20
40
60
80
100
Time, days
CubeSat only, S = 0.01 m2
CubeSat + Magsail, R = 0.008 Ω
Release altitude = 420 km
MagSail On-time = 0.95h per orbit, 44h/48h cycle
MagSail P = 1.54 W, Area = 0.5 m2
Total mass = 1.33 kg
Wire mass = 75 g; R = 0.008 Ω

Relative separation