Webinars 2 and 3 Summary

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1 Webinar 2: Spacecraft Design 101

1.1 spacecraft design

The process is a cycle with the following stages, starting from mission and ending at spacecraft.

1.1.1 Mission

We need to first define the mission of our spacecraft. What is it that we want it to do? An example could be after flooding of an area, we come up with the idea of monitoring levels of freshwater to prevent this from happening again.

1.1.2 Payload

Payload outlines the requirements such as what device to use. You need to compare devices from various aspects such as lifetime, power, cost, etcetera.

1.1.3 Orbit

Questions to consider when selecting an orbit:

1. How much data will be transferred?
    - What are the coverage area, memory size and transfer rate?
    - How many ground segment is needed to achieve the mission requirements?
2. Polar orbit or sun-synchronous orbit?
3. What if the orbit design based on the launch location? (in our case this is the ISS)

1.1.4 Spacecraft

Questions to consider when selecting a spacecraft:

1. How much power does payload require?
2. How precise does the pointing need to be?
3. What will be the stabilization method?
4. What communication frequencies will be used?

If testing shows not all stage requirements are satisfied, another cycle starts until all requirements are satisfied.

1.2 CubeSat

CubeSat falls under nano size, weighs 1-10 kg $\sim$ 1kg/unit, $1U = (10)(10)(10)$cm, with length $\sim$0.34 m to $\sim$0.75 m, and power usage is from $\sim$7 W to $\sim$50 W.

Major challenge is that once it is launched, we can't go up and fix it. Therefore we need to:

- Follow a rigorous design process: Follow standards put in place by space industries.
- Redundancy and mitigation techniques: If something fails what is going to happen? Need to balance this with size and cost.
- Include margin of safety: Make sure to add margin everywhere even in cost.
- Test: It is important to test in the process.

1.2.1 Environment

Environment is defined as where will we launch our spacecraft to. We need to be aware of radiation and charged particles, Earth's atmosphere, space debris, and harsh temperatures.

- Radiation and charged particles
  - mainly from the sun
  - lots trapped in Earth's magnetic field and creates a region around Earth known as Van Allen Radiation Belts
  - impacts:
    * charging
    * single event effect, latch ups (e.g. charge built up changes 2.3 v to 4 v)
    * memory upset happens a lot in south of Atlantic region because Van Allen Radiation Belts are closer to Earth in that region
- Earth's atmosphere
  - due to launch from ISS expect drag. Although the drag will not be as much as what ISS experiences due to the small size of CubeSat, it will still slow it down. Thereby, imposing a limit on its lifetime and could also affect the material
- Launch
  - in order to pass the safety requirements we need to test and make sure CubeSat will survive launch
  - CubeSat could be destroyed due to vibrations if not designed correctly
- Space debris
  - even a paint flake could cause damage, or a particle could create a crater on the body of the CubeSat
- Temperature
  - Conduction and radiation sources of heat are:
    * direct sunlight
    * sunlight reflecting off Earth (albedo)
    * internal sources: electronics, batteries

1.2.2 Orbit

CubeSat completes one period in 90 minutes or completes 16 cycles per day.

- LEO (Low Earth Orbit)
  - has a range of 160-2000 km
  - most spacecrafts put there are to look at Earth on a fast and repetitive mode
  - examples include science-based and weather-based crafts
- MEO (Medium-Earth Orbit)
  - ranges from 2000-35786 km
  - provides a complete view of Earth and some other spacecrafts therefore it is popular for navigation systems
- geostationary orbit
  - due to having a 24 hr period, looks at the same point at all times
  - if this orbit tilts a bit becomes geosynchronous orbit

1.2.3 Spacecraft Bus

- mechanical:
  - precise alignment
  - integration of all subsystems
  - launch environment
- severe vibrations during launch may cause spacecraft to resonate

1.2.4 Thermal Control

- absence of thermal convection
- use thermistors, heater and radiators
- thermal design
  - need to ensure that electronics don't overheat
  - enter data into simulation tool and make adjustments
- thermal deformation
  - consequence of temperature variation (thermal cycling) within satellite
- thermal testing
  - simulation of the space environment
  - vacuum can be created by using special chambers to pump out the air. Access to these chambers can be expensive but this can be substituted with custom-made chamber or other forms of inexpensive testing
  - hot temperature is >100 $°C$
  - cold temperature is <-150 $°C$

1.2.5 Power and Electronics

Power budget is defined as the amount of power that is enough for all systems

- power available from sun: 3.83×10^{26} W
- most efficient solar cell on market is only $30 - 35\%$ efficient
- battery lifetime depends on:
  - depth of discharge
  - number of charge/discharge cycles
  - temperature
- sunlight is not available during eclipse period so power design needs to ensure all parts have enough power
- enough conduction to dissipate heat

1.2.6 Attitude Control

- is concerned with where you are and which way you are tumbling
- uses sun sensor, star tracker, Earth sensor and magnetometer
- goal is to adjust spacecraft attitude
  - actuators are used
  - momentum wheel gives some stability in a certain direction
  - reaction wheels are four wheels, one per axis plus a redundant wheel. If any of the three fail, the redundant wheel replaces it but will not be efficient due to being on a different axis
- magnetic torquer
  - torque rod is a simple coil attached to spacecraft's body and when a pulse current is sent through the coil, it creates a magnetic field. The line of force of that magnetic field tries to align with Earth's magnetic field

1.2.7 Communication

- transformation of a high-frequency electric signal into an electromagnetic wave
- use of antennas, transreceiver and modem
- uplink is the outgoing command and downlink is the incoming command

2 Webinar 3: Safety and Launch Requirements

- key challenges for a space mission:
  - launch and space environments are challenging. Satellite will endure vibrations, acoustic, shock and decompression wave environments during ascent, and extreme thermal and vacuum environments in space
  - Therefore, environmental tests are developed to verify compliance
- launch opportunities remain rare and expensive

- launch price per kg ranges from $\$30,000$ to $\$70,000$
- the launch provider demands that every satellite and payload put on the launcher is safe
- it is imperative for satellite builders to appreciate their launch opportunity and exercise due diligence
- every satellite must be built with a certain level of quality assurance

• key safety considerations:
  - CubeSat shall be safe to be handled by astronauts (e.g. no sharp edges that can cut the skin)
  - CubeSat shall not emit any chemicals or gases
  - no component shall disintegrate during or in orbit
  - CubeSat shall be able to deploy smoothly
  - CubeSat deployment shall not pose risk or interfere with ISS operations

• CCP design specifications
  - NanoRacks Interference Definition Document (IDD) Covers all CubeSats that will be launched on NRCSD
  - CCP design specifications were created as companion document to IDD and tailored for CCP
  - CCP document only focuses on 1U to 3U and mass up to 4.8 kg
  - CCP document explains the procedures for handling Request for Deviation (RFD) and Request for Waiver (RFW)
  - it is recommended that every member of CCP team be familiar with the CCP design specifications

• RFD
  - applicable when a component or a requirement cannot be met (e.g. the mass of 2U CubeSat exceeds 3.6 kg)
  - CCP team submits an RFD for CSA/NanoRacks consideration
  - considerations in granting deviation:
    * has the CCP team provided an analysis that the deviation cannot be avoided?
    * Will this deviation lead have an impact on a separate requirement, especially launch safety?
  - if rejected CCP team needs to change their design
  - when RFD is made after the procurement of the hardware, the impact on cost and schedule can be significant in the event the request is denied

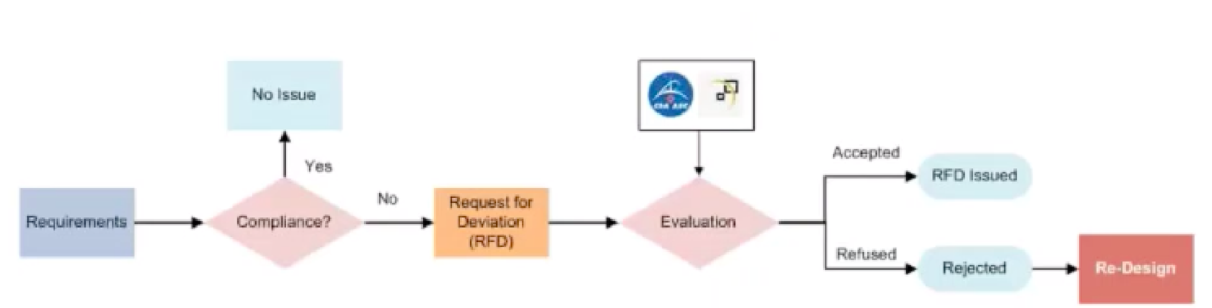

Figure 1: Diagram of the RFD steps

- RFW
  - in testing phase, when a component fails to meet a requirement the CCP team should generate a Non Compliance Report and 3 possible paths to follow:
    * if the CCP team demonstrates that the component can be used without change, the team can submit an RFW for consideration
    * the CCP team can do repair/rework, then go through testing phase again
    * the CCP team can make modifications to the component and then submit the Engineering Change Notice followed by te testing phase

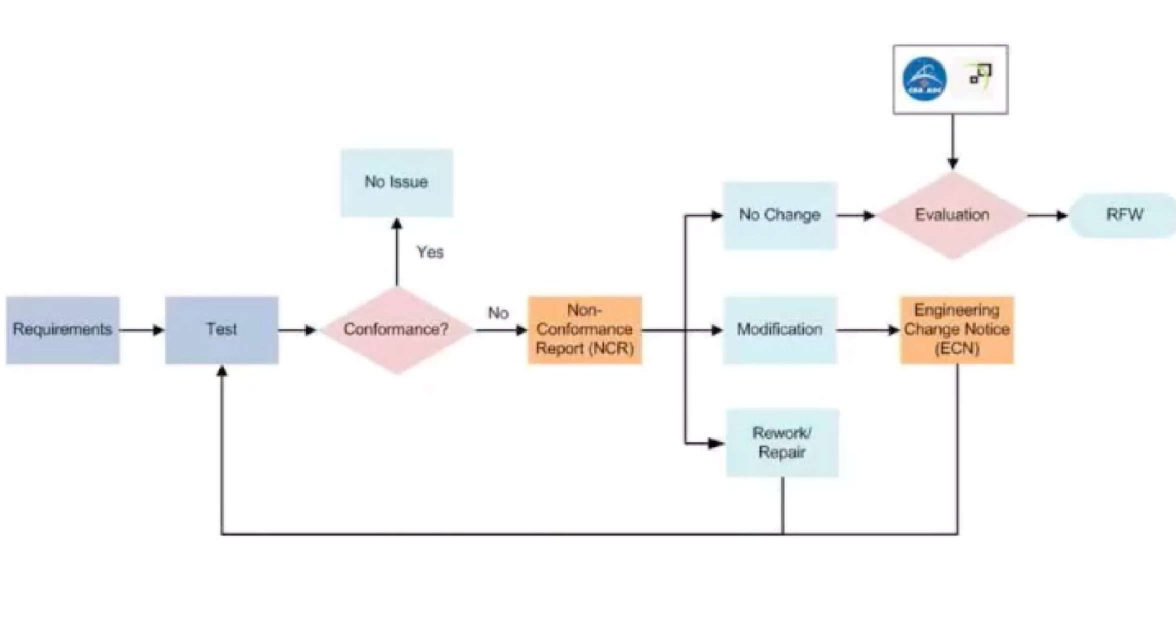

Figure 2: Diagram of the RFW steps

  - test with respect to all the requirements
  - considerations in granting waiver, has the CCP team:
    * analyzed all root causes of non-compliance?
    * demonstrated that the non-compliance cannot be fixed through reowork/repair?
    * is there any impact on safety review in granting the waiver?

- summary of RFD/RFW process
  - the CCP team should request planned deviations/unplanned waivers from requests or design using an RFD/RFW form
  - NCR should accompany the RFW. The report summarizes the identification of the problem, the cause analysis and possible solution
  - the CCP team should request an RFW only if:
    * the modification, rework or repair cannot resolve the non-performance
    * the solution requires a redesign and it is not affordable

    - the deviation should not have any impacts on safety requirements

- example RFD
  - each NRCSD has a small extra space known as tuna can
  - NanoRacks is open to teams asking to use this extra space
  - obviously using this space means violating the requirement of rail length is a minimum of 2mm above Z surfaces
  - team needs to provide a reason for the use (e.g. testing new antenna)
- mechanical interface requirement (MIR)
  - focuses on safe and jam-free deployment of the CubeSat
  - the following MIR must be respected:
    - tolerance of the rail dimensions
    - hard anodize of the rails
    - no parts of the CubeSat, other than the rail and deployment switches, touches the deployer
- dimensions: in general, no RFD can be accepted for violation fo dimension requirement
- launch environment
  - random vibration test is necessary to ensure CubeSat will not suffer any physical damage during launch
  - any loose parts can cause short-circuit in space for the CubeSat
  - any loose parts can be harmful to astronauts (e.g. broken solar panel)
- the launch load requirement for NR IDD (up to 7G) is more benign than other launchers
- random vibration tests
  - two random vibration test profiles are provided in the NR IDD
  - soft-stow is slightly more benign. They require use of padding materials
- Bill of Material (BoM) - not a requirement
  - key purpose is to ensure every single non-metallic component meets the volatility requirements for human space flight
  - BoM also covers all non-metallic components on a circuit board
  - recommended material for spacecraft structure is aluminum alloy 6061-T6. Other acceptable one is 7075-T7531
  - BoM needs to include metallic components if satellite exceeds 5 kg
  - pyrotechnics are not allowed within CCP
  - propulsion systems are not allowed within CCP
  - pressure vessels are allowed only for a sealed container less than 100 psia, additional data will be required to confirm structural integrity
  - permanent magnets are permitted but the strength will be limited to 3 Gauss measured at a distance of 7 cm

- power requirement
  - satellite must have 3 independent deployment switches that prevent accidental turn-on of the satellite after integration into NRCSD until deployment into space
  - the general practice is to install the deployment switches at the end of the rails and along the rail
  - the deployment switches are connected to 3 electrical inhibits in the electrical power circuitry
  - to prevent additional turn-on, the timer will reset itself when on or two switches are closed in 30 minutes
  - at least one of the inhibitors should disconnect the ground from the battery
- batteries
  - they will receive the most attention from NASA Payload Safety Review Panel (PSRP)
  - CCP teams must stay within the 80 Wh requirement
  - batteries must be procured from reputable sources
- logbook
  - create a logbook for every piece of flight hardware that will be turned on/off frequently
  - one logbook for each component and electrical board
  - keep track of accessibility and version of software loaded
  - document all tests that have been performed with reference to the test procedures
  - very useful for team member transition
  - do not alter records or remove pages in logbook
  - it is very useful for tracking anomaly in supporting writing of NCR
- procedures
  - for all specialized or injury-causing equipment/hardware it is recommended that procedures be written for their operation (e.g. thermal chamber, power supplies, soldering station)
  - for every piece of flight hardware, there must be a set of procedures for its handling and testing
  - everyone in the team needs to follow procedures
- procedure format
  - should not be long and complex, it should be simple
  - can be written in table format in excel which include expected test result and measured results
  - the document can easily be transferred into test report