Space Engineering Period 1 Summary

1. Calculations

1.1 Heat Balance

To get heat balance, the total energy that the satellite or space ship absorbs, must be equal to the total energy that it transmits. Assuming that one side of the ship or satellite is towards the sun, and the other side, which is perfectly isolated, is towards cold space, the following equation applies:

$$\alpha A S = \epsilon A q \left(T^4 - T_{sp}^4\right) \tag{1.1.1}$$

where α is the solar absorptance (fraction of solar radiation absorbed; metal 0.1, black paint 0.9, white paint 0.4), S is the solar flux (usually $1350 - 1400 \frac{W}{m^2}$ around the earth, and S is proportional to $\frac{1}{r^2}$, with r being the distance to the sun), A is the surface area, ϵ is the (infra-red) emissivity (fraction of black body radiation emitted; metal 0.04, black or white paint 0.9, glass 0.9), q is the Stefan-Boltzmann constant ($56.7051 * 10^{-9} \frac{W}{m^2 K^4}$), T is the satellite surface temperature and T_{sp} is the temperature of cold space.

1.2 Deriving Tsiolkowsky's formula of rocketry

Using the definition of impulse, it can be shown that:

$$M \frac{dV}{dt} = -\omega \frac{dM}{dt} \tag{1.2.1}$$

where M is the mass of the rocket, dV is the change in velocity, dt is the change in time and ω is the exhaust velocity of the fuel relative to the rocket. The equation can be rearranged as follows:

$$dV = -\omega \frac{dM}{M} \tag{1.2.2}$$

Assuming zero gravity and vacuum, we can derive Tsiolkowsky's formula of rocketry:

$$\Delta V_e = \omega \ln \frac{M_0}{M_e} \tag{1.2.3}$$

where ΔV_e is the velocity change, M_0 is the start mass of the rocket and M_e is the end mass. The usual value for ω in a launcher rocket is about $3000 \frac{m}{s}$. The usual value for $\frac{M_0}{M_e}$ is about 5-6.

If we also include the presence of a gravity field and air drag, the formula gets a bit more complicated. So to keep it a bit simple, we neglect drag, and assume just a homogeneous gravitational field. Now we get the following equation:

$$\Delta V_e = \omega \ln \frac{M_0}{M_e} - g_0 t_b \tag{1.2.4}$$

where g_0 is the gravitational constant at sea level and t_b is the burning time of the rocket.

1.3 Coasting

After the rocket engine has stopped working, the rocket is coasting. When coasting, the coasting time t_c (until the rocket has reached its highest point) is:

$$t_c = \frac{V_e}{g_0} \tag{1.3.1}$$

where V_e is the initial speed. The vertical distance h_c covered by the rocket during coast time is:

$$h_c = t_c V_e - \frac{1}{2} g_0 t_c^2 = \frac{1}{2} \frac{V_e^2}{g_0} \tag{1.3.2}$$

1.4 Aerodynamic Disturbance Forces

The aerodynamic disturbance force on a satellite in a low earth orbit, also known as the aerodynamic drag, is small, but can make a big difference after a lot of time. This drag D can be calculated as follows:

$$D = \frac{1}{2} C_D \rho V^2 A \cos i \tag{1.4.1}$$

where C_D is the drag coefficient, V is the speed (relative to air) with which the satellite is traveling, A is the surface area on one side of the satellite and i is the angle between the direction of movement, and the line perpendicular to the plain of the surface area. If you have already taken A as the frontal area of the satellite (which is usually the case), then $i = 0$, which means that $\cos i$ is simply 1.

1.5 Solar Radiation Disturbance Forces

The formula for the solar radiation disturbance force is not given in the space engineering book, and therefore needs not to be known. However, the solar radiation force is proportional to the following parameters:

- The surface area A.
- The solar flux S.
- The factor 2 - (α), where α is the solar absorbance. The two is there, because solar radiation that hits the space ship, often gets "bounced" back with equal speed in the opposite direction (remember that the momentum of the total situation stays the same, so the total impulse is 0). However, because of this, the radiation that gets absorbed, only counts once.
- $\cos i$, where i (rad/deg)is the angle between the sun vector and the surface normal. If you have taken A as the frontal area already, $\cos i$ is simply 1, just like with the aerodynamic drag formula.

2. Definitions

The following definitions need to be known.

- Space system: The whole of hard-and software, personnel, training, support, etc. necessary for conducting a space mission.
- Space flight: All activities, where a manned or unmanned vehicle is brought outside the Earth atmosphere with the purpose of performing a task in space
- Space research: Scientific research performed by means of a space vehicle (either manned or unmanned)
- Space technology: Technology required to design, develop and build space vehicles, including launchers
- Remote Sensing: The acquisition of information about an object without being in physical contact with it.
- Geostationary orbit: Circular equatorial orbit where the satellite remains always on the same Earth longitude.
- Apogee: Point in the orbit where the distance to the Earth is largest.
- Perigee: Point in the orbit where the distance to the Earth is smallest.
- Inclination: Angle of the orbit plane with the Earth equator
- Sun-synchronous orbit: Circular "polar" orbit, where the angle between the orbit plane and the sun vector is constant. Satellite passes at each location on the Earth at the same localtime. A satellite in such an orbit that it sees the full celestial sphere in half a year.
- Geo-stationary Transfer Orbit (GTO): Orbit with a near-Earth perigee (e.g. 200 km altitude) and an apogee on geo-stationary altitude. Normal procedure to get a geo-stationary satellite in its orbit
- Apogee boost (for a geo-stationary satellite): Thrust manoeuvrerequired in GTO apogee to raise the perigee to geo-stationary altitude.
- Libration point: A point in space, where the attractive force of two celestial bodies is in equilibrium. A satellite in that point has a fixed position relative to these two bodies.
- Elevation: The angle of a satellite above the horizon. Also the angle of a launcher trajectory relative to the horizon.
- Azimuth: The angle of a launcher trajectory with the direction of the North Pole.
- Coverage: The part of the celestial body, that is visible from or can be communicated to by the payload of a satellite.
- Access: The part of the orbit a satellite is "visible" from an Earth located point.
- Launcher (rocket) stage: The assembly of structure, propellants, tanks, engines and other equipment that (in principle) can function as one single stage launcher. E.g. for a three-stage launcher: first stage, second stage, third stage etc. in the order as they are activated during the launch trajectory.
- Sub-rocket: The assembly of one or more launcher stages with a payload, as it occurs during the launch of a satellite. E.g. for a three-stage launcher:
  - First sub-rocket = first stage + second stage + third stage + payload
  - Second sub-rocket = second stage + third stage + payload
  - Third sub-rocket = third stage + payload
- Booster: A high-thrust rocket engine with associated propellant and structure ignited on the ground and assisting the main (first stage) launcher engines in the first flight phase.
- Mass ratio R: The ratio of start mass and empty mass of a sub-rocket or launcher stage. A practically achievable value of the mass ratio of a sub-rocket is 6 maximum. The value of R, together with the chosen propellant combination, determines the maximum achievable velocity increment of a sub-rocket.
- Structural efficiency s: The ratio of structural mass and propellant mass of a launcher stage or sub-rocket. A practically achievable value of s is 0.10.

- Swing by: A maneuver of a spacecraft, which uses the gravitational forces of a planet to obtain a higher speed (without hitting that planet).
- Coasting: The rocket continues it's vertical flight after burn-out: it's coasting.
- Space market: The set of all actual and potential buyers of a product or service which depend or relate to having a spacecraft in orbit (Based on: Kotleret al. 1996).
- Space industry: The sellers of the above products/services.
- Service: An activity, benefit or satisfaction that is offered for sale.
- Market segment: Part of the overall market encompassing users that have more or less identical needs.

3. Spacecraft mission parts

3.1 Mission segments

A mission may be broken down in several segments. (This is the convention used in the book ”Space Mission Analysis & Design” - by Larson.) Each segment has its own function, as can be seen in table 3.1.

Mission segment	**Function**	**Definition**
Subject	Observe ”it”; transmit”it”	The thing that interacts with or is sensed by the payload
Launch segment	Provide transportation from ground to location in space	The launch facility, launch vehicle and any upper stage to place the spacecraft in orbit, as well as interfaces, payload fairing and associated ground equipment
Orbit & constellation	Provide access andcoverage to/from object to ground	The spacecraft's trajectory or path
Space segment; payload	Transfer data on subject to transmittable information	The hard- and software that sense or interact with the subject
Space segment; bus	Support the payload with services and resources	The hard- and software that provides services and resources to the payload
Communications architecture	Provide telemetry, command and other datacommunication between the space segment and all users on the ground	The arrangement of components which satifies the mission's communication, command and control (C3) requirements
Ground segment	Provide on-ground monitoring, command and communication services to the mission	Fixed and mobile ground stations around the globe connected by various data links
Mission operations	Provide the human staffing of ground and space segment	The people occupying the ground and space segment

Table 3.1: Mission Segments

3.2 Breaking down a space craft

A spacecraft contains both a payload as a bus. The latter one contains a lot of subsystems, each with its own functions, as can be seen in table 3.2.

Subsystem	**Principal functions**	**Other names**
Propulsion	Adjust orbit and attitude, dump angular momentum	Reaction Control System (RCS)
Guidance, Navigation & Control (GNC)	Determine and control orbit	Orbit Control System (OCS)
Attitude Determination & Control (ADCS)	Determine and control attitude, point and manoeuver the spacecraft, manage angular momentum	Attitude Determination and Control System (ADCS) or Control System
Communications	Communicate with ground, support spacecraft tracking	Tracking, Telemetry & Command (TT&C)
Command & Data Handling (C&DH)	Process commands, perform data processing/formatting, provide computing power	Spacecraft Computer System or Spacecraft Processor
Thermal Control	Control equipment temperature	Environmental Control System
Power	Generate and distribute power	Electric Power Subsystem (EPS)
Structures & Mechanisms	Provide structural integrity, provide motion possibility to structural parts	Structure Subsystem

Table 3.2: Breaking down a spacecraft

4. Spacecraft Market

4.1 Four main areas of space applications

- Telecommunications - Sending messages by electronic means
- Remote sensing - Information gathering from a distance by electronic means
- Navigation - Knowledge of location
- Science and technology validation - ”For the benefit of knowing”

4.2 Market review

Questions to be answered when conducting a Market Review:

- Which market I am aiming for and what is its size?
- Which product I am going to offer?
  - Competitive edge
  - Price
  - Cost
  - Quality/characteristics
- Which market share can I obtain?
- What is the competition and how do I compare with it?

4.3 Market segments

Market segments are part of the overall market encompassing users that have more or less identical needs. Market segments are seperated by certain segmentation principles. Segmentation principles are for example:

- Purpose (what the product/service is for)
- Geographic (world, region)
- Government or commercial
- Level of education

Two market segments are distinguished based on the type of customer:

- Commercial markets: Mission serves a paying customer base. =¿ highest performance per dollar.
- Institutional or governmental market: Missions are not viable commercially, require oversight or bring exceptionally high risk. Typical such missions today include mostly science and technology validation missions, launcher development and, of course, defence. =¿ performance driven.

4.4 Another way of segmenting the market

- Infrastructure: Including the manufacture, test, delivery and launch of satellites, other spacecraft, and related hardware.
- Telecommunications: Including transmission of international telephony services, interconnection with national telephone networks, and distribution of video signals for cable and television programmers.
- Emerging Applications: Like remote sensing, geographical information systems (GIS) or global positioning services (GPS).
- Support Services: Like publishing, business consulting, financial, legal and space insurance.

5. Spacecraft development

5.1 Steps in space system development

- Concept exploration: Results in a broad definition of the space mission and the various elements that work in unison to realize the mission. Consists of:
  - Needs analysis
  - Concept development
- Detailed design and development: Results in a detailed definition of the system components and, in larger programs, development of test hardware and/or software. Consists of:
  - Demonstration and validation
  - Engineering development
- Production and deployment: The construction of the ground and flight hardware and launch of the (constellation of) satellite(s).
- Operations and support: The day-to-day operations of the space system, its maintenance and support.
- Decommissioning: Finally its de-orbit or recovery at the end of the mission life.

5.2 What are important parameters for spacecraft?

No matter which mission, the following performance parameters are always important for a spacecraft:

- Orbit: Determines the quality and kind of observations and/or communications achievable.
- Mass: Determines the launcher and on-board propellant needed.
- Size: Determines the launcher needed.
- Electrical power: Determines the size of primary and secondary power sources (generally solar array and batteries).
- Mission duration in relation to reliability: Determines the amount of spare resources needed (propellant, over-sizing for degradation due to radiation and ageing, redundancy).
- Attitude and orbit accuracy: Determines the quality of the scientific data, the quality of communicationsand the safety of the spacecraft.
- On-board computer power and data storage: Determines autonomy and amount of data to be down linked.
- Up-and down-link data rate: Determines the size of antennae, receiver and transmitter power (both on board and on ground).
- Specific parameters, that are a function of the payload: For example: cooling, electrical properties of the spacecraft, shading from unwanted radiation, ground contact constraints, etc.

5.3 Why a space platform?

- Remote sensing of space (planets, stars, comets, environment, etc.) or space science: Comparable to Earth-based space observation, except that the sight is not obscured by the Earths atmosphere and viewing distances can be reduced substantially.
- Remote sensing of the Earth or Earth Observation (EO): Comparable to observation by aircraft, balloons, etc, except that space provides global and synoptic detailed information.
- In-situ observations: Cannot be done elsewhere.

6. Spacecraft control

- Solar radiation: Can be used as propelling force.
- Aerodynamics: Can be used to capture a satellite around a planet with an atmosphere. Is used to dispose of satellites in a low (Earth) orbit. Shall be compensated to keep a satellite in its low orbit.
- Gravity: Is used to perform efficient (interplanetary) flight (celestial body swing-by); in case of Cassini, this saves 68 tons of propellants. Shall be compensated to keep satellites in their intended orbit (geostationary satellites). Is used to achieve specific orbits (sun-synchronous orbits, orbits in libration points, etc.).

6.1 Disturbance torques

- External disturbance torques
  - Aerodynamic (Can be used for passive stabilisation)
  - Solar radiation (Can be used for passive stabilisation)
  - Magnetic field (Can be used for active and passive stabilisation)
  - Gravity gradient (Can be used for passive stabilisation)
- Internal disturbance torques
  - Thrust misalignment (generally: actuator misalignment)
  - On-board mechanisms

6.2 Means to control the attitude of a spacecraft

- Passive
  - Gravity gradient, magnetic, aerodynamic (rarely), solar radiation
  - Gyroscopic (spinning spacecraft)
- Active
  - Thrusters
    - Cost propellants, which are depleted
    - Can remove disturbance torque
  - Reaction or momentum wheels
    - Cost electrical energy
    - Cannot remove disturbance torque, can only store it
  - Magnetic coils or torque rods
    - Cost electrical energy
    - Work only in a relatively large magnetic field
    - Can remove disturbance torque

6.3 Disturbance torque and spacecraft sizing

- The maximum disturbance torque sizes the maximum actuator (control) torque. But spacecraft manoeuvring may require more torque.
- The time integrated cyclic disturbance torque sizes the angular momentum storage capacity required. A reaction or momentum wheel can store momentum, a thruster system cannot (it only eliminates angular momentum).
- The time integrated non-cyclic disturbance torque sizes the angular momentum dump capacity required. To dump angular momentum you need an actuator than can generate a torque through interaction with the environment or can generate a torque by mass expulsion.