1. (10%) systems engineering A

Below are several steps in the design process for a remote sensing spacecraft. Place them in order. (Clearly indicate your answer as a single sequence of ten letters.)

A define requirement: identify missile launches from potential launch sites worldwide
B build sensor
C test sensor against calibrated energy source
D define requirement: $\geq$ 3 GEO spacecraft
E dispose in graveyard orbit
F install sensor in spacecraft
G operate spacecraft constellation
H define requirement: identify energy sources $\geq$ 25 W/sr
I system tested by dedicated USSF test squadron
J validation and operational acceptance

2. (8%) systems engineering B

You are designing FalconSAT 24, which will carry a visible light camera. Initial plans call for a sun-synchronous orbit with no eclipses ($\beta = 90°$). You have been asked to analyze the consequences of moving to a maximum-eclipse sun-synchronous orbit ($\beta = 0$).

List at least two changes you will need to make to the electrical system as a direct result of the orbit change. (Show equations and discuss, but do not solve.)

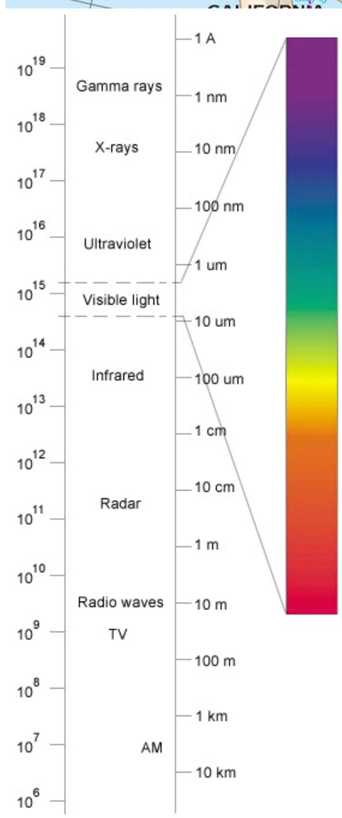
What might change about the payload?

Can your payload change cause additional second-order changes to your electrical system? Discuss.

8. (10%) Requirements

Below is a partial list of requirements for a space system funded by the state of California to provide warning of wildfires throughout the state.

Identify 5 problems in this set using the properties of good requirements as covered in class. Justify your decisions—specifically, highlight and name a problem rather than simply saying “this is bad.” Finally, improve the deficiencies you identify. If appropriate, improvements can include deleting requirements.



programmatics

- The system shall provide full time jobs for at least 200 Californians.
- The system shall be ready within 3–5 years.
- The system shall cost no more than \$5 M.

system

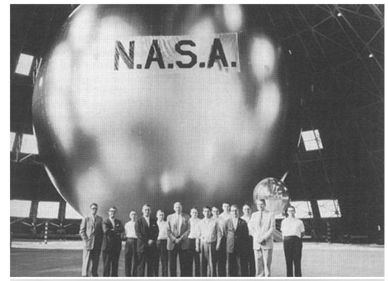
- To save costs, the system shall consist of no more than one space vehicle.
- The spacecraft shall provide continuous coverage of California from 30°N to 85°N.
- The system shall alert firefighters to a fire very fast.
- The space vehicle shall orbit at a semi-major axis of exactly 300 miles.

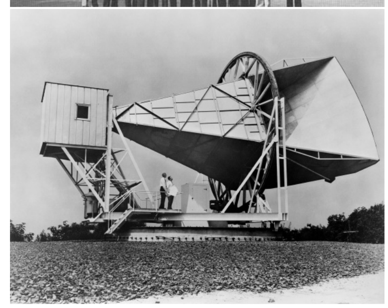
sensor

- The sensor shall detect all fires.
- To avoid false alarms, the sensor should not detect any wavelengths shorter than 700 nm.
- It would be good to detect gamma radiation.

1. (16%) Mission Geometry

Project Echo used a 30 m aluminized balloon to reflect radio signals between ground stations. Using the given parameters, determine if it is possible to use Echo 1 to communicate between Goldstone, CA and Holmdel, NJ. Draw a diagram to support your work.





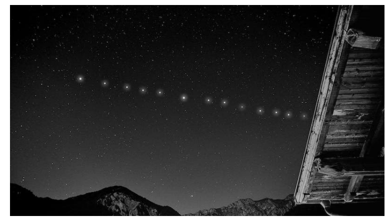
Goldstone–Holmdel distance:	3880 km
Echo 1 altitude:	1500 km
minimum elevation angle:	15°

List your assumptions:

Solve:

5. (16%) Perturbations

How does SpaceX launch Starlink spacecraft into multiple orbital planes from a single launch without using fuel for plane changes?



Five Starlink spacecraft from the latest launch will join the operational spacecraft in a plane that is currently 5° behind the launch plane. How long should these spacecraft wait to begin raising their orbit?

$$h_{park} = 440\,\text{km}$$
$$h_{msn} = 550\,\text{km}$$
$$i = 53^\circ$$

List your assumptions:

Solve:

6. (8%) Astrodynamics
Identify and describe at least four discrete requirements of the whole-lifetime ΔV budget for a commercial geostationary communication satellite.

7. (8%) Spacecraft Budgets
List four systems that should be accounted for in a spacecraft's power budget.

What is the purpose of margin in a power budget?

6. (5%) budgets A

Below are four cost estimation methods.

1) parametric
2) extrapolation from actuals
3) engineering
4) analogy

Place them in order according to their utility during a program's lifetime.

7. (10%) budgets B

Estimate the subsystem masses and total spacecraft dry mass (including 25% margin) of a remote sensing spacecraft with a 100 kg optical payload using the provided average mass distributions for remote sensing spacecraft.

payload	34.6%
structure	18.9%
thermal	2.1%
power	24.3%
control	3.4%
attitude	4.5%
propulsion	6.1%

Soldering

Watch these soldering videos:

- https://youtu.be/-qk-ulz05J8 (4:35)
- https://youtu.be/eHu_fGAyNY4 (3:18)

FalconSAT-3 attitude paper

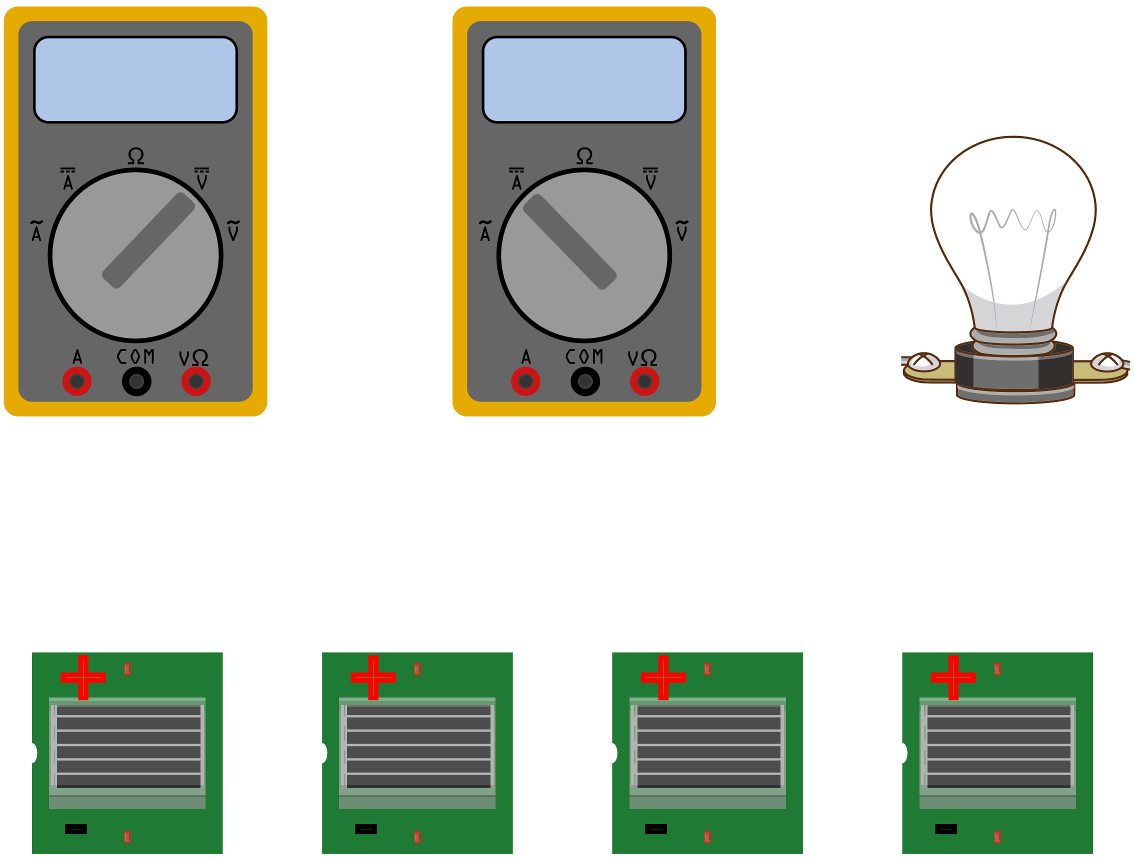
20-40 min

read AIAA paper by Richie and Robinson

- identify 3 major problems with FalconSAT-3
    - how did they happen?
    - how did USAFA correct them?
- make notes on paper style
    - 1st vs 3rd person
    - layout: intro, background math with descriptions
    - level of detail in introduction/background
    - level of technical detail
    - look of graphics and figures

5. (6%) circuits B

Draw lines on the diagram showing the cells in series powering the light bulb. Include the connections required to measure current and voltage.



3. (15%) Electrical

FalconSAT-48 will be a follow-on to ESA's GOCE gravity-mapping spacecraft. Size the solar array and battery to ensure they can survive a 3-year design life

altitude	250 km
eccentricity	0
inclination	96.5°
bus power	200 W
thruster power	300 W
daylight efficiency	80%
eclipse efficiency	60%
beta angle	0
solar cell type	IMM
efficiency	33%
annual degradation	8%
battery cell type	Li-ion
battery efficiency	75%

10. (16%) Camera payloads

You are designing the camera system for Planet Labs' upcoming Pelican spacecraft. The current design satisfies the swath width requirement of 4 km. Does it meet the 50 cm resolution requirement?

sensor wavelength	380 nm
sensor size	$7000 \times 2016\,\text{px}^2$
sensor size	$48.75 \times 14.04\,\text{mm}^2$
aperture diameter	730 mm
focal length	3.90 m
swath width	5 km
mission altitude	400 km

Does the image sensor meet the resolution requirement? Circle one: yes/no

Does the optical system (lens) meet the resolution requirement? Circle one: yes/no

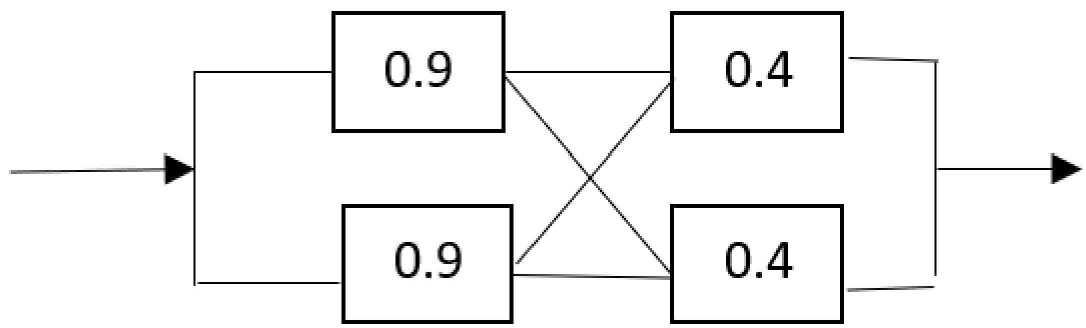
You have enough budget margin to redesign either the optics or the image sensor. If necessary, which will you redesign? Circle one: optics/image sensor/not necessary

Does the other system (image sensor or optics) need any changes? Circle one: yes/no

If yes, what can you change? (You do not need calculations, just describe what you could change.)

Reliability

- How do we compute the probability of failure?
- If we have three components in series, each with a reliability of 0.9, what is the reliability of the whole system?
- If we have three components in parallel, each with a reliability of 0.9, what is the reliability of the whole system?
- What is the reliability of the following cross strapped system?



- Briefly describe the risk categories of NASA and the DoD.

6. (20%) Communication

T-Mobile intends to provide text messaging anywhere on Earth via Starlink spacecraft. A typical cell phone can produce an EIRP of 300 mW. How big of a parabolic antenna will Starlink need to receive text messages from Earth's surface with an $\frac{E_B}{N_0} \geq 10$?

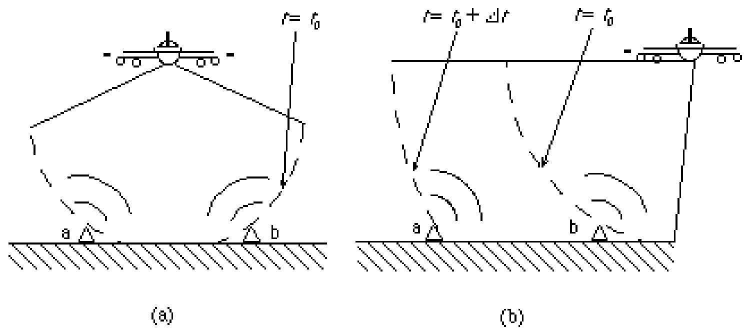
altitude	550	km
antenna efficiency	60%	
rx temperature	271.15	K
$(10\log_{10} T)$	24.364	dB
data rate	10.536	Mbps
$(10\log_{10} R)$	70.227	dB
frequency	1.91	GHz
miscellaneous losses	−5.00	dB
minimum elevation	75°	

8. (10%) payloads

List two payload types suitable for imaging/remote sensing at night.

List one payload type suitable for imaging/remote sensing under cloud cover.

A radar sensing spacecraft cannot operate looking straight down at its target. Why not?



Resolution of an optical sensor depends on distance. $Res = \frac{2.44\lambda h}{R}$. However, the cross-track resolution of a SAR sensor is independent of distance. Why? It may help to draw a picture.

5. (10%) Attitude

FledglingSAT is a 3-axis stabilized 3U cubesat. The x-axis reaction wheel suffers a catastrophic failure and seizes due to a bad bearing.

How fast will the spacecraft spin after the wheel seizes?

Assume reaction wheels in other axes are motionless.

I_z	7.5×10^{-3} kg m^2
I_x, I_y	4.5×10^{-2} kg m^2
I_{wheel}	7.5×10^{-6} kg m^2
m_{wheel}	375 g
spacecraft mass	6 kg
initial speed	2000 RPM

Fortunately, FledglingSAT has a smaller redundant experimental reaction wheel. Unfortunately, it is not large enough to immediately counteract the new rotation. What can you do to regain control of the spacecraft?

4. (15%) attitude B

FalconSAT's moment of inertia is $52\,\text{kgm}^2$.

Reaction wheel:

MOI	1.767×10^{-3} kgm^2
torque	7.289×10^{-2} Nm

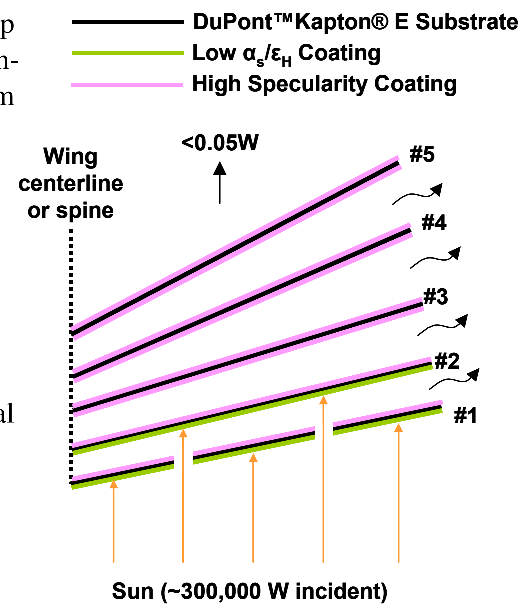
Using a minimum-time maneuver, how long will it take to change FalconSAT's orientation by 45° using a single reaction wheel? Both the wheel and the spacecraft start from rest.

What is the maximum speed the wheel will experience during this maneuver?

Bonus (+5%): If the max wheel speed is limited to 3000 RPM, how long will the maneuver take?

2. (20%) Thermal

James Webb Space Telescope uses a 5-layer sunshade to keep its instruments cold. Material properties are given below. Sunshade area is approximately $300\,\mathrm{m}^2$. Layer 1 has an equilibrium temperature of $314.8\,\mathrm{K}$.



layer	side	ρ	α	ε
3–5	both	0.97	0.03	0.03
1–2	dark	0.97	0.03	0.03
1–2	light	0.56	0.44	0.76

Unfortunately, space debris has punctured layer 1. After several years it is now 10% transparent.

Find the equilibrium temperature of layer 2.

Ignore Earthshine and albedo.

4. (10%) Propulsion

FalconSAT-48 will use stainless steel tubing for its fuel lines. Calculate the minimum wall thickness required. Use a safety factor of 1.1 for yield stress and 1.5 for ultimate strength.

Young's modulus	190 GPa
yield strength	205 MPa
ultimate strength	515 MPa
propellant	xenon gas
pressure	20.0 MPa
tube diameter	5 mm

9. (8%) Launch Environment

Launch vehicle payload fairings are heavy and expensive, and they are jettisoned before the launch vehicle reaches orbit.

Why is this particular time chosen to jettison them? Describe why they are retained so long AND why they are not retained longer.

Briefly describe (1–4 sentences) how you would calculate a launch vehicle's second-stage performance if the payload fairing is jettisoned partway through second-stage firing. The ideal rocket equation is shown here for your reference.

$$\Delta V = I_{sp} g_0 \ln \frac{m_i}{m_f}$$