CLTP4: Structures and Deployables

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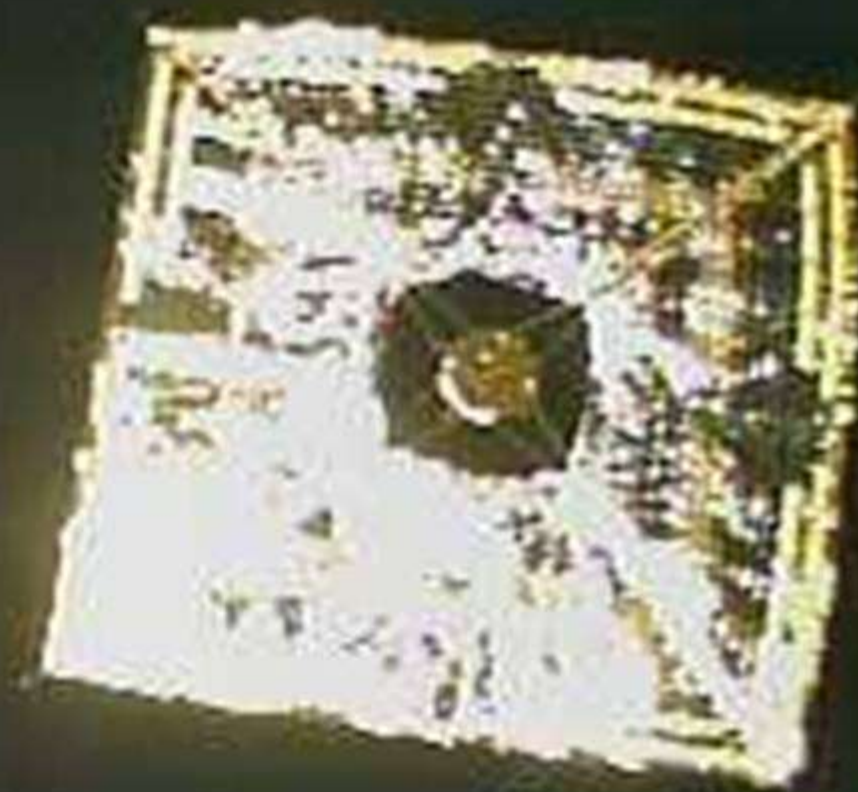
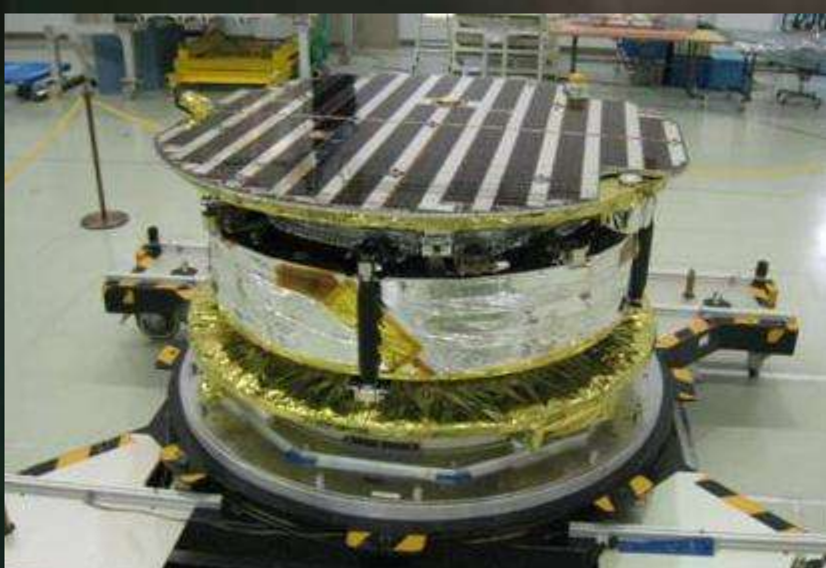
Deep Space Solar Sail Demonstrator

IKAROS





ARLISS at Nevada, USA

2007

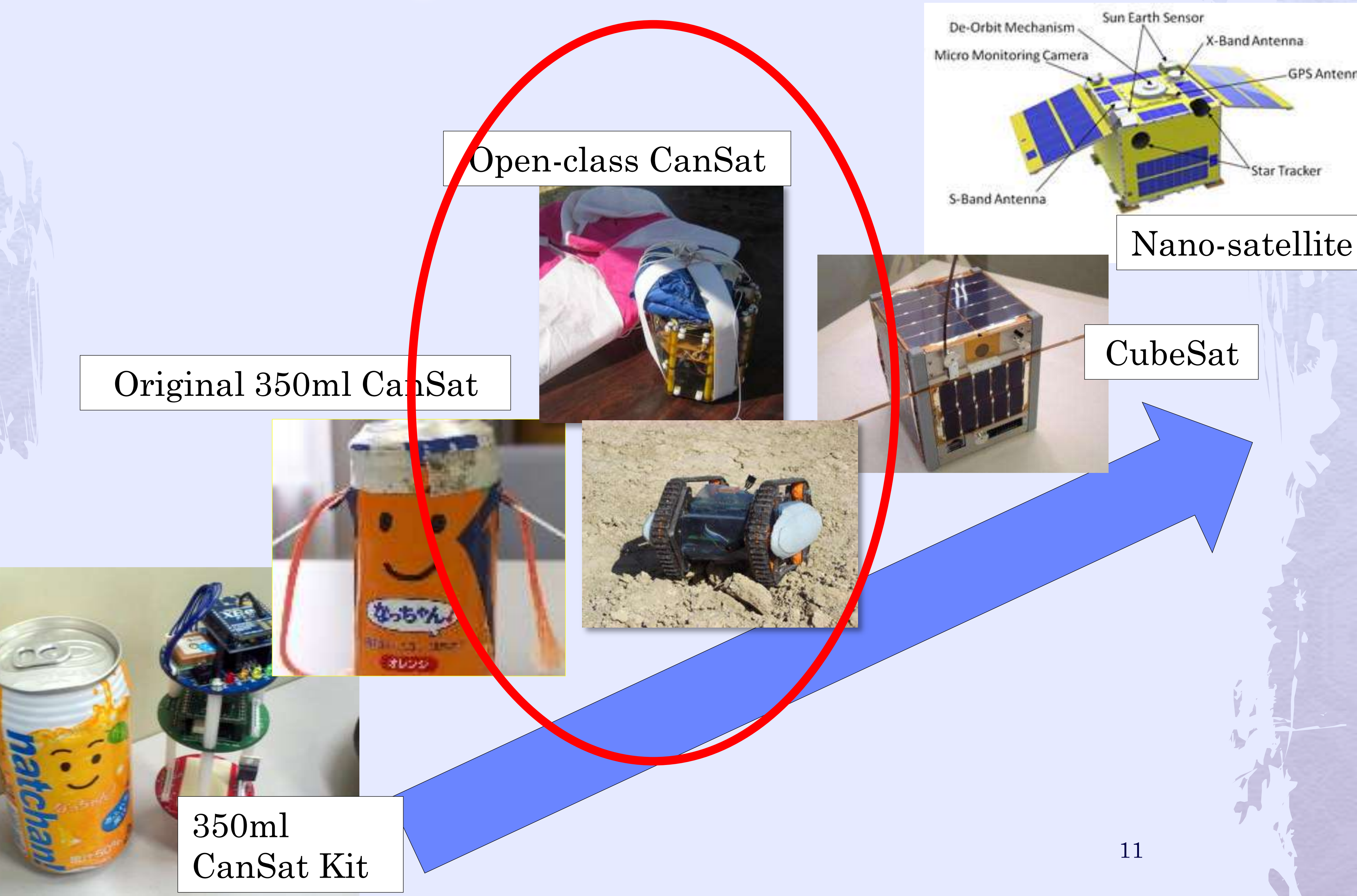
2008

2009

2011

2012

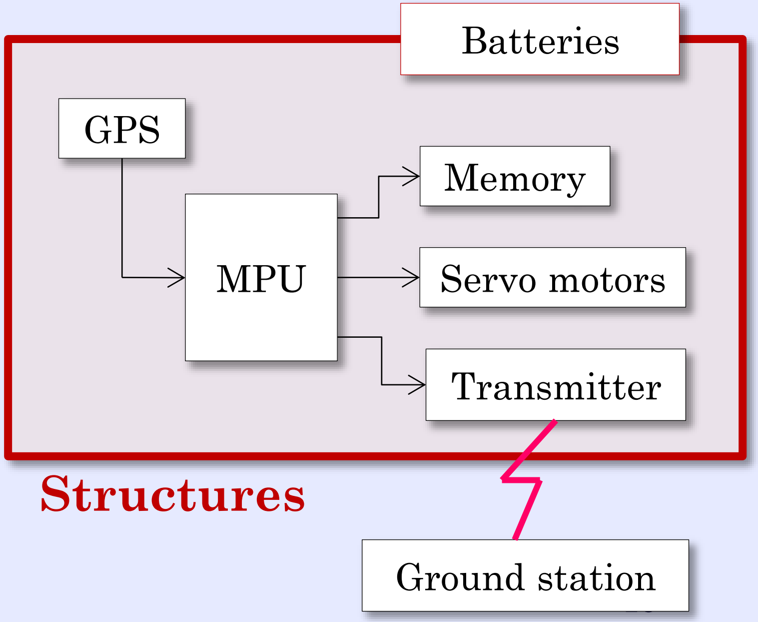
Scope of this lecture



Structures and deployables: Roles

- The structures mechanically supports all other spacecraft subsystems from manufacture to the end of the mission.

Typical CanSat subsystems



Environment:

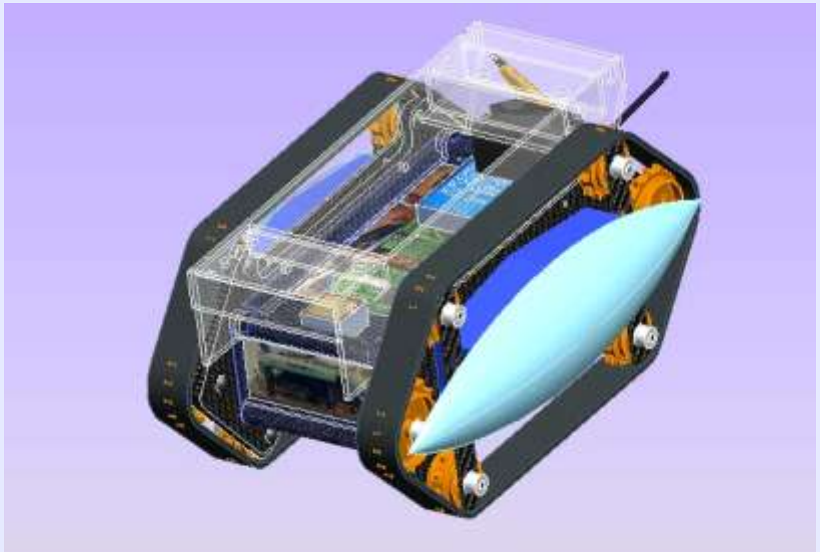
- ✓ Static loading
- ✓ Vibrational loading
- ✓ Shock loading
- ✓ Heating (not covered today)

Structures and deployables: Roles

- The structures mechanically supports all other spacecraft subsystems from manufacture to the end of the mission.
- The deployables (a.k.a. deployable structures) are compactly stored in a launch vehicle, and deployed after separation.

Mission Example

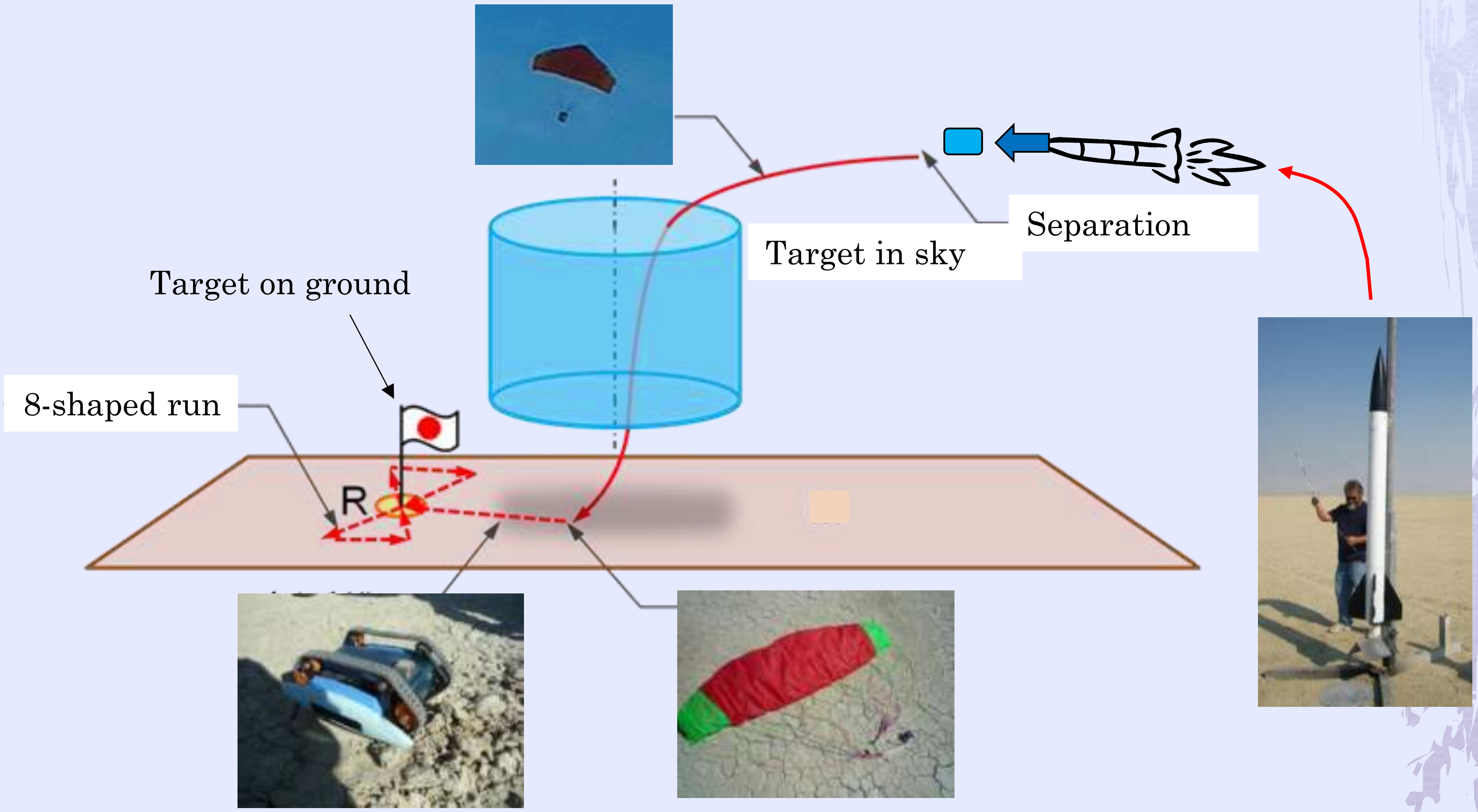
- Hybrid CanSat, Space Crawler (2009)



Structures and deployables: **Agenda**

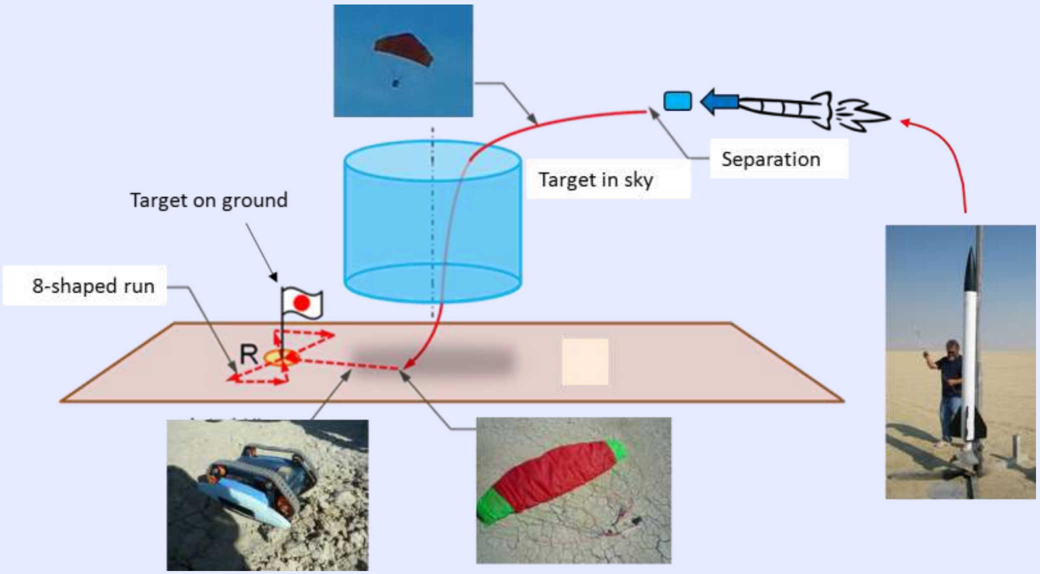
- Requirement analysis
- Strength and stiffness
  - Vibration test
  - Landing test
- Packaging configurations
  - Volume/mass constraints
  - Producibility, accessibility
  - Interaction between subsystems
- Deployables (parachutes)
- Design example

Mission sequence of Space Crawler

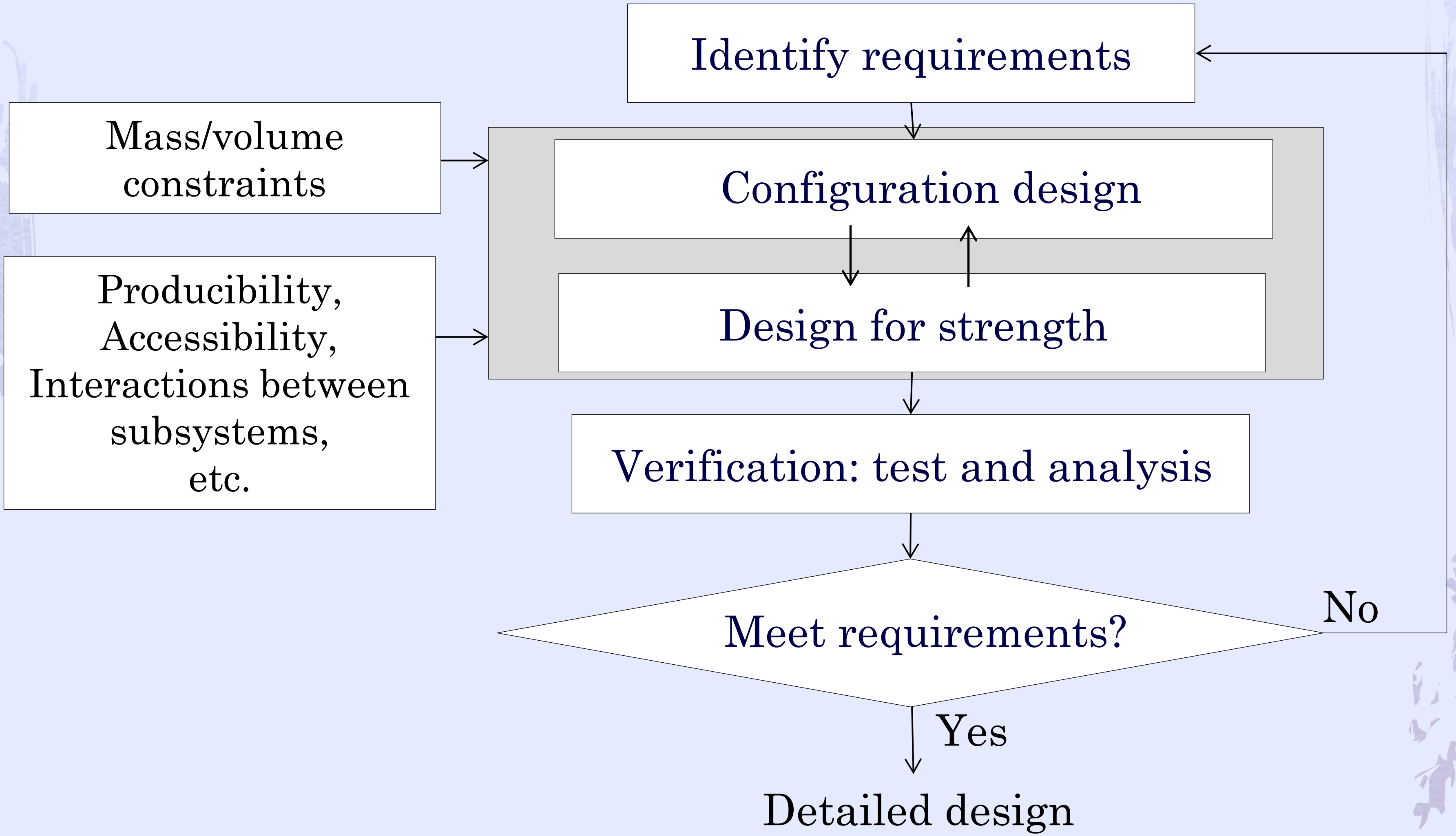


CanSat mission sequence (1)

- Launch and ascent
- Separation, deployment of appendages
- Descending
- Landing
- Separation of appendages
- Running

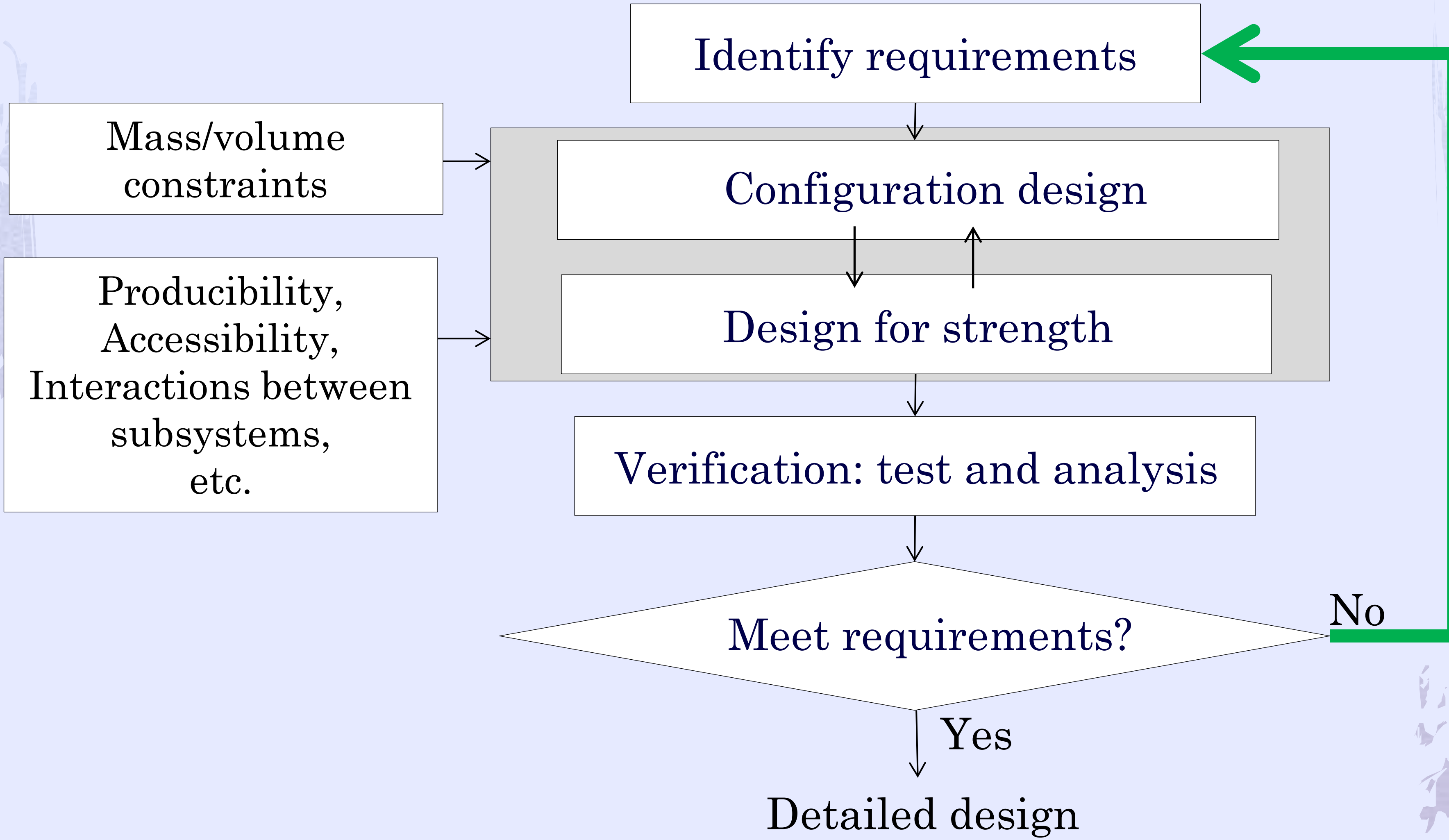


Design process



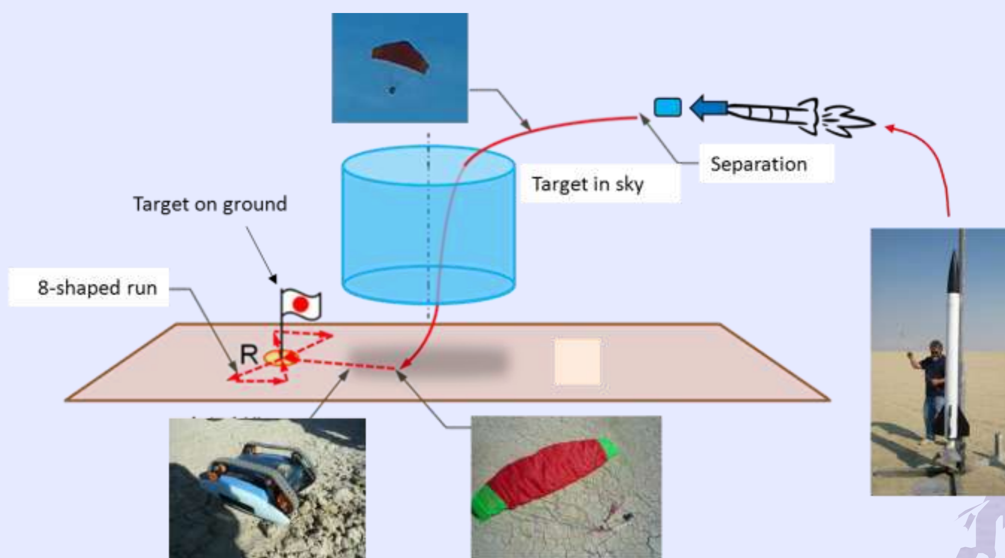
Design process

✓Prototyping!!

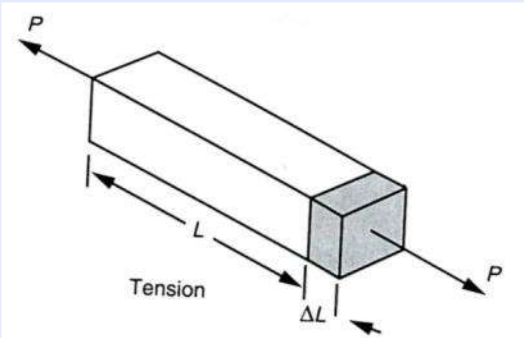


Requirements in mission sequence (1)
-Strength and stiffness

- Launch and ascent
  - Static load: Strength
  - Vibration: Stiffness
- Separation, deployment of appendages
  - Shock load: Strength
- Landing
  - Shock load: Strength



Basic mechanics (1/4) -axial deformation

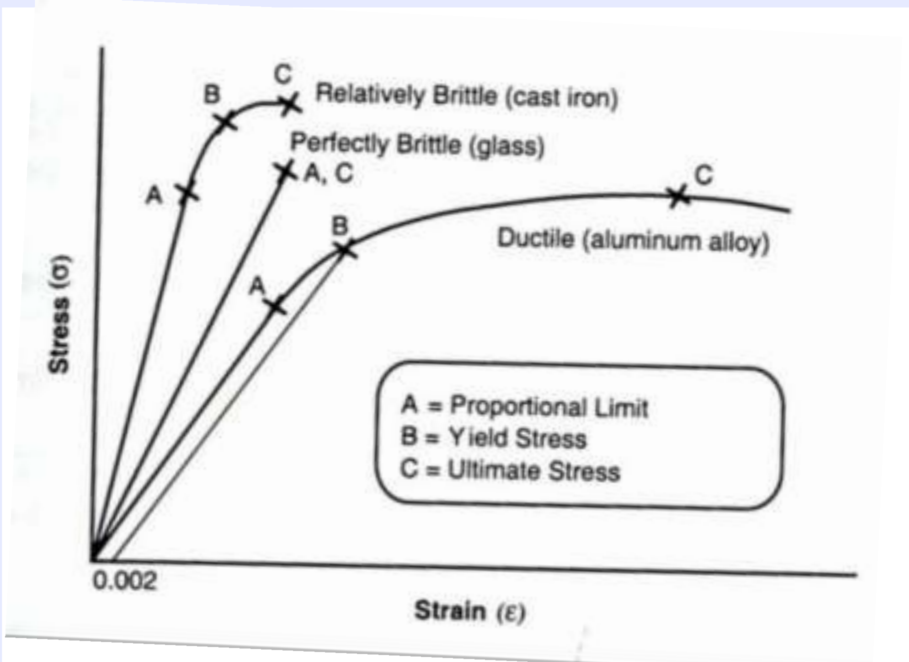


Stress: $\sigma = \frac{P}{A}$

Strain: $\varepsilon = \frac{\Delta L}{L}$

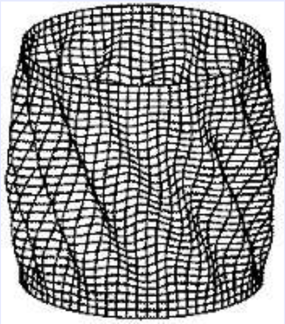
Young's modulus: $E = \frac{\sigma}{\varepsilon}$

Stress-strain relation:



- ✓ Brittle materials:
  - ➡ Watch ultimate stress
- ✓ Ductile materials:
  - ➡ Watch yield stress
- ✓ Factor of safety = material strength / design stress
  - ➡ 1.25 – 1.5
- ✓ In fact, axial deformation is not a big problem for small sat.

Basic mechanics (2/4) -buckling



Euler's buckling formula:

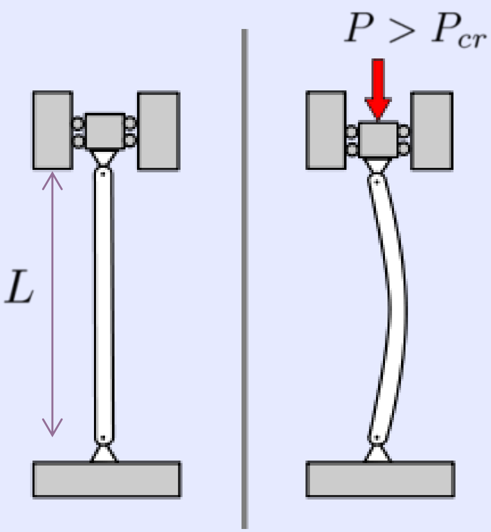
Bending stiffness

$$P_{cr} = \frac{\pi^2 EI}{L^2}$$

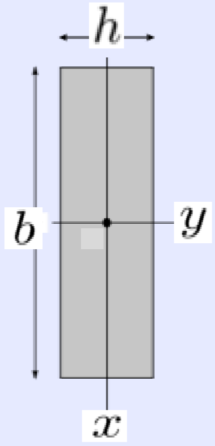
E : Young's modulus

I : Second moment of area

$$I = \iint_A y^2 \, dxdy$$



e.g.) Rectangular section

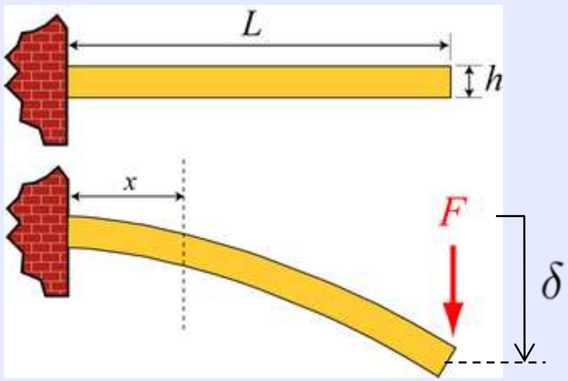


$$I = \frac{bh^3}{12}$$

- ✓ $P_{cr} \propto L^{-2}$
- ✓ $P_{cr} \propto E$
- ✓ $P_{cr} \propto b$
- ✓ $P_{cr} \propto h^3$

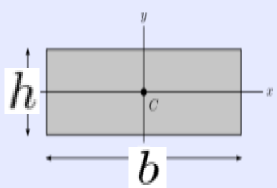
Basic mechanics (3/4) –bending

Euler-Bernoulli beam theory:



$$\delta = \frac{FL^3}{3EI}$$

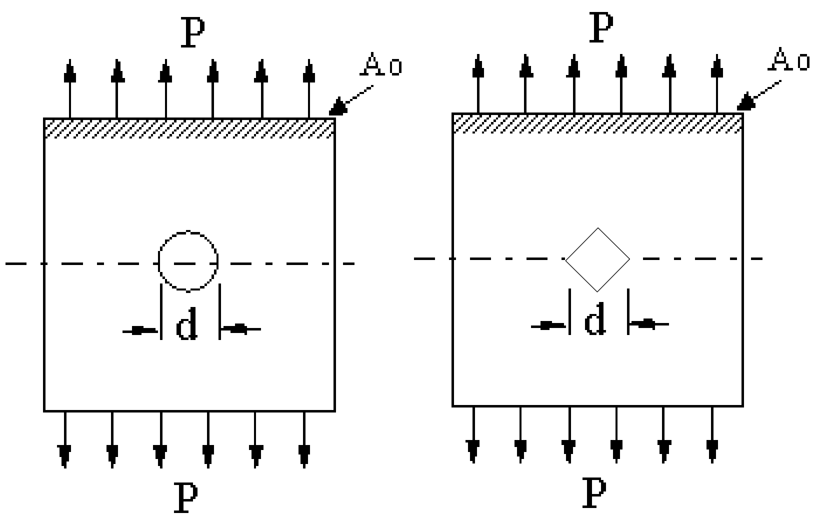
Bending stiffness



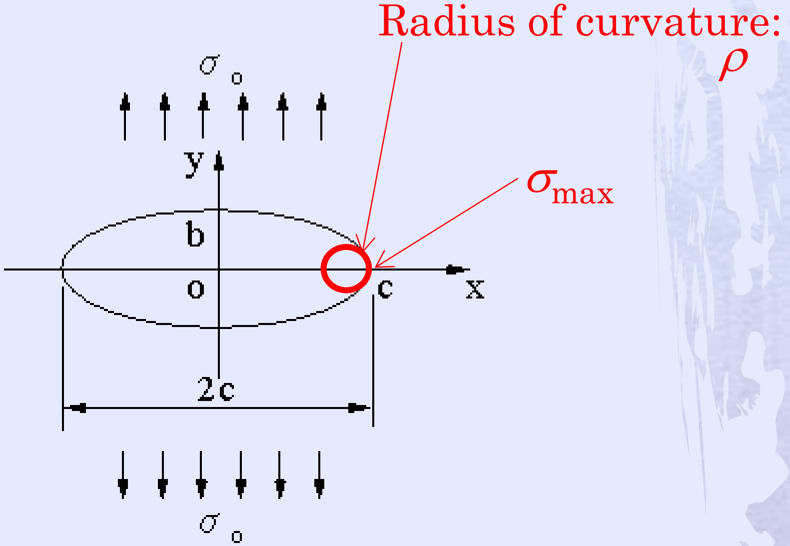
$$I = \frac{bh^3}{12}$$

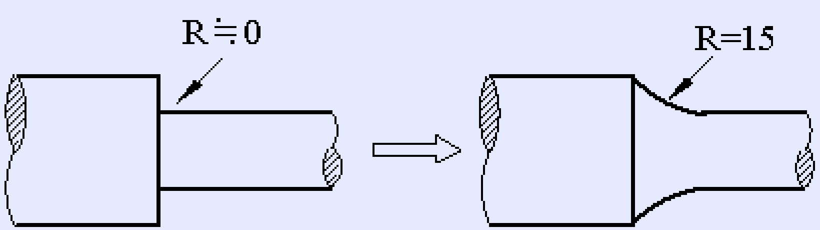
- ✓ $\delta \propto L^3$
- ✓ $\delta \propto h^{-3}$
- ✓ $\delta \propto E^{-1}, b^{-1}, F$

Basic mechanics (4/4) –stress concentration



Which is better? Why?





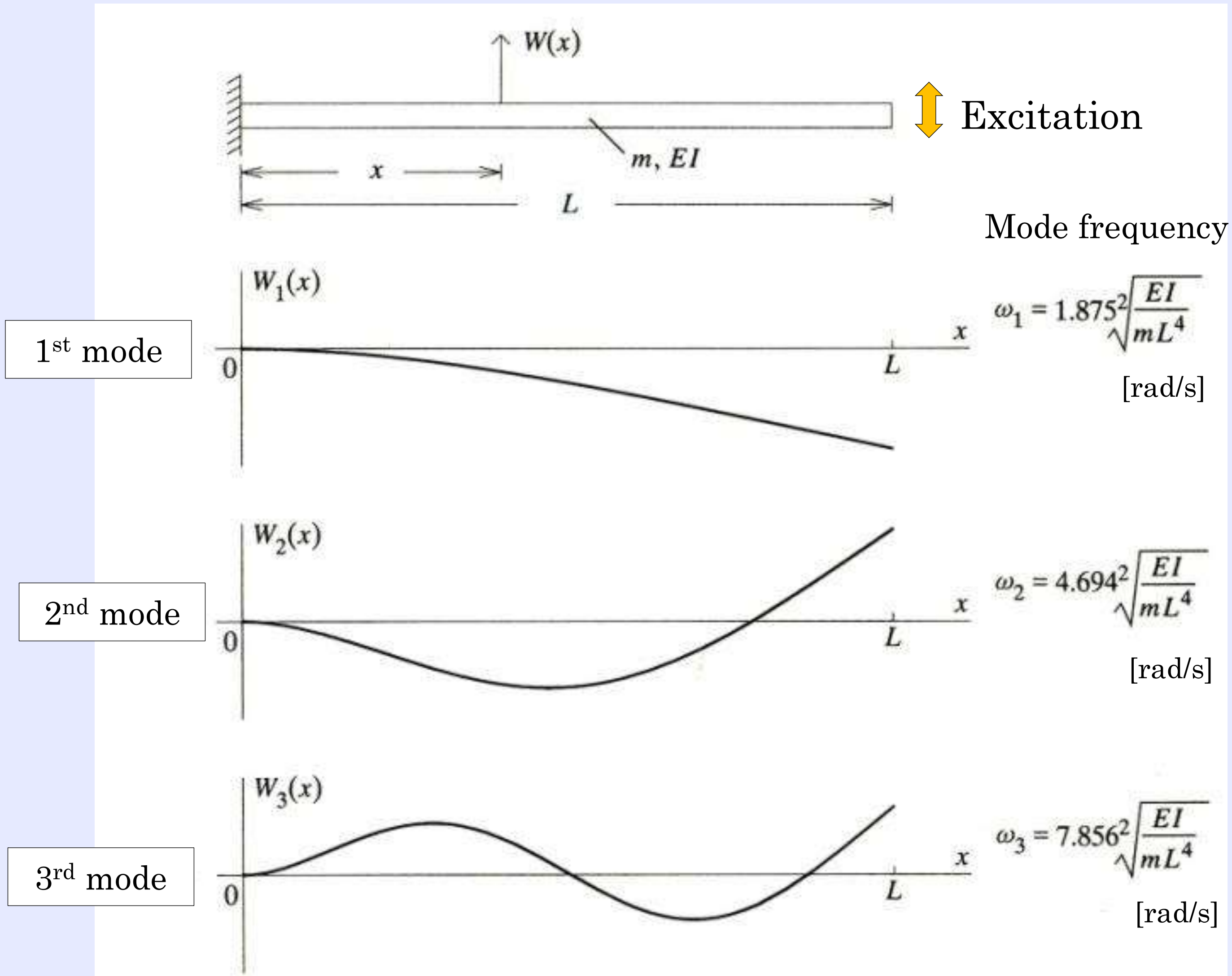
Stress concentration:
Large
Smaller

Stress concentration factor

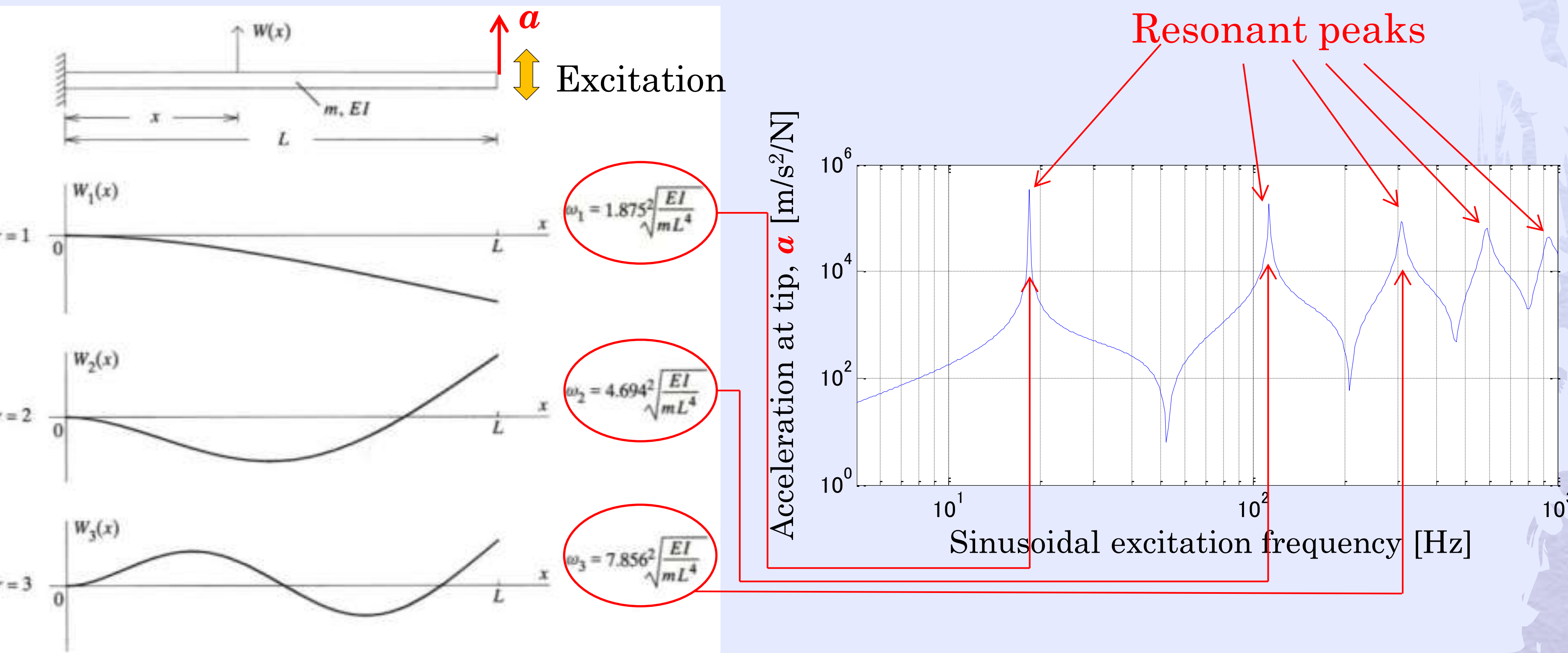
$$\frac{\sigma_{max}}{\sigma_0} = 1 + 2\sqrt{\frac{c}{\rho}}$$

Basic dynamics (1/2) –vibration modes

Euler-Bernoulli beam theory (eigenvalue analysis):



Basic dynamics (2/2) –frequency response



- ✓ Make ω_1 as high as possible
  - ➡ Stiff structure
- ✓ Structure should not break even at resonance
  - ➡ Stiff, strong, and highly damped structure

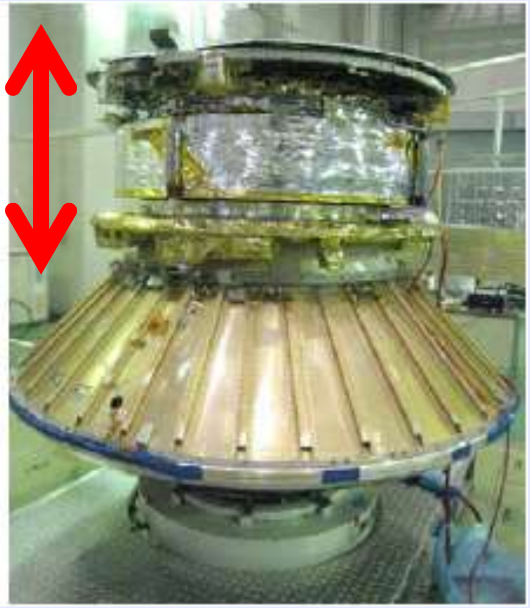
Vibration tests (1/3)

Launch vehicle specifies the test conditions:

- Quasi-static load
- 1^{st} mode frequency
- Sinusoidal vibration
- Random vibration
- Shock load

ARLISS's rocket:

- Static load: 10G
- Random vibration: 25Grms



Vibration test (2/3)

- CanSat is small: Satisfying stiffness & strength requirements for global structures is relatively easy. But…
- Need: Identification of failure mode due to "local resonance"

➡ Local vibration may break structures/devices

- Soldering
- Cables/connectors
- Volts/joints
- Motors/gear boxes
- etc…

Vibration test (3/3)
-Vibration test setup for CanSat

CanSat

Accelerometer

Signal conditioner

Oscilloscope

Amplifier

Function generator

✓ Identify the failure modes

Landing test

- Verify strength for shock loading

Dropping test

Balloon test

Structures and deployables: **Agenda**

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  - Landing test
- Packaging configurations
  - Volume/mass constraints
  - Producibility, accessibility
  - Interaction between subsystems
- Deployables (parachutes)
- Design examples

Design process

Stiffness, strength

Identify requirements

Mass/volume constraints

Producibility, Accessibility, Interactions between subsystems, etc.

Configuration design

Design for strength

Verification: test and analysis

Meet requirements?

No

Yes

Detailed design

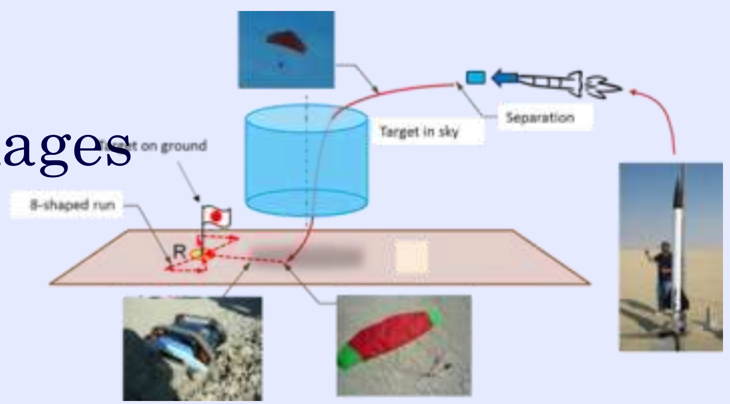
CanSat mission sequence (2)

- Manufacture
- Testing
- Maintenance
- Preflight operation

→ Impose requirements regarding <u>producibility</u> and <u>accessibility</u>

- Launch and ascent → Volume and mass constraints
- Separation, deployment of appendages
- Descending
- Landing
- Separation of appendages
- Running

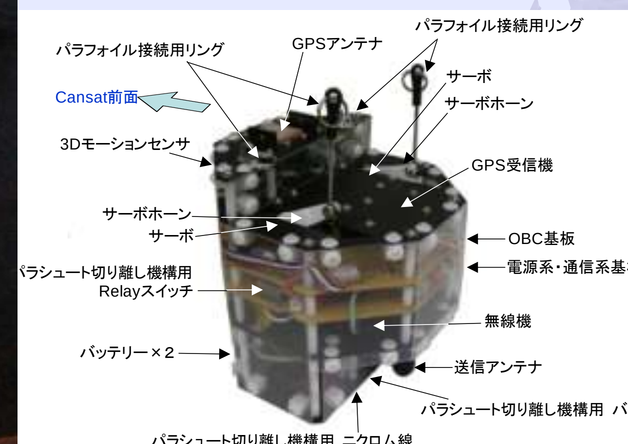
→ Interaction between subsystems



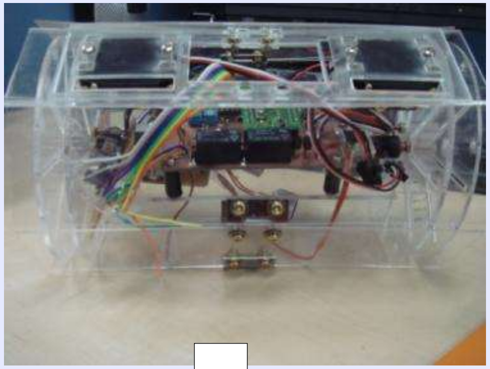
Your country

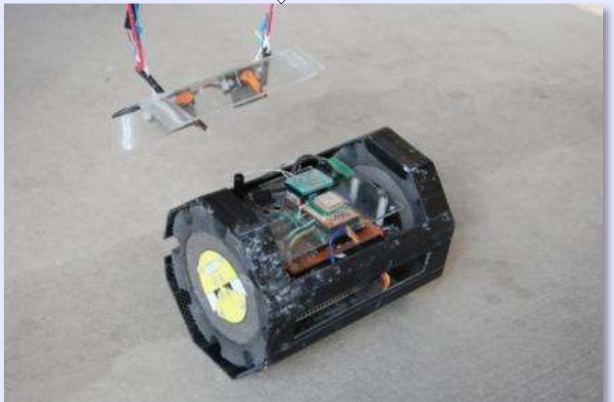
Design methods

- Hand drawing
- Prototyping (mockups)
- 3D CAD



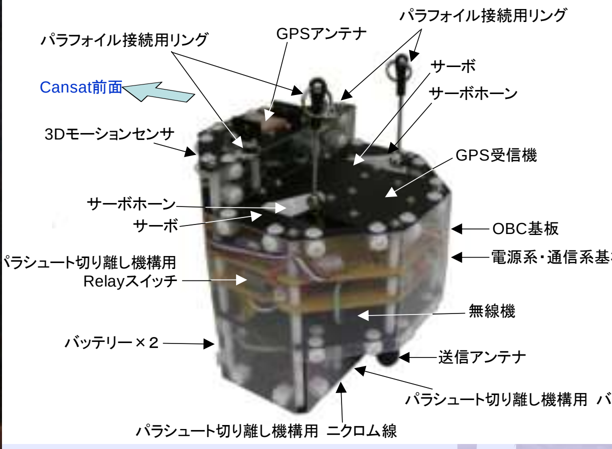
Prototyping (1/3)



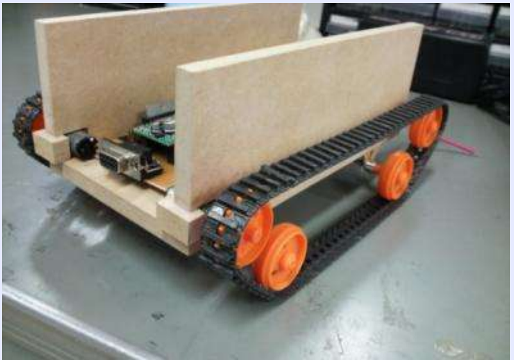


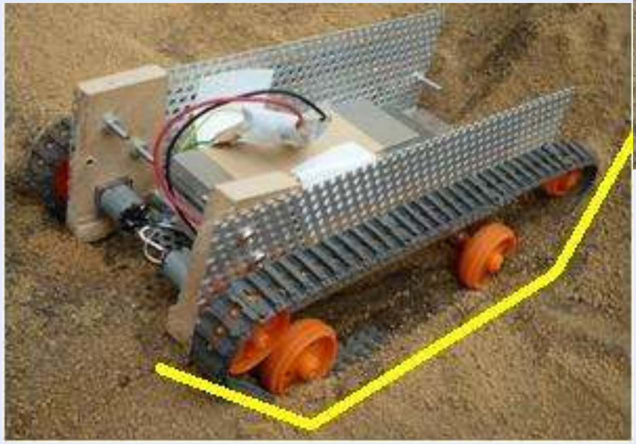
- ✓ Cardboard
- ✓ Plastic plates (acryl, …)
- ✓ Styrene foam
- ✓ Wood

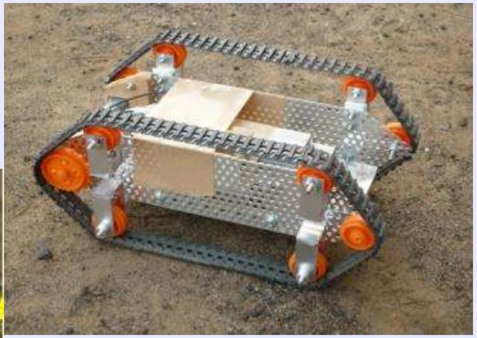
etc…

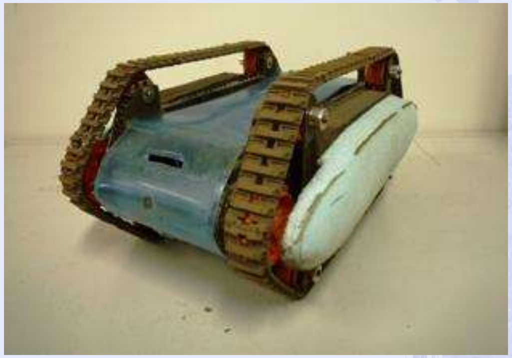


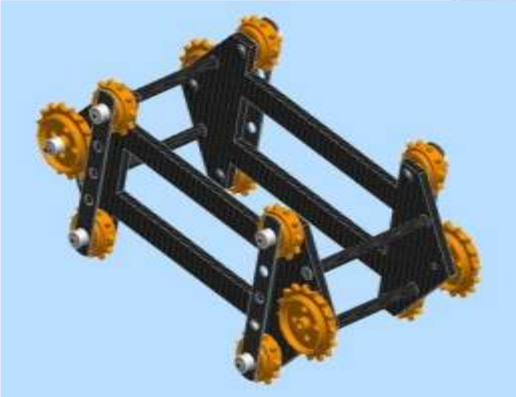
Prototyping (2/3)







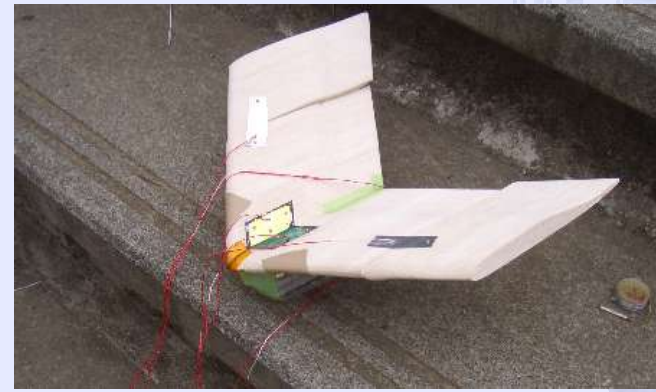




Prototyping (3/3)

PHOENIX





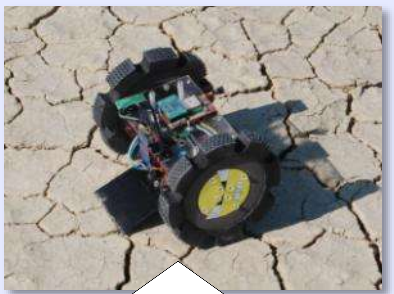


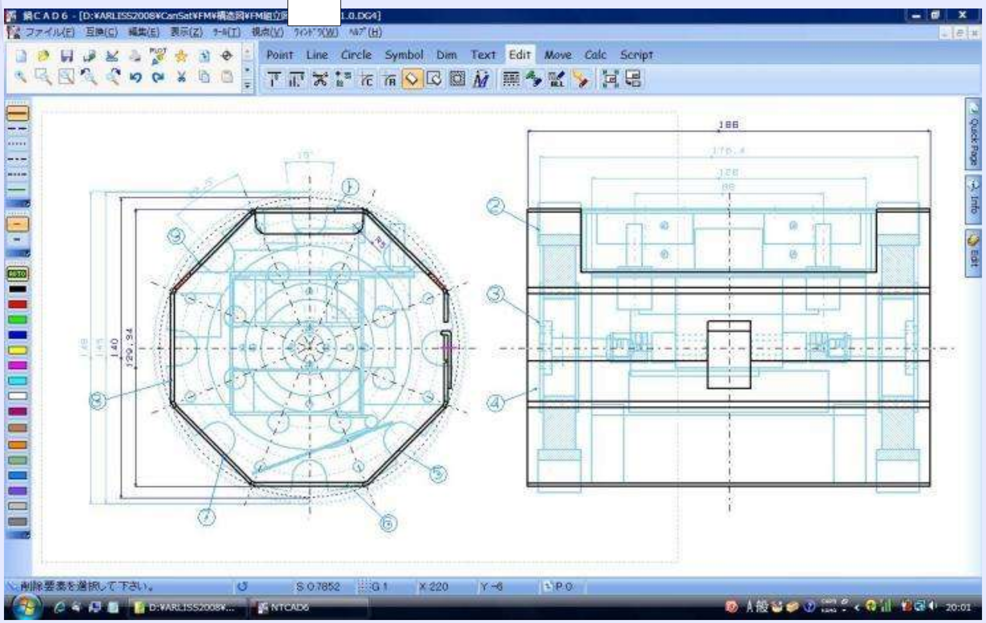


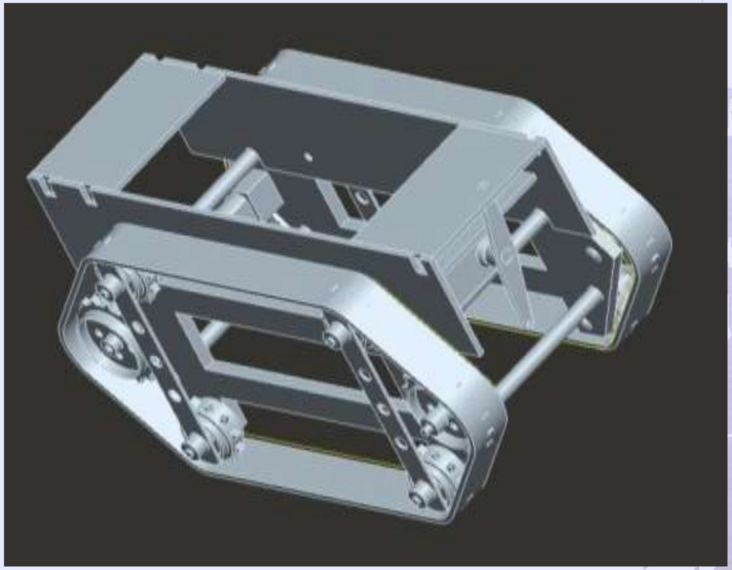
Total 20 models.

3D CAD

- Very helpful to consider configurations
- Various commercial/free software (e.g. SolidWorks, Creo Elements/Pro, CATIA)







Producibility

- Simple shape
  - Combination of plate, rods,…
- Materials
  - Aluminum alloy facilitates machining
  - CFRP is light, stiff, strong, but difficult for machining
- You should be familiar with your machining facility!

Lathe

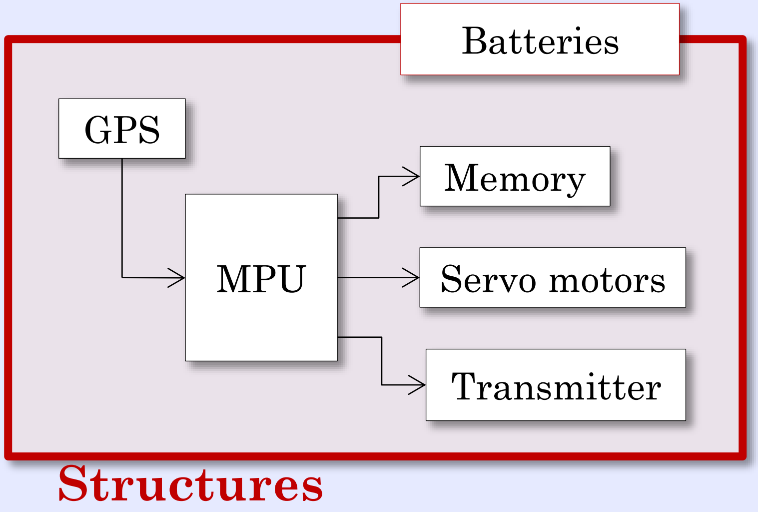
Milling machine

Drill

Accessibility

- **Maintenance:** Many subsystems break during testing.
  - Need easy access, replacement
- **Prelaunch operation:** All subsystems should be checked, and maybe replaced quickly

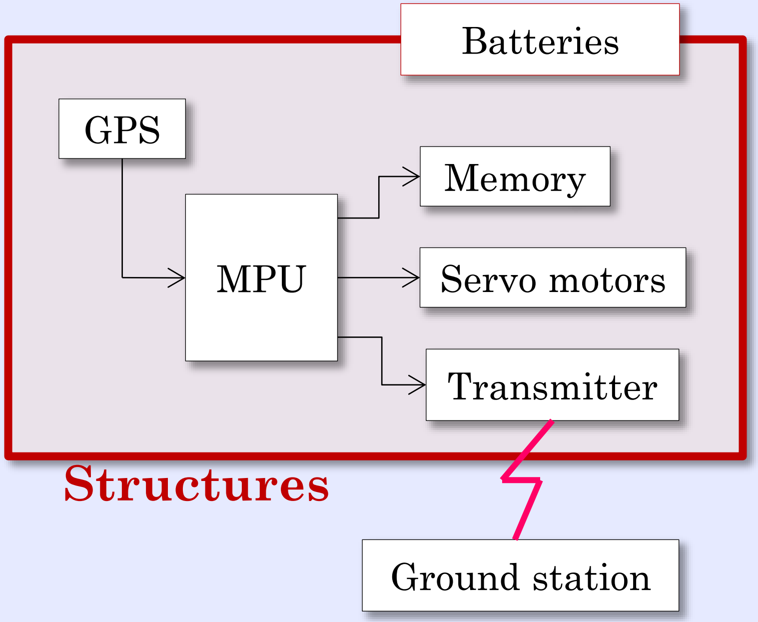
➡ Structural designer should be aware of the maintenance methods for all subsystems in CanSat.



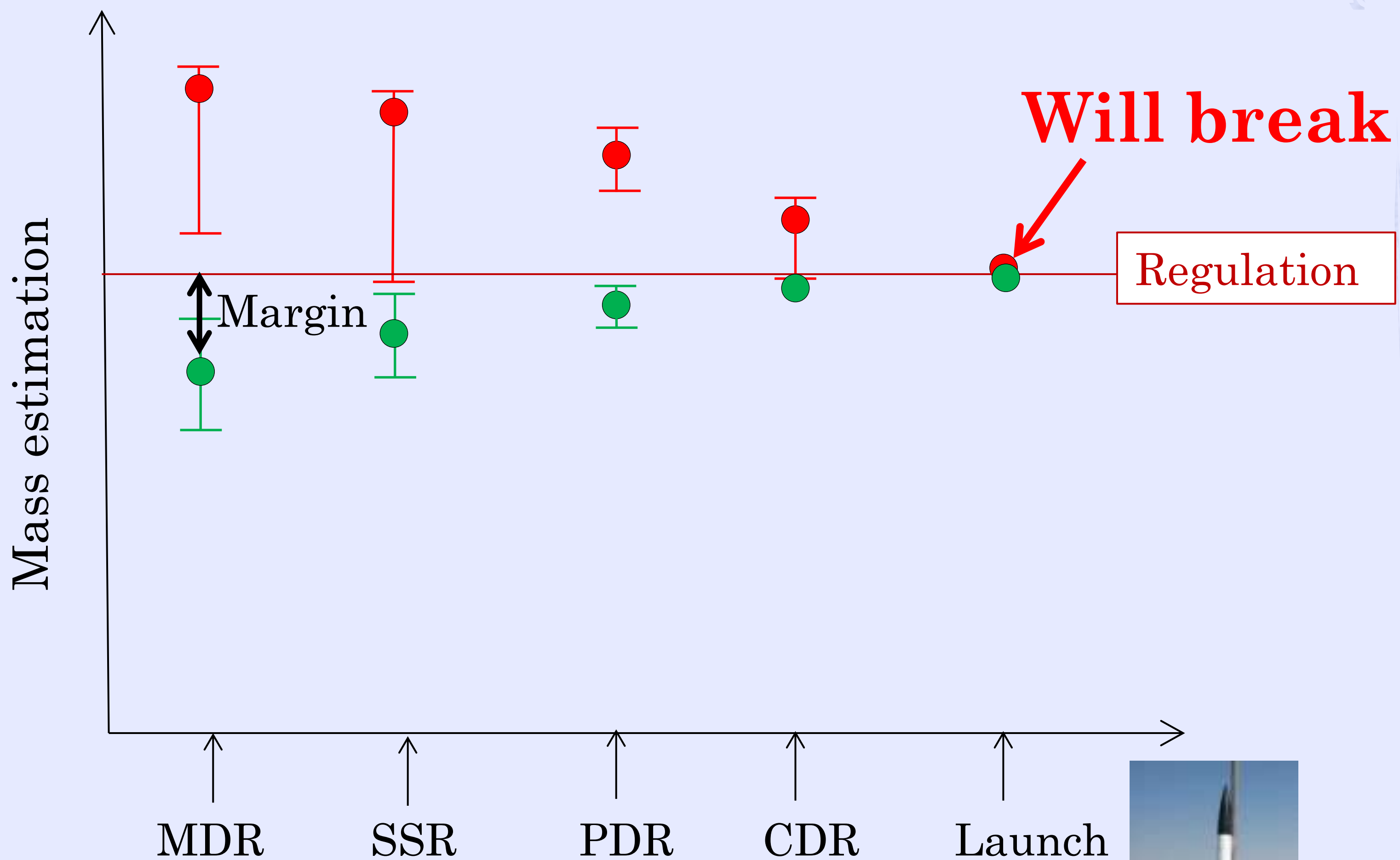
Interaction between subsystems

- GPS receiver – structure
- Communication antenna – structure
- Crystal oscillator – GPS receiver
- Magnetic compass – motor

 etc…



Mass budget (1/2)



Mass budget (2/2)

- For a reliable design, start with ~20% mass margin and gradually enhance precision.
- 3D CAD is very useful for mass estimation.
  - Try several lightening methods: thinning, making holes
- Do not forget the mass of screws! They are heavy.

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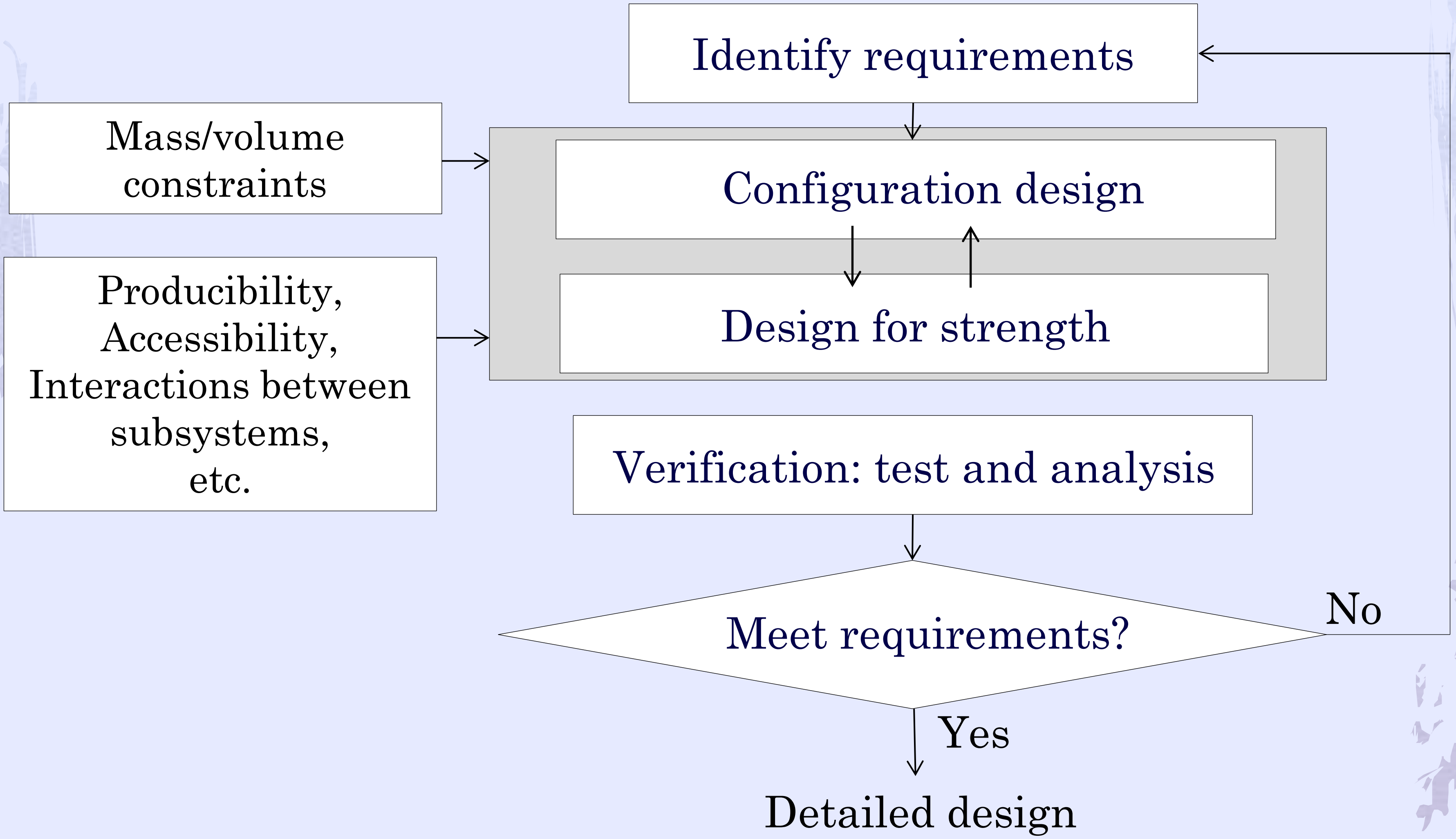
- Deployables (parachutes)
- Design examples

Deployables (parachute)

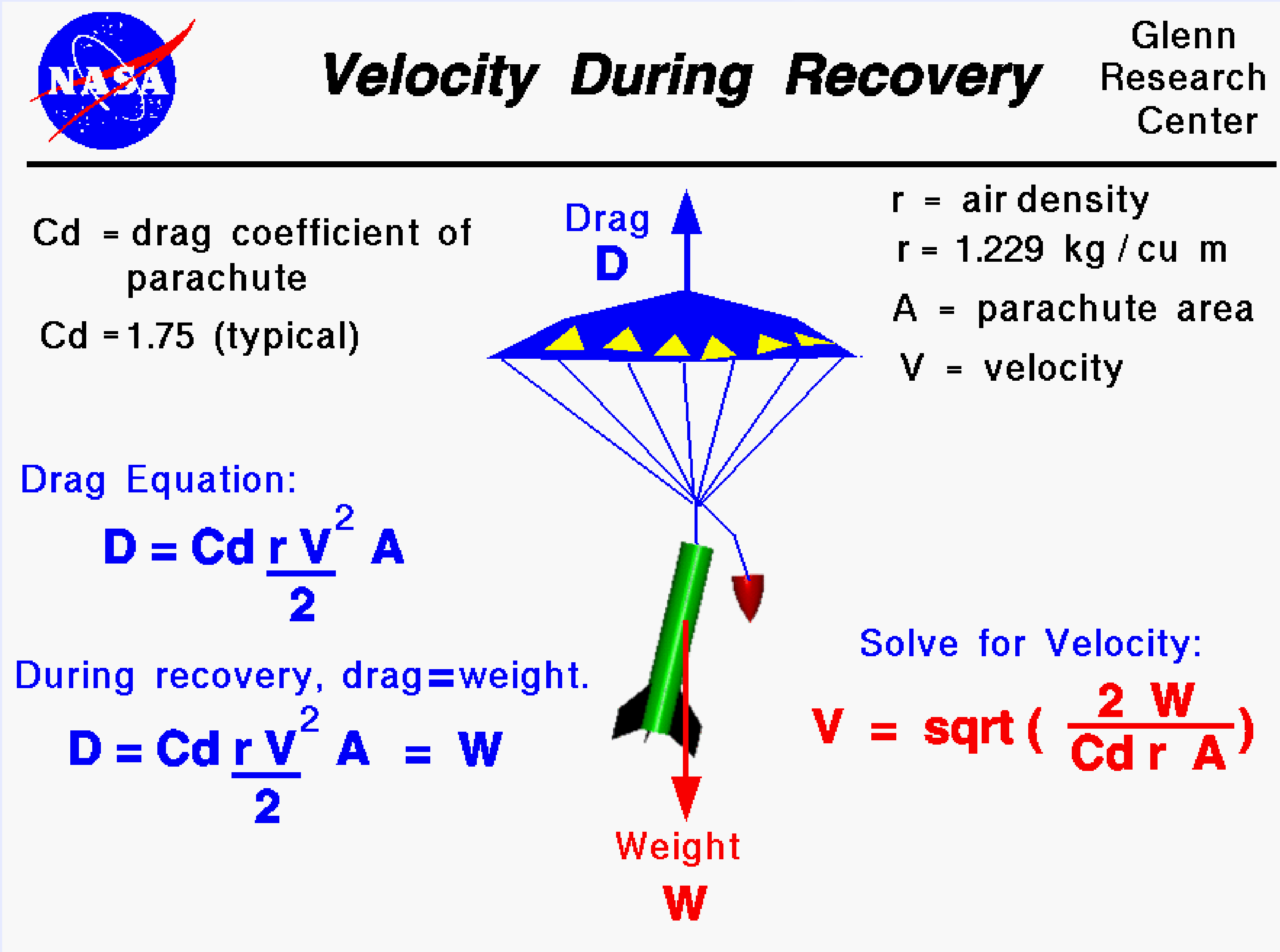
- Sizing
- Design and manufacture
- Storage
- Deployment/separation system
- Deployment shock –strength

Other deployables:

Design process



1. Sizing



http://www.grc.nasa.gov

2. Design and manufacture

- # of lines, with/without a hole
- Material: ripstop nylon, etc.
- Use sewing machine

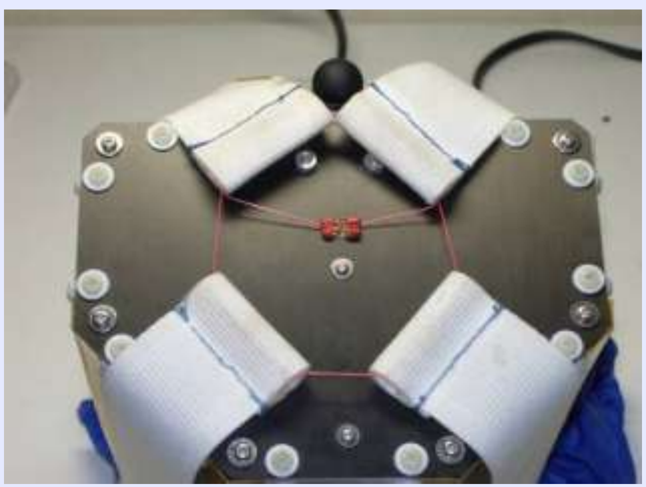
3. Storage

- Folding pattern is very important for reliable deployment.
- Remove wrinkles, entanglement of cables
- Test, test, test! (Stored configuration should be repeatable.)

4. Deployment/separation system

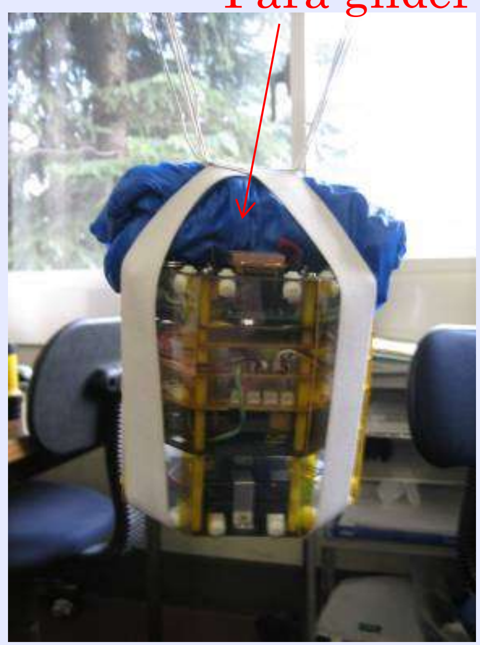
- In most of CanSats, parachute is stored right above a CanSat, and deployed at the separation from a launch vehicle.
  - “Flight pin (kill switch)” is pulled.
- Some CanSats use deployment system or separation system, such as Nichrome wire cutter.

Flight pins

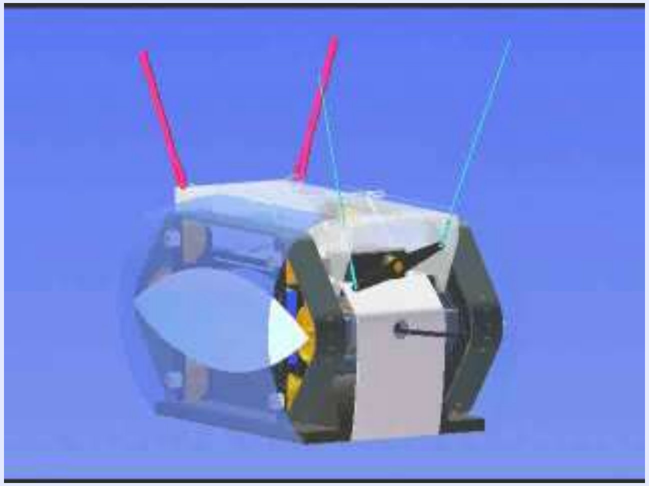


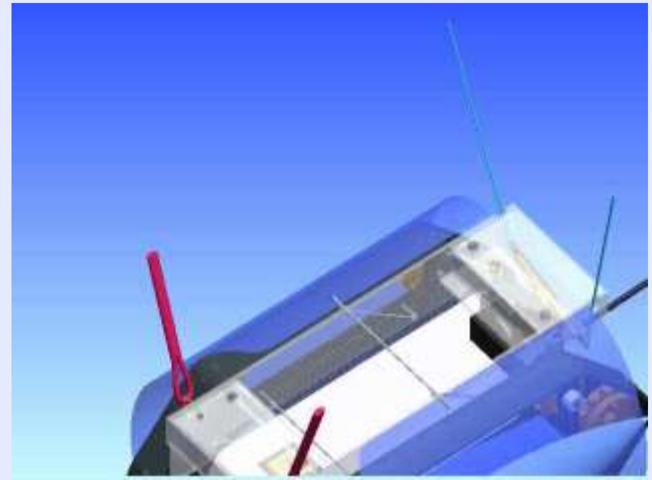
Bottom

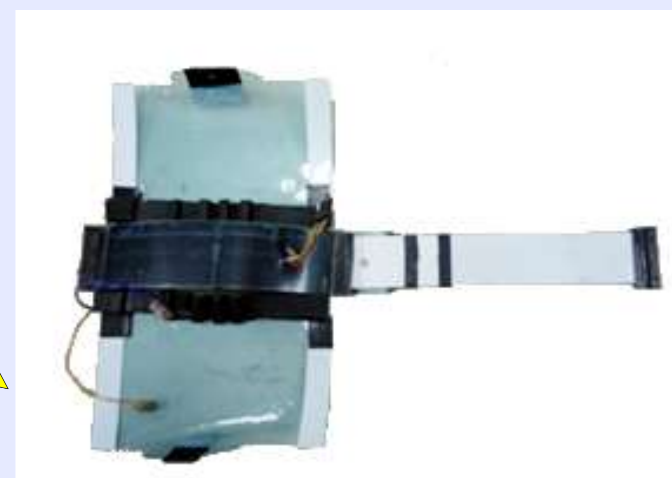
Para glider



Para glider/Cover separations of Space Crawler







5. Deployment shock

- When the parachute is deployed, shock load is applied especially at the cable connecting points on a CanSat.
- Design for strength, and test!

Free fall at the 1st flight

Students test strength of connection for 2nd flight

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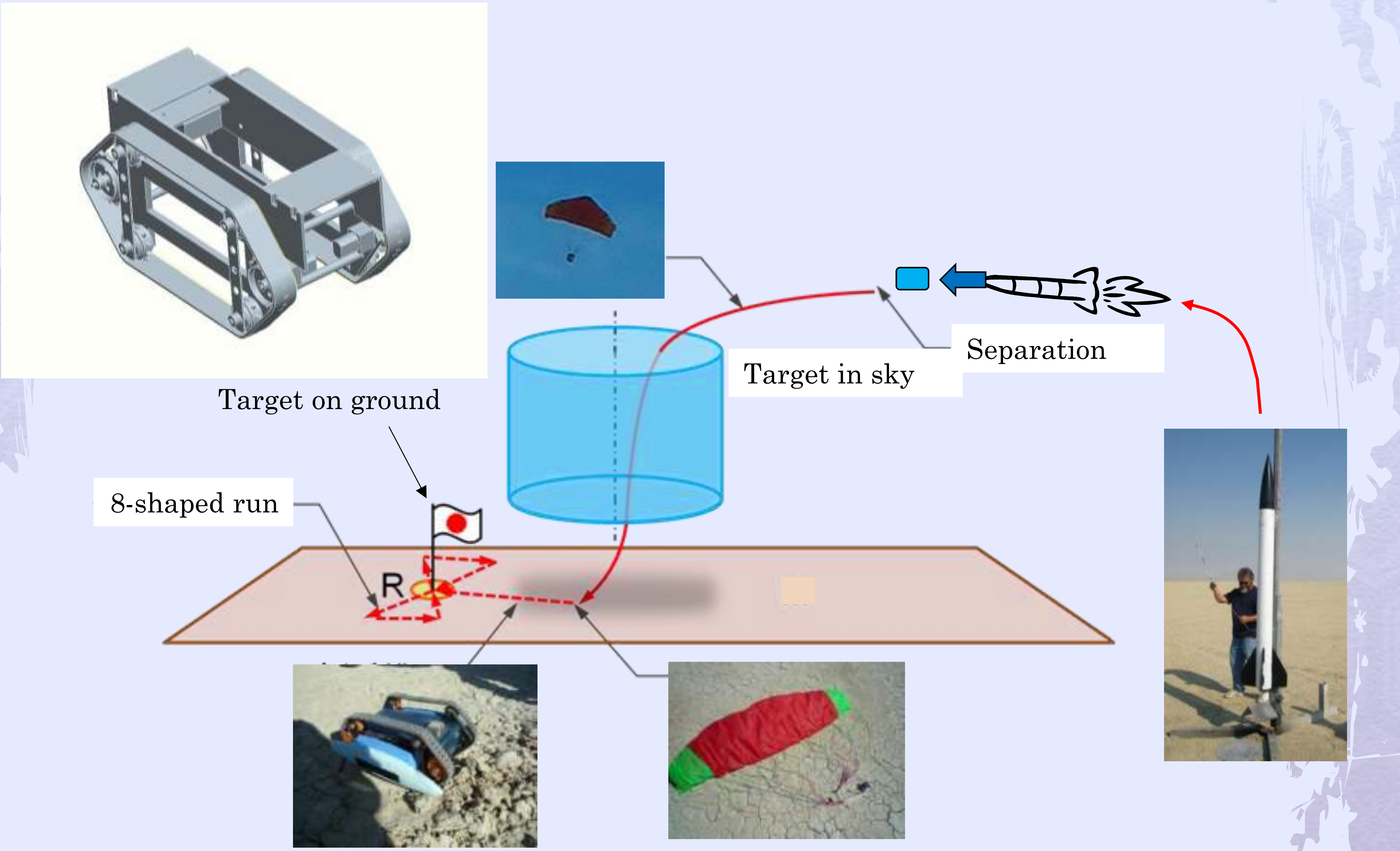
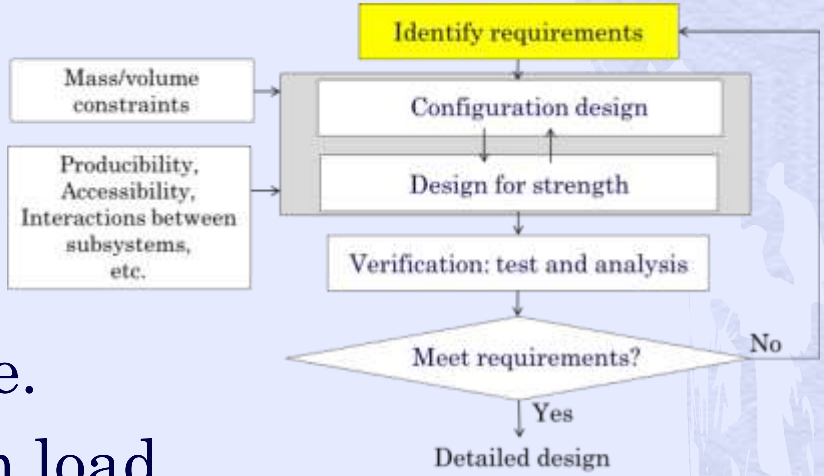
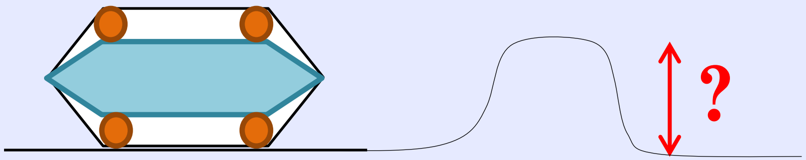
Structural design of Space Crawler

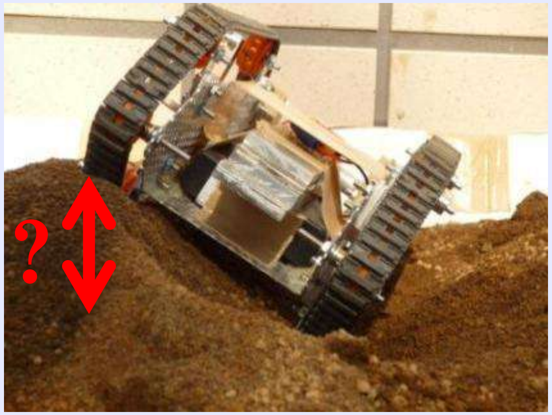


Design example (1): Requirements

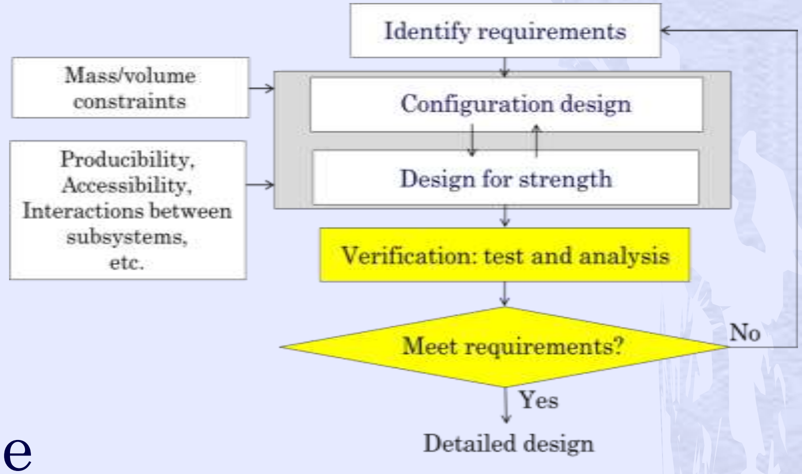


- CanSat should be crawler type.
- CanSat should tolerate launch load, parachute deployment shock, landing shock. (quantify!)
- CanSat should be able to run on a rough terrain. (quantify!)



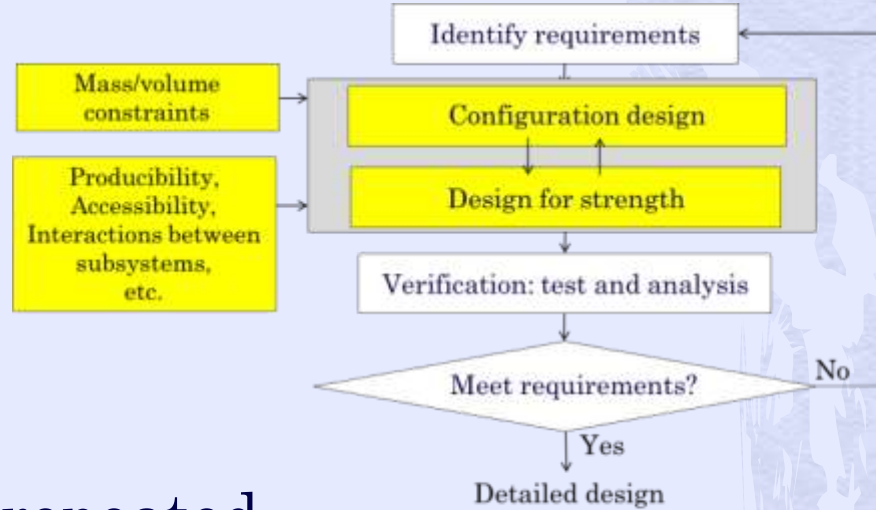


Design example (2): Verification methods

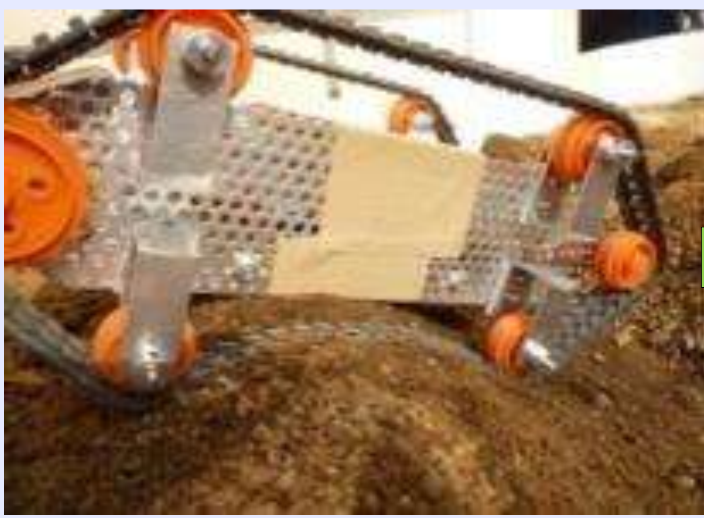


- Consider how you can verify the requirement specification when you design!

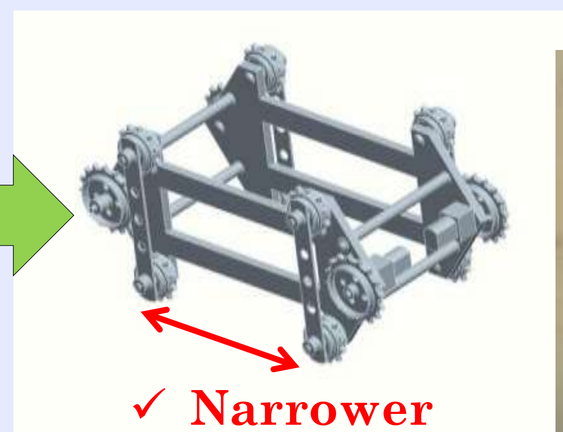
Design example (3): Design iteration



- Prototyping and testing were repeated.
- For designing flight model, 3D CAD model was made.

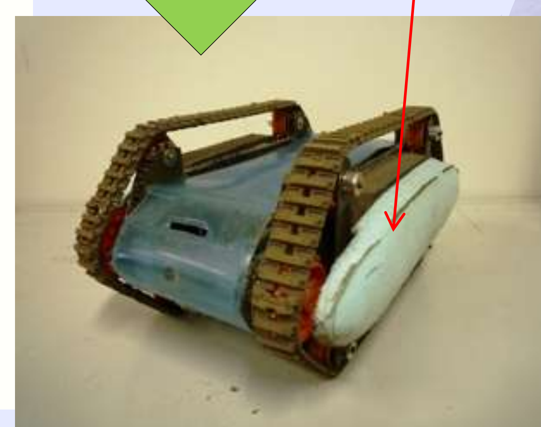


Failure mode



Overturn

✓ Added



Lessons learned

- Murphy's law: "Anything that can go wrong, will go wrong."
- If any function of CanSat is left untested, that function will fail during the flight.

Free fall

Cover not separated

References

[1] W. J. Larson, J. R. Wertz (ed.), *Space Mission Analysis and Design Third Edition* (SMAD III), Microcosm Press, 1999.

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[3] Yasuyuki Miyazaki, *Making of Satellites – from Design to Launch*, Ohmsha, 2011, (written in Japanese).