SR555: Heat Transfer in Space Applications

Aerobreaking, Launch, Ascent, Reentry Analysis

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Aerobreaking

- **Aerobreaking:**
  - Achieve large changes in orbit altitude / inclination
  - Change is such that spacecraft on an interplanetary trajectory slows down to the point where part of orbit is in the planet's atmosphere
  - Aerodynamic drag → rapid heating

Aerobreaking

- **Thermal environment during aerobreaking:**
  - Alters due to change in orbit per pass
  - Computation of heating rates required orbital dynamics and atmospheric data
  - Fraction of heating increases per pass → severity increases per pass

Aerobreaking

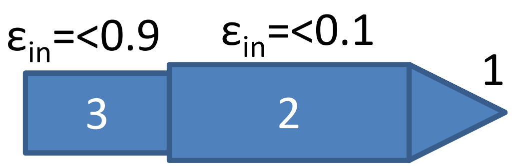
- **Computation of heating rate:**
  - **Tricky but simple**
  - **Local heat flux:**
    - available heat flux is given on an area normal to the velocity vector
    - Multiply the heat flux by cosine of angle between surface normal and velocity vector to estimate local heat flux
    - Then carry out analysis of local heating using the local heat flux

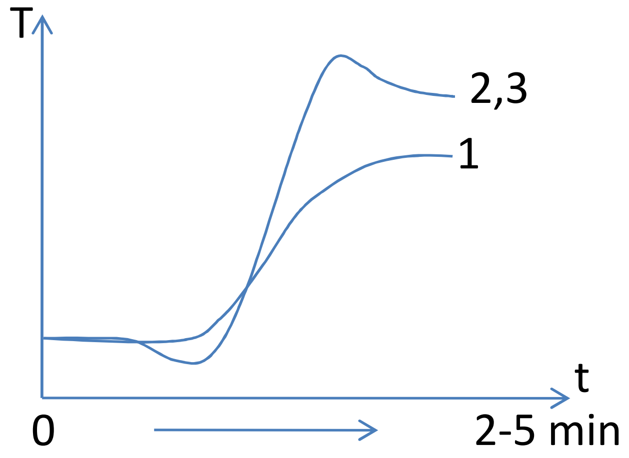
Launch and Ascent

- Launch and ascent phases need thermal analysis to prevent high temperature rise;
  - excessively low/high temperatures should not occur
- **First few minutes:**
  - Environment surrounding the spacecraft is driven by payload-fairing temperature and aerodynamic heating (ΔT = 90-200 ^{o}C)
  - Depressurization of gas in the payload compartment causes negligible cooling
  - Affected parts: solar arrays, MLI, antennae (all these are light-weight)

Launch and Ascent

- **Free molecular heating:**
  - Significant up to 30 minutes after suspension of fairing; solar, earth IR, albedo, and some plume heating
- Ascent lasts from 30-45 minutes
- Cooling can occur during orbital transfer





Radiation Analysis

- **Objective: estimate the temperature of spacecraft due to thermal environments while in orbit**
- **Scope:** include solar radiation, albedo, Earth IR; neglect internal heat generation
- **Given data:**
  - Cubical satellite: 10 * 10 * 30 cm^3
  - Altitude = 640 km
  - e = 0.001
  - Inclination = 97.943^o
  - Perigee = 0^o
  - Orbital period = 5851 s
  - Local time at ascending node = 10:45:00

Radiation Analysis

- **Model:**
  - Assumptions:
    - Spacecraft as a spherical object
    - Sun completely illuminates the spacecraft with a projected area of the same radius as craft
    - Spacecraft will be fully illuminated by Earth IR because of huge size difference

Radiation Analysis

- **Solution:**
  - Find radius of sphere: r_{sph} = 0.1056 m
  - Compute the heat fluxes
  - Spacecraft will be exposed to radiation only during part of the flight → it is shielded from radiation during eclipse phase of the orbit → T_{max} and T_{min}
  - Estimate T_{max} and T_{min}

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Reentry

- **Problem:**
  - How would the spacecraft perform thermally under prescribed reentry flight profile (time histories of velocity, altitude, and angle of attack)
- **Solution:**
  - Distribution of tempearture on the outer structure
  - Knowledge of thermal stresses

Reentry

- **Method of analysis:**
  - Full knowledge of structural details
  - Modes of heat transfer: radiation, convection, conduction
  - Selection of areas for analysis
  - Aerodynamic heating