You are not allowed to work with any other students on this exam. INDIVIDUAL EFFORT ONLY.

MAE 5595: Space Mission Analysis

Fall 2008

NAME _____________________

MIDTERM EXAM

DUE: 22 Oct 2008, 1630 MDT

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Congratulations!! You have been selected as the environmental interactions engineer for the upcoming Defense Meteorological Satellite Program (DSMP) mission. Preliminary mission reports have been included in this package (see pages 4 and 5).

We need an initial report to send the “customer.” Describe any assumptions used to formulate your answers. The customer has requested the following information:

1. (6 pts) Calculate the orbital period of the satellite. What is the satellite orbit’s eccentricity? Calculate the perigee rotation rate due to J2 in degrees per day. Calculate the angular Earth radius at the nominal orbital altitude. Draw a “typical” ground track for the satellite’s orbit using sufficient detail.

2. (7 pts) The NiCd batteries can not experience a temperature change greater than 20°C over the life of the mission. A temperature increase greater than this will decrease the beginning of life (BOL) capacity of 30 A hr to unacceptable levels. A simple analysis suggests that a change of more than 25% in the absorptivity on the battery enclosure will lead to a temperature change of more than 20°C. Is there an issue for this DSMP mission? Explain.

3. (20 pts) The Sun Sensor Unit (SSU) instrument on the outer part of the spacecraft can not be subjected to a radiation dose greater than 10kRad over the life of the mission. An estimate of the shield thickness (aluminum) is required to meet this mission requirement AND to meet the mission requirement with a factor 8 in safety. Assess whether the additional mass for the safety factor of 8 is justified.

4. (20 pts) An estimate of the force on the spacecraft due to drag is required to assess the nitrogen propellant mass to maintain the orbit at nominal levels over the life of the mission. Estimate the drag force on the DSMP spacecraft. Calculate the mass of nitrogen propellant (cold gas thruster, Isp = 72 sec) needed to counteract the drag force per year.

5. (20 pts) The DSMP satellite is expected to enter a 400 km (altitude), polar parking orbit after launch. If the booster fails to raise the DSMP orbit to the mission altitude, the mission can still proceed with limited effectiveness. Calculate the approximate fluence of atomic oxygen that the DSMP satellite will encounter over its mission lifetime if it remains in the parking orbit. Estimate how much Kapton thermal insulation will be removed over the mission lifetime if it remains in the parking orbit. Would atomic oxygen degradation be an issue at the mission altitude(s)? Explain.

6. (15 pts) The European Space Agency has issued an alert (see page 6) for the time frame in which this spacecraft will become operational. An assessment of the risk due to the Leonid Meteor Event is required. An assessment for the Sun Sensor Unit is also required to ensure that the radiation shield is adequate protection in the event of a micrometeor impact on the device.
7. (7 pts) Your boss gives you the following chart that he found in a book somewhere and thought it might be useful. Describe what the chart is showing in as much detail as possible. Will this be useful for your analysis? Explain.

Figure 5.9 Solar Flare Proton Environment in a 200-nmi Circular Orbit
Due to a Class Three Flare Event on July 18, 1961 5.30

8. (5 pts) Your co-worker just came in with the following picture of an old satellite that he thought was really cool. Describe as much about the probable mission and the mission architecture for this satellite as you can. The characteristic diameter of the satellite is 1.4 meters.
DSMP F-8 Mission Profile Report

Mission Objective: The DMSP mission is to provide global visible and infrared meteorological, oceanographic and solar-geophysical data in support of worldwide Department of Defense (DoD) operations. DMSP F-12 will be built by Martin Marietta Astro Space and will be launched on 1 September 2010. The mission is expected to last 36 months.

Fig. 1: General DSMP F-8 Spacecraft Schematic

Orbital Profile:

Maximum Altitude: 851 km
Minimum Altitude: 832 km
Inclination: 98.8°
Sun-synchronous
1. Spacecraft Structure:
   - Length - 3.4 m (excluding solar panel)
   - Width - 1.2 m (max. diameter, excluding solar panel)
   - Spacecraft Wet Mass - 725 kg (est.)
   - Total Payload Mass - 110 kg (est.)
   - Allowable Micrometeoroid Penetration Before Failure - 10 (assuming no critical components are struck)

2. Power Subsystem: (solar array and battery)
   - Solar Panel Area - 9.30 m²
   - Solar Panel Power (BOL) - 900 Watts
   - Max. \(\Delta P\) - 0.02 BOL Power (due to propulsion system contamination)
   - Solar Array Temperature - 350 K (avg.)
   - Battery Type - NiCd
   - Battery Capacity - 30 A hr. at 15°C
   - Max. \(\Delta T\) - 20°C (for min. capacity)
   - Battery Enclosure Thermal Protection Material - Coated Kapton
     (absorptivity, \(\alpha = 0.40\); emissivity, \(\varepsilon = 0.71\))
   - Battery Enclosure Surface Area - 1 m²
   - Battery Orientation - Always pointing in the sun direction
   - NOTE: Battery enclosure is thermally isolated from spacecraft bus

3. Propulsion Subsystem:
   - Orbit insertion - Hydrazine propellant
   - Stationkeeping - Cold gas propellant (N2)
   - Cold Gas Propulsion System:
     - Propellant Temperature - 300 K
     - Propellant Molecular Weight - 28
     - Propellant Molecular Diameter - 4.17 Å

4. Payload Subsystem:
   - Sun Sensor Unit:
     - Sensor Enclosure Surface Area - 1.5 m² (total)
       - 0.75 m² (perpendicular to sun/top sfc)
     - Sensor Enclosure Material - Aluminum (density = 2.7 g/cm³)
     - Sensor Orientation - Always pointing in the sun direction
     - Allowable Micrometeoroid Penetration Before Failure – 0
The Leonid 2010 Meteor Shower

Information for spacecraft operators

1. Introduction

Earth orbiting spacecraft are at risk of being hit by Earth orbiting debris but to some extent also by meteoroids. For example, the demise of ESA's Olympus spacecraft may be attributed to the Perseid meteoroid stream. The Leonid meteoroid stream is expected to pose a particular risk in the coming years around November 17-18, the time in the year when the Earth passes closely the orbit of comet Tempel-Tuttle, which is the progenitor of this stream. P/Tempel-Tuttle, which takes 33 years to complete one revolution around the Sun, passed through perihelion in February 1998. The latest orbital elements (J2000) of P/Tempel-Tuttle are (Ref. 1):

time of perihelion passage: 1998 Feb 28.09666

eccentricity: 0.9055036

perihelion distance: 0.9765849 AU

argument of perihelion: 172.49731 deg

long. of ascending node: 235.25883 deg

inclination: 162.48614 deg.

Because of the recent perihelion passage, a strong increase in flux of the Leonid meteoroids can be anticipated in the coming years, which may even lead to a meteor storm. Forecasts of the Leonid meteor shower stream in the coming years range from a zenithal hourly rate (the number of meteoroids visible per hour and corrected for the observed location in the sky) of 200 to 5000 or even higher. Since the Leonids approach
the Earth with a velocity of about 71 km/s, even small particles can damage a spacecraft. The damage potential is similar as during the flyby of the Giotto spacecraft at comet Halley, where the speed of the impacting dust particles was near 68 km/s.

2. Risk for Earth Orbiting Spacecraft

Potential damage to spacecraft

Operational satellites can be damaged by high-speed impacting particles in two primary ways:

• damage through physical impact (destruction of sensitive parts)

• with the high-speed impact a plasma cloud (mixture of neutral and charged particles) can be generated. This plasma cloud can interface with spacecraft electronics. The plasma cloud can also trigger an electrostatic discharge of a previously charged spacecraft. Such electrostatic discharges can couple into the spacecraft electronics and lead to electronic anomalies. The likelihood of electrostatic discharges will depend on the ambient plasma electron environment (in the KeV to MeV energy range) during the shower but also hours and days before the shower.

Large impacting particles may also change the spacecraft attitude due to momentum transfer. Erosion will occur of outer surfaces like thermal blankets, mirrors, solar cells by type of sand-blast effect.

Zenithal hourly rate

The quantity used by astronomers to describe the intensity of meteor streams is the zenithal hourly rate (ZHR). It tells how many meteors per hour would be visible if the observed shower were to come from the direction of the zenith under optimum seeing conditions (no moon, no clouds). In determining the ZHR, the limiting visual magnitude is put at 6.5, which is equivalent to a particle mass of about 100 micrograms (for objects at 71 km/s) or a diameter of about 0.5 mm.

The normal background ZHR is around 10-20.

Our estimate of the ZHR for the Leonids in 1998 is based on historical data. In 1867 the distance Earth-comet orbit was 0.0066 AU and the ZHR was 5000. In 1932 the distance was similar (0.0062 AU) but the ZHR was only 240. In 1998 the distance will be only slightly larger (0.008 AU) and therefore similar conditions as in 1867 and 1932 might be expected. However, sufficient uncertainty remains such that the flux rates may be similar to the 1966 storm, i.e. 15000 ZHR (with some observers even reporting 150 000 ZHR). The maximum ZHRS are usually reached in the two years following the perihelion passage of the comet, that is for the present apparition of P/Tempel-Tuttle in 1998 and 1999.
Flux on spacecraft surfaces

For the sake of a worst case scenario we assume a ZHR of 15000. To convert ZHR to impact rates McDonnell et al. (Ref. 2) presented a formula at the 2nd European Conference on Space Debris. Assuming a ZHR of 15000, the following relation between the maximum penetration threshold on an aluminium target $F_{\text{max}}$ (in $\mu$m) and product $AxT$ (m²s) of exposed area ($A$) and time ($T$) holds:

$$F_{\text{max}} = \left[ (1.35 \times 10^4 AxT)^{-0.126} + (2.04 \times 10^{-3} AxT)^{-0.620} \right]^{-2.193}$$

(1)

Modelling of the Leonid stream flux distribution produces the flux prediction to a LEO satellite (McBride 1998) shown in Fig. 1. As a comparison the background flux is also given by a model based on the Grün flux distribution (bottom dashed line).

An example how to use this plot is now given. A 1 mm ($10^3 \mu$m) thick aluminium foil will experience about $10^{-7}$ penetrations /m²/s. If 10 m² are exposed to the direction of the Leonid stream then the probability of penetration is about 9% for one day. (Eq. 1 is normalized for 1 day exposure.) For 100 $\mu$m the flux increases to about $10^{-4}$/m²/s and the estimated number of penetrations will be about 100 for a 10 m² surface.
Eq. 1 can also be used to calculate the penetration of the largest impact through an aluminium wall. In Fig. 2 this value is plotted as function of total cross sectional area of the satellite(s). Fig. 2 may be read for example like this: a spacecraft with 10 m² surface needs an aluminium wall of more than 0.4 mm thickness in order not to experience a penetration. If the surface is 100 m² then bigger impacts are likely and the minimum wall thickness should be 1.0 mm. It must be stressed that these numbers are very rough estimates and that larger impacts may happen even if their probability is small.

![Graph](image)

**Fig. 2** Maximum penetration depth of largest Leonid impact through an aluminium wall

The equivalent sporadic exposure time is 10 days, i.e. the number of impacts during the short time of the Leonids peak is equal to the number of impacts during 10 'quiet' days. Note that impact plasma generation may offer the greatest damage mechanism as plasma discharges are proportional to $V^4$ whereas the penetration effects are only proportional to $V^2$. A Leonid will produce about 160 times more plasma charge than a typical sporadic meteoroid of the same mass and a velocity of 20 km/s (Ref. 3). Hence the equivalent sporadic exposure time in terms of impact plasma production is around half a year.

**Radiant and Velocity**

The radiant, i.e. the direction from which the particles approach the Earth, is right ascension = 154° and declination = 22°. The velocity of the Leonids with respect to the Earth is 71 km/s. To calculate the velocity of the Leonids relative to a spacecraft, the velocity of the spacecraft with respect to the Earth must be taken into account. So a LEO satellite will suffer impacts between about 64 and 79 km/s.
3. Recommendations for spacecraft operators

Spacecraft operators can take a number of measures to minimize the risk for their spacecraft:

- **Spacecraft launches near mid-November 2010 should be postponed to after the Leonid shower, i.e. after November 17.**

- **It is recommended to minimize the cross sectional area of the spacecraft facing the radiant of the Leonids.** Since the direction from which the particles approach the Earth is almost perpendicular to the direction to the Sun, the solar arrays will fortunately be facing the shower edge on (assuming that the solar arrays are pointing towards the Sun). If possible, the attitude of the spacecraft should be chosen such that sensitive parts are not exposed to the meteoroids.

- **It is recommended to examine the possibilities of damage due to plasma discharging.** By turning off sensitive equipment the spacecraft may be configured to a "safe" mode. Increased electron fluxes could lead to increased spacecraft anomalies during the shower.

- **It is recommended to reinforce the operation team prior to and during the shower in order to cope with potential spacecraft anomalies.** The spacecraft status should be continuously monitored prior to and during the shower.

To change the orbit of a spacecraft such that the spacecraft is shielded by the Earth during the peak of the Leonids is not recommended. Firstly, shielding is only effective for spacecraft in low Earth orbit for about half an hour, which is much less than the accuracy of the predicted time of the peak. Secondly, this approach would require the use of propellant and would interrupt significantly normal operations.

4. References